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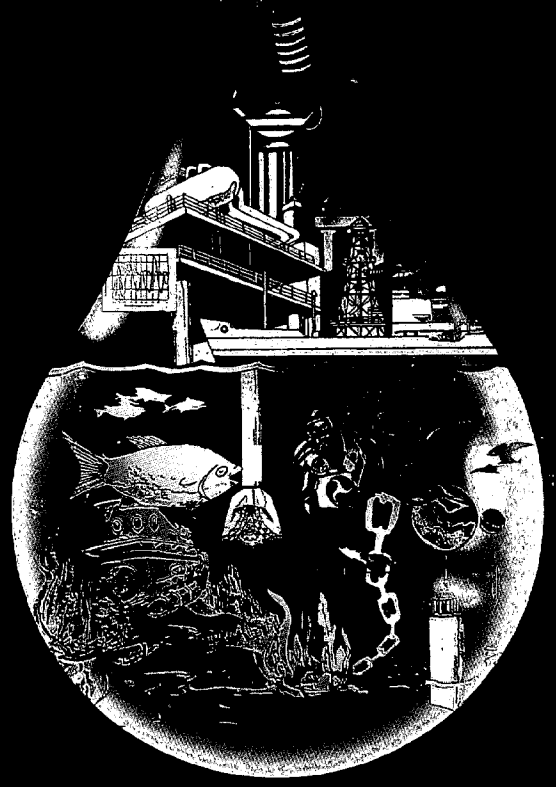

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A REVIEW OF THE ORIGINS, RESPONSIBILITIES, COMPOSITION AND MAIN ACTIVITIES OF THE INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA (ICES)

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ABSTRACT

This contribution first outlines the main factors leading to the foundation of ICES in 1902 as an intergovernmental body, the first of its kind, concerned with the promotion and coordination of international cooperation in scientific investigations of the sea and its living resources in the North Atlantic area. It then traces the development of the Council's aims, responsibilities, composition, organization, and main activities from its foundation to the present time, with special attention to the years since World War II, during which time the Council acquired a more formally defined status through its 1964 Convention. The Council's role in providing scientific information and advice to member governments and international fishery management (NEAFC, IBSFC, NASCO) and pollution control (Oslo, Paris, and Helsinki Commissions) organizations, and possible future developments in this and other activities are also described.

INTRODUCTION

The International Council for the Exploration of the Sea (ICES) is the oldest intergovernmental marine organization in the world (Ref. 1). It was founded in 1902 in response to concerns expressed by leading marine scientists and governments in northern Europe that the formation of an international body to coordinate scientific research in marine fields was needed to understand the conditions in the sea and avoid the possibility of overfishing. From an initial founding membership of eight countries, ICES has expanded over the years to include eighteen member countries and the entire North Atlantic and adjacent seas as its area of interest. While the general aims of ICES have changed little over the eight decades of its existence, the scientific fields covered by its work have expanded greatly, particularly during the past two decades. The original fields of activity in marine, especially fisheries, biology and hydrography have been expanded to encompass issues related to mariculture, fish diseases, and pollution of the marine environment. This expansion in numbers and types of activities has been accompanied by an increase in the number and subject areas of committees within ICES and the development of an extensive number of working groups reporting to these committees.

FOUNDATION AND MEMBERSHIP IN ICES

During the last decade of the Nineteenth Century, marine scientists and the governments of a number of European countries became concerned over the state of marine fish stocks following the expansion in European fisheries during the second half of that century, that occurred after the introduction of steam propulsion on fishing vessels. They recognized the need for an international body to organize and coordinate scientific investigations related to fisheries. Moreover, they also realized that isolated biological or hydrographic observations were of little value in understanding a sea area as a whole. Accordingly, these scientists proposed the establishment of an international body that should coordinate marine scientific research on a broad basis, to understand the sea and its living resources.

After several years of discussion among these scientists and approaches by them to their respective governments, the Swedish Government hosted a meeting in Stockholm in June 1899 to discuss international cooperation in the fisheries and oceanographic fields in the Atlantic. While the desirability of establishing an international body to coordinate marine scientific research was recognized at that meeting, agreement was not reached as to the precise functions of such a body. A subsequent meeting in May 1901 in Kristiania (Oslo) drew up a program of investigations on an international basis that should serve as the framework for scientific research by member states. Details concerning the establishment of the Council were also discussed (Ref. 2).

The formal establishment of ICES occurred on July 22, 1902 at a meeting in Copenhagen of representatives of governments. At this meeting, it was agreed that the seat of the Council should be in Copenhagen. A Central Laboratory was established in Kristiania, but was later closed. Officers of the Council were chosen, a General Secretary was appointed, and a five-year program of coordinated marine research was adopted.

The following eight countries founded ICES: Denmark, Finland, Germany, the Netherlands, Norway, Sweden, Russia, and the United Kingdom.

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Following the establishment of the Council, it rapidly became a major forum for the promotion of international cooperation in fishery science as well as in the field of hydrography. Owing to the Council's influence, a number of the member countries provided accommodation and facilities for research that had not been available previously. Most member countries had special vessels built for international marine scientific investigations. These developments were clearly very important accomplishments resulting from the establishment of the Council (Ref. 3).

Membership in ICES has varied through the years, depending on the interests of the countries and political conditions. Belgium joined the Council in 1903, and the USA in 1912. During World War I, Germany, Russia and the USA withdrew from the Council. France joined in 1920, Portugal in 1922, Estonia, Lithuania and Poland in 1923, Spain and Latvia in 1924, and Ireland in 1925. Germany re-entered the Council in 1926, Italy joined in 1927 and Iceland in 1938.

During World War II, Estonia, Germany, Italy, Latvia and Lithuania withdrew from membership, and Poland did not renew its participation from 1950 to 1955, when it re-entered as a member. The Federal Republic of Germany re-entered in 1952 and the USSR in 1955. Italy re-entered the Council in 1957 and withdrew again in 1974. Canada joined the Council in 1967, the USA re-entered in 1973, and the German Democratic Republic joined in 1975 (Ref. 4).

The following eighteen countries are present members of ICES: Belgium, Canada, Denmark, Finland, France, German Democratic Republic, the Federal Republic of Germany, Iceland, Ireland, the Netherlands, Norway, Poland, Portugal. Spain. Sweden, the United Kingdom, the USA, and the USSR.

ICES was initially founded to coordinate a five-year program of marine scientific research. Before this period had expired, however, it was decided that the Council should continue to exist, with membership based upon an agreement between each member country and the Council. This form of membership continued until July 22, 1968, when the 1964 Convention for the International Council for the Exploration of the Sea went into effect.

AIMS AND ORGANIZATION OF ICES

When ICES was founded, the initial agreement was for international collaboration on a five-year comprehensive program, aimed at practical results, to study hydrographic conditions, biology of the food fishes, and plankton of the northern seas. The three areas of scientific study were: (1) investigation of the hydrographic conditions in the North Sea, Norwegian Sea, Barents Sea, White Sea, and Baltic Sea, and their associations with oceanic circulation; (2) the study of the biological conditions of the animal and plant life in these seas, with special regard to the food, reproduction, growth, and distribution and migrations of food fishes; and (3) an investigation into the basis for commercial fisheries, including possible overfishing in any of the areas (Ref. 5). The investigations on commercial fisheries included the collection and publication of fishery statistics.

The Council conducted its work according to a set of Statutes agreed among the member countries and changed from time to time. After World War II, the question of a more official international status for the Council was raised. This ultimately resulted in the convening of a conference by the Government of Denmark in 1964 to conclude an international convention on the Council.

The 1964 Convention

The 1964 Convention on the International Council for the Exploration of the Sea entered into force on July 22, 1968. This Convention defines the structure of ICES and states that the duties of the Council are:

(a) to promote and encourage research and investigations for the study of the sea, particularly those relating to the living resources thereof;

(b) to draw up programmes required for this purpose and to organize, in agreement with the Contracting Parties, such research and investigations as may appear necessary; and

(c) to publish or otherwise disseminate the results of research and investigations carried out under its auspices or to encourage the publication thereof.

According to Article 2 of this Convention, ICES shall "be concerned with the Atlantic Ocean and its adjacent seas, and primarily concerned with the North Atlantic".

Immediately after the Convention came into force, a host agreement was concluded between the Council and the Government of Denmark, which gave the Council full international status, with privileges and immunities similar to those granted to agencies under the United Nations.

The Council's headquarters have been located in Copenhagen since its foundation. At present, the Secretariat includes a General Secretary, a Fisheries Statistician, a Hydrographer, an Environment Officer, and 22 other staff members, including persons involved in computerized data processing, technical editing of ICES publications, and printing.

The Council

The overall responsibility for the ICES program of work lies with the Council, which is composed of not more than two Delegates from each of the member countries. The Delegates are the chief contact in their country in all matters with which the Council is concerned. The Council is presided over by the President, who is elected from among the Delegates for a period of three years. Upon being elected, the President ceases to be a Delegate and

is an independent officer of the Council.

The Bureau

The President, together with the a Vice President and five other Vice Presidents, also elected for three years by and from among the Delegates, constitute the Bureau. Unlike the President, the Vice Presidents continue to serve as national Delegates during their terms in office. The Bureau is the Executive Committee of the Council. It is responsible for convening the annual Statutory Meetings, preparing budgets, and ensuring that the Council's decisions are implemented. It forms the main link between the Council and the Secretariat.

The Consultative Committee

The responsibility for maintaining a supervisory overview of the Council's scientific interests lies with the Consultative Committee, which currently consists of the Chairmen of the twelve scientific Standing Committees, the Chairmen of the two Advisory Committees, plus its own Chairman, elected by the Consultative Committee from among the Delegates and experts for a term of three years. The Chairman of the Consultative Committee is an officer of the Council and ceases to be a Delegate during his term of office. The Chairman of the Consultative Committee also participates in meetings of the Bureau.

According to the ICES Rules of Procedure, the Consultative Committee has general oversight over:

(1) the scientific interests of the Council and its scientific work,
(2) the programs of research organized or coordinated by the Council,
(3) the arrangements for carrying out the Council's scientific work and the programs of research organized by it, and
(4) the arrangements for discussing all the foregoing matters at the Council's meetings, including the organization of special scientific meetings.

The Consultative Committee is responsible for advising the Council and the Bureau on the above matters.

The Consultative Committee meets immediately before and during the Council's annual Statutory Meeting, both ensuring that all final plans are complete before the opening session and reviewing the outcome of the scientific sessions after they have been completed. In this context, the Consultative Committee reviews the recommendations from each Standing and Advisory Committee and decides whether they should be approved for consideration by the Council. With this overview of all the recommendations arising from the scientific sessions, both Standing Committee sessions and Theme Sessions devoted to multidisciplinary topics, the Consultative Committee is in a position to determine whether there are overlaps between research programs or other projects proposed and whether certain proposals should have priority over others. The Consultative Committee also keeps an overview of the working group meetings proposed for the next year and the tasks assigned to them, to ensure that all such meetings will represent a productive use of time and effort. All recommendations approved by the Consultative Committee and the results of its consideration of other matters are passed forward to the Council for ultimate approval. Recommendations accepted by the Council become Council Resolutions, to be implemented by Member States; they are published in the annual reports of the Statutory Meetings, the Procès-Verbal de la Réunion.

The Standing Committees

The planning, coordination, and detailed appraisal of the individual items of work within the ICES research programs are conducted by the Standing Committees. Member countries may appoint up to two members to each Standing Committee. These members serve as the chief contacts in their countries concerning the activities of that Committee. A Chairman is elected by the Committee from among its members for a term of three years. The duties of Standing Committee Chairmen are specified in the ICES Rules of Procedure and include maintaining contact with persons in member countries who are carrying out the programs of the Committee to ensure their conduct and preparing an annual report on the activities conducted in member countries to implement the programs of the Committee.

There are presently twelve Standing Committees, six of which have terms of reference, specified in the Council's Rules of Procedure, covering broad topics in marine science or technology; the other six are concerned with studies of specific groups of marine organisms.

The Standing Committees concerned with broad topics in marine science or technology, including their terms of reference, are:

(1) The Fish Capture Committee keeps under review and coordinates investigations concerned with fish detection and searching techniques, the design and operation of fishing gear, and the behavior of fish in relation to fishing operations;

(2) The Hydrography Committee keeps under review and coordinates investigations in physical and chemical oceanography, including studies of the environment of living resources;

(3) The Statistics Committee keeps under review, in consultation with other relevant organizations, the arrangements for the collection, treatment and publication of statistics concerned with the regulation of fisheries in the area with which the Council is concerned;

(4) The Mariculture Committee keeps under review and coordinates investigations relating to the culture of marine organisms, including the transplantation and introduction of new species;

(5) The Marine Environmental Quality Committee keeps under review and coordinates investigations

relating to the scientific study of man-made impacts, other than fishing, on the sea and its living resources, in particular, studies of pollution [see paper by Pearce, this volume]; and

(6) The Biological Oceanography Committee keeps under review and coordinates the studies of biological oceanography in the Council's area, including studies of plankton and benthos, and investigations on food chain dynamics.

The other six Standing Committees have the general terms of reference of keeping under review information about the species with which each is concerned and the state of the relevant stocks, and coordinating investigations related to them. These Committees are:

(7) The Demersal Fish Committee, which is concerned with, among others, cod, haddock, whiting, saithe, plaice, flounder, sole, halibut, redfish, Norway pout, and sandeel;

(8) The Pelagic Fish Committee, which is concerned with, among others, herring, mackerel, capelin, blue whiting, sardine, and sprat;

(9) The Baltic Fish Committee, which covers both pelagic and demersal species in the Baltic Sea, including cod, herring, and sprat;

(10) The Shellfish Committee, which covers all major commercially exploited types of shellfish in the North Atlantic, such as, lobster, clams (e.g., surf clams, ocean quahogs), mussels, oysters, shrimps, squid, and Nephrops;

(11) The Anadromous and Catadromous Fish Committee which is concerned with such species as salmon, eel, sea trout, and alewife; and

(12) The Marine Mammals Committee, which is concerned with all species of marine mammals in the North Atlantic, particularly seals, whales, purpoises, and dolphins.

The Standing Committees meet once per year, during the ICES Statutory Meeting. At this meeting, each Committee reviews scientific papers, prepared by Committee members or other scientists, and reports on various relevant activities. Most Standing Committees have one or more working groups, established by the Council on recommendation of the Committee, that serve to coordinate studies or provide information on specific issues of concern to the parent Committee. The Standing Committee considers the report of each working group under it and reviews the recommendations made by that working group for future activities, such as joint research programs, surveys, workshops, intercalibration exercises, etc. The Standing Committee also reviews any recommendation by the working group for a next meeting and the tasks proposed for that meeting. All recommendations for activities and working group meetings accepted or formulated by the Standing Committee are then passed on to the Consultative Committee for further handling.

The Advisory Committee on Fishery Management

The Advisory Committee on Fishery Management (ACFM) is responsible for providing, on behalf of the Council, scientific information and advice to Fisheries Commissions and to the Council's Member Governments on matters on which they may request advice, or on matters that the Council or the ACFM may consider relevant. The ACFM presently consists of a Chairman, nominated by the ACFM and appointed by the Council, the Chairmen of the Demersal, Pelagic and Baltic Fish Committees, and one scientist nominated by each Member State and appointed by the Council. The ICES Fisheries Statistician serves as Secretary of ACFM. Since 1987, the Commission of the European Communities has been represented by an observer at ACFM meetings.

The ACFM meets twice per year, usually in May and November, to formulate scientific advice for the management of stocks of fish and shellfish and to respond to specific requests and questions posed by the management bodies. In formulating its advice, the ACFM utilizes the results of the work of stock assessment working groups, that have been established by the Council at the request of ACFM to provide information on the state of stocks of particular species of fish or shellfish in certain sea areas and conduct other relevant work. At the present time, there are 27 stock assessment working groups, most of which are concerned with fish stocks, some with shellfish, and one group with seals. This work will be discussed in greater detail later in this paper.

The Advisory Committee on Marine Pollution

The Advisory Committee on Marine Pollution (ACMP) is responsible, on behalf of the Council, for providing scientific information and advice on marine pollution and its effects on living resources and their exploitation to Member Governments and any intergovernmental body for the control of pollution that may request such advice. The ACMP presently consists of a Chairman, nominated by the ACMP and appointed by the Council, the Chairmen of the Marine Environmental Quality, Hydrography, Biological Oceanography, and Mariculture Committees, and a number of coopted members chosen for their expertise in scientific areas of relevance to ACMP. At present, there are ten coopted members, with expertise in such areas as organic and inorganic chemistry, microbiology, fish diseases, sedimentology, and marine ecology. The ICES Environment Officer is the Secretary of ACMP.

The ACMP meets once per year, usually in June, to formulate scientific advice and provide appropriate information on a number of topics related to the contamination of the marine environment and its living resources and the effects of contaminants and to prepare responses to requests from pollution regulatory commissions. In carrying out this work, the ACMP reviews the reports of a number of working groups concerned with various aspects of the study of contaminants and their effects in the marine environment. This topic will be discussed in more detail later in this paper.

The Working Groups

Although working groups are not mentioned in the Council's Rules of Procedure, they have become increasingly important vehicles for the ground-level planning of new activities and the implementation of Council-approved programs or projects. Working groups are established by the Council to assemble information or coordinate activities on certain specific subjects. When its terms of reference have been fulfilled, a working group is disbanded. However, the tasks of many working groups are of a continuing nature, such as the assessment of particular stocks of fish, the study of oceanographic conditions, and the study of fish diseases. Thus, most working groups meet on an annual basis. Each working group reports to a "parent" Committee, that reviews the activities of the working group during the previous year, provides comments and guidance, decides whether the working group should meet the following year and, if so, formulates tasks for this next meeting. The reports of many working groups are considered not only by the "parent" Committee, but, particularly for working groups concerned with environmental topics, also by other Standing Committees and/or by the ACMP.

Each Member Country may appoint as many members to a working group as it wishes. Attendance at working group meetings is at national expense.

At present, ICES has 70 active working groups, distributed as follows:

(a) 27 stock assessment working groups, most of which are for fish, some for shellfish, and one for seals; all of these groups report to ACFM;

(b) 16 working groups dealing with other aspects of fish and fisheries, including fisheries acoustics, fishing technology, young fish surveys, larval fish ecology, etc.; these working groups report to various Standing Committees related to fish;

(c) one working group on fisheries statistics, reporting to the Statistics Committee;

(d) 26 working groups concerned with environmental subjects, including working groups related to marine chemistry, physical oceanography, sediments, benthos ecology, primary production, environmental impact of mariculture, fish diseases, effects of contaminants in marine mammals, and biological effects of contaminants [see paper by Thurberg, this volume]; most of these working groups report to the Hydrography, Marine Environmental Quality, Biological Oceanography, or Mariculture Committees; the reports of many of these working groups are also considered by the ACMP.

RESPONSIBILITIES AND MAIN ACTIVITIES OF ICES

The responsibilities and main activities of ICES can be divided into the broad areas of fisheries, oceanography, and, during the past two decades, marine pollution. The discussion in this section will relate to these activities separately, but it must be emphasized that the founding "fathers" of ICES, and their successors throughout the years, have fully recognized that the understanding of marine fishery problems necessitates studies of the sea itself and its complex ecology.

Fisheries

One of the main responsibilities of ICES is the coordination of fisheries-related scientific research. This comprises monitoring the abundance and composition of fish stocks in the Northeast Atlantic, including the development of appropriate methods to estimate abundance, and research on the early life stages of fish, recruitment to fish stocks, and multi-species interactions.

In the monitoring of fish and shellfish stocks, ICES collects statistics on fish catches, fishing effort, and relevant biological data (e.g., age, length, sex, maturity compositions; egg and larval production and young fish surveys). Officially reported fishery statistics are published in the Bulletin Statistique, which has been published annually since 1905, apart from breaks during the wars. In addition, a computerized data bank containing detailed information relevant to the assessment of stocks is held at the ICES Secretariat for use by fish stock assessment working groups and ACFM. Since its foundation, ICES has served as an important forum for the promotion and appraisal of work on stock assessment methodology, including the development of mathematical models for use in determining the effects of fishing on individual resources and assessing the need for their conservation and management through regulatory actions. An important area of focus at the present time is the development of models for multi-species interactions and their effects on individual fish stocks.

Although ICES has remained a scientific body without any regulatory power, it has been instrumental in prompting the establishment of regulatory commissions (see Ref. 6). At present, ICES is the officially recognized international scientific advisory body to three international fisheries regulatory commissions: (1) North East Atlantic Fisheries Commission (NEAFC), (2) International Baltic Sea Fisheries Commission (IBSFC), and (3) North Atlantic Salmon Conservation Organization (NASCO). These Commissions, the Commission of the European Communities on behalf of its members, and governments of other ICES member countries formulate requests to ICES for information and advice on specific stocks or groups of stocks. It is the work of the ACFM to ensure that appropriate responses are made to these requests, based on the detailed data and other information compiled and analyzed by the stock assessment working groups. In total, hundreds of scientists and other specialists in ICES member countries contribute to the conduct of this work, from participation in fish stock assessment cruises or egg, larval, or young fish surveys to the evaluation of the data gathered for each stock by the working groups and ultimately the ACFM. In the course of its work, the ACFM for-

mulates scientific advice for the management of over 90 stocks or management units in the Northeast Atlantic and the Baltic Sea.

Until recently, the advice provided by ACFM was generally in the form of a single recommended action, such as the setting of a TAC (Total Allowable Catch) for a particular stock. However, in recent years, following changes in the management regime and at the request of management authorities, ACFM advice has been provided increasingly in the form of a range of management options (e.g., a series of TACs of different magnitude) with accompanying indications of the implications of each option in terms of the resources and fisheries. Where there is a situation of severe stock decline and a need for urgent remedial measures, ACFM provides advice on the appropriate action to take regardless of whether there has been a specific request for it (Ref. 7). The reports of ACFM, containing all of the advice provided to member governments and fisheries commissions, are published annually in the Cooperative Research Report series.

Oceanography

The coordination of investigations of physical oceanographic conditions and the chemical nature of the sea in support of fisheries studies was the other main area for which ICES was founded. At its first meeting in 1902, the Council decided that international cruises should take place quarterly in February, May, August, and November. Data on, for example, currents, temperature and salinity, acquired during these and other cruises were submitted to ICES and, during the first six decades, published in various types of bulletins. However, since the early 1960s, the increase in the amount of data and the introduction of computers led to the cessation of publication of such volumes. Particularly during the earlier decades, this function of ICES as a center for the deposition of data has been very important. In fact, until the establishment of the World Oceanographic Data Centers A (Washington) and B (Moscow), ICES was the only international data center for hydrograhic purposes in Europe (Ref. 2). In addition to the collection and exchange of hydrographic data, the Council's Hydrographers have provided appropriate analyses of various types of hydrographic data that have been published by ICES (Ref. 8).

Another important area of work has been the development and calibration of hydrographic equipment and the maintenance of appropriate standards of quality and intercomparability of hydrographic data. From 1902 to 1908, ICES ran the Central Laboratory, which served as a facility for designing, testing and calibrating various types of hydrographic equipment, and preparing and distributing standard sea water; this latter function was continued by ICES until 1968. Although no longer involved in the design of equipment, ICES has continued to promote the intercomparability of data through the periodic conduct of intercalibration exercises, e.g., on the use of salinometers and the measurement of nutrients in sea water. In addition, the Hydrographer maintains a check on the physical and chemical oceanographic data submitted to the ICES data center verify their consistency.

ICES has coordinated a number of major oceanographic investigations and multi-disciplinary investigations with strong physical oceanographic components. Among recent such exercises are: the hydrographic program of the International Geophysical Year (IGY) (1158-1959); the Overflow Experiments in the Iceland-Shetland Ridge (1973); the Joint North Sea Data Aquisition Program (JONSDAP) (1976); the Baltic Open Sea Experiment 1977 (BOSEX); and the Joint Multi-Ship Investigation of Patchiness in the Baltic Sea (PEX) (1986).

Marine Pollution

During the middle of the 1960s, ICES member countries became concerned about the levels of contaminants in marine fish and shellfish and the possible effects of marine pollution on them. Accordingly, the Fisheries Improvement Committee was established to coordinate work on marine pollution; in 1978, this was replaced by the Marine Environmental Quality Committee.

Much of the early work concerned the measurement of concentrations of organic and inorganic contaminants in fish and shellfish, including associated intercalibration exercises on analyses of these contaminants and work to improve data quality. A Coordinated Monitoring Programme on contaminants in fish and shellfish was begun in the North Sea in 1972 and expanded to the North Atlantic in 1974. Two major Baseline Studies of Contaminants in Fish and Shellfish have been conducted covering the North Atlantic, including the Baltic Sea, in 1975 and 1985. Now entitled the Cooperative ICES Monitoring Studies Programme, the work is primarily aimed at monitoring temporal trends in contaminants in certain areas.

ICES also coordinates work on the measurement of trace metals in sea water and sediments, primarily intercalibrating sampling techniques and analyses. A Baseline Study of Trace Metals in Coastal and Shelf Sea Waters was conducted in 1985-1987. Other areas of work include the development of techniques to monitor the biological effects of contaminants, studies of biogeochemical cycles of contaminants in the sea, identification of new contaminants, reviewing issues related to the study of contaminants in sediments and their bioavailability, providing advice on monitoring strategies and methods, and coordinating assessments of the state of the marine environment on a regional basis.

In addition to its own work on marine pollution, ICES serves as a scientific advisory body to three pollution regulatory commissions: (1) Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft (Oslo Commission), (2) Convention for the Prevention of Marine Pollution from Land-Based Sources (Paris Commission), and (3) Convention for the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Commission). These Commissions formulate requests to

ICES for information and advice on topics relevant to their programs, including their respective marine pollution monitoring programs. This advice is provided by the ACMP, on the basis of its review of the reports and other information provided by relevant ICES working groups. The ACMP advice and information is published annually in the Cooperative Research Report series.

ICES has the first computerized international center for data on marine contaminants, containing data from its Cooperative Monitoring Studies Programme and also serving as the center for storing and processing data from the Oslo and Paris Commissions' Joint Monitoring Programme, covering contaminants in biota, sea water, and sediments. In this context, ICES has developed data reporting formats for contaminants in all marine media.

PUBLICATIONS

ICES has published scientific literature since its foundation. Through the years it has issued well over a thousand different publications, many of which are considered standard reference works in their particular fields. Current ICES serial publications comprise the following:

Journal du Conseil is the ICES journal of marine science, covering advances in all aspects of the work of the Council. It is a primary source for articles on fish population biology and assessment, shellfish and plankton studies, and sampling gear and instrumentation. Environmental topics and oceanography are also covered. Three to four numbers are issued annually.

Rapports et Procès-Verbaux des Réunions is the series in which papers and proceedings of ICES-sponsored symposia and special meetings are published.

The Cooperative Research Report series comprises reports prepared by ICES working groups, ad hoc groups, workshops, or other ICES-sponsored activities. The series also includes the annual reports of the ACFM and ACMP. Approximately eight volumes are usually issued annually.

The Bulletin Statistique is the yearbook of fishery statistics of the Northeast Atlantic.

ICES Oceanographic Data List and Inventories contain oceanographic data, mainly for the Northeast Atlantic, in tables and charts prepared by the ICES Hydrographer.

The Fiches d'Identification du Plancton are illustrated identification keys for planktonic organisms, including fish eggs and larvae, in the ICES area.

Fiches d'Identification des Maladies et Parasites des Poissons, Crustacés et Mollusques/Identification Leaflets for the Diseases and Parasites of Fish and Shellfish are illustrated diagnostic keys for the principal diseases and parasites of fish and shellfish in the ICES area.

Techniques in Marine Environmental Sciences is a new series containing detailed descriptions of methods and procedures relating to chemical and biological measurements in the marine environment.

ICES/CIEM Information is a newsletter, published twice a year.

FUTURE ACTIVITIES

For over eight decades, ICES has served as the main forum for the coordination of scientific investigations of marine fisheries and their environment. While enormous advances have occurred, the complexity of the ecosystem and man's influence on it underscores the continuing need for internationally coordinated studies of the marine ecosystem and its living resources. New activities under ICES are being developed to explore further the interactions between the physical, chemical, and biological systems in the North Atlantic and its sub-areas.

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AN EVALUATION OF SHELLFISH RESEARCH IN THE INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA

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ABSTRACT

Since its beginnings in 1902, the International Council for the Exploration of the Sea (ICES) has served as a catalyst for research on the biology and management of shellfish species. This research has been focused in three major areas: (1) development and support of mariculture (2) effects of coastal pollution on shellfish abundance and sanitation, and (3) dynamics and management of natural populations of mollusks and crustaceans in relation to fishing. In all these fields, research by ICES member nations has been important in resolving technical issues and has served as the scientific basis for various authorities to enact regulatory measures. Currently, at least three standing committees of ICES are tasked to coordinate and review shellfish-related research (i.e., Mariculture, Marine Environmental Quality, and Shellfish). In addition, both the Advisory Committee on Fishery Management and the Advisory Committee on Marine Pollution routinely address topics concerning shellfish. As research and management-related issues become more interdisciplinary in nature, the challenge in the future will be to more fully integrate mariculture, pollution, biological oceanography, and population dynamics studies to better understand these issues in the context of coastal ocean ecosystems.

INTRODUCTION

Evaluating the current status and historical contribution to shellfish research by the International Council for the Exploration of the Sea (ICES) is indeed a daunting task. This is due in no small measure to the 85+ year history of innovative and productive study conducted under the auspices of ICES, but, more importantly, to the multi-disciplinary nature of what is collectively referred to as 'shellfish research'. Even prior to the first meeting of ICES in 1902, European and North American researchers were pursuing shellfish related research along three relatively divergent paths: (1) mariculture (primarily of oysters and mussels) , (2) effects of sewage and industrial pollutants on shellfish sanitation and abundance, and (3) population dynamics and fishery regulation of natural stocks. Today, these three areas are recognizably distinct in the structure of ICES. One need only consider the names of current selected Standing Committees, Advisory Committees and Working Groups of ICES concerned with shellfish problems to trace their historical roots to the earliest specializations:

Advisory Committee on Fishery Management
Advisory Committee on Marine Pollution
- Shellfish Committee
- Mariculture Committee
- Marine Environmental Quality Committee
- Demersal Committee
- Fish Capture Committee
  - Pandalus Working Group
  - Nephrops WG
  - Study Group on Squids
  - Fish Technology WG
  - Marine Aggregate Extraction WG
  - Benthos Ecology WG
  - Algal Blooms, Mariculture and Fisheries
  - Biol. Effects of Contaminants WG
  - Transfers of Marine Organisms WG
  - Genetics WG
  - Pathology and Diseases WG

In this paper I outline the development of shellfish research in its various disciplines conducted under the auspices of ICES, and its member nations. Rather than presenting a chronology of papers, meetings, events, etc., I have chosen to review selected contributions as indicative of changing directions and emphases. The history of shellfish research under ICES perhaps serves as prologue, and I have taken the liberty of speculating as to the potential future directions of both the science and the role of ICES as a medium for scientific exchange.

OVERVIEW OF ICES SHELLFISH RESEARCH

The importance of mollusk and crustacean fisheries and mariculture has dictated a long history of investigations into fluctuations in abundance of natural populations, methods for culture, and the effects of environmental contamination on the safety of these products. No more so than in northern European and North American waters. Today, nearly 700 thousand metric tons of shellfish are produced from the ICES area, of which nearly one half is derived from mariculture (Figure 1; Anderson[1]). Although dwarfed by the 10 million metric ton combined production of finfish, because of their high unit value, shellfisheries and mariculture operations are important sources of income and employment.

Research on problems of marine mollusk and crustacean culture and fisheries was well developed

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as a science long before ICES was formed as an organization in 1902, and before the first formal ICES meeting devoted to shellfish problems convened in 1932 (Went[2]). Indeed, between 1870 and 1910 overfishing of natural beds of mussels and oysters had become so problematic in the northern European area that intensive culture of these species was thriving by the turn of the century (Bashford Dean[3,4], Wollebaek[5], Friele[6], Petersen[7]). Havinga[8] notes that oyster culture in Holland was initiated in the 1870s, and that by 1890 the annual production was 30 million individuals.

The negative impacts of coastal pollution on shellfish sanitation was clearly recognized as an impediment to development of many mollusk fisheries by the early 1900s. Discharge of sewage and other by-products of the industrial revolution had rendered numerous coastal stocks of cockles, oysters and mussels in the North and Baltic Seas unfit for human consumption. Much of the research on shellfish conducted during the early 1900s concerned the development of methods of testing for shellfish contamination (Johnstone[9]). Wright[10] noted in 1927 that 'the chief difficulty in extending the home-trade for cockles is the fact that the shellfish are liable to be contaminated by sewage'. Such was the case for numerous molluscan fisheries in the region (Anon.[11]; Orton[12]).

The first organized meeting of shellfish experts convened under the auspices of ICES occurred in Middleburgh, The Netherlands, in 1932 (Went[1]; Havinga[13]). This initial meeting concerned 'Bacteriological investigations of mollusks', and was convened for the purpose of developing standard procedures to measure the extent of shellfish contamination. Although these experts could not agree on uniform procedures for such testing (Havinga[13]) they nevertheless established the precedent for multi-national cooperation in shellfish research that would extend to fields far removed from shellfish sanitation in the decades to follow.

The period of the 1920s and 1930s also witnessed development of research on the effects of industrial pollutants such as oil on fish and shellfish populations. Roberts[14] concluded in 1926 that the effects of oil were 'not very marked, but if unchecked will become a menace in the future'. The period of the '20s and '30s also saw intensive research and perfection of pilot methods for mariculture of a number of mollusk and crustacean species. Methods for artificial spawning and rearing of shellfish, and methods for mass culture were perfected in this era (Orton[15]; Cole[16]; Dannevig and Meek[17]). Just as important at this time were early experimental introductions of non-indigenous species, and in particular oysters (Borodine[18]; Anon.[19]). In an interesting juxtaposition of papers Ranson[20] and Orton[21] simultaneously questioned the feasibility of replacing local populations of oysters in France and England with introductions of the Portuguese oyster (Crassostrea angulata).

Publication of the Journal du Conseil, beginning in 1926, had an important influence on the direction of cooperative shellfisheries research. Early volumes of the Journal contained extensive bibliographic citations of research published world-wide. Thus, researchers during this period were kept abreast of, for example, pioneering work by P. Galtsoff and V. Loosanoff in America, and oriental methods of mariculture.

Some of the earliest work on the dynamics and regulation of natural shellfish populations involved nearshore and deep-water crustaceans (Williamson[22]; Herdman[23]; Meek[24], Hjort and Ruud[25]). In particular, small-mesh fisheries directed at brown (=Crangon) and northern

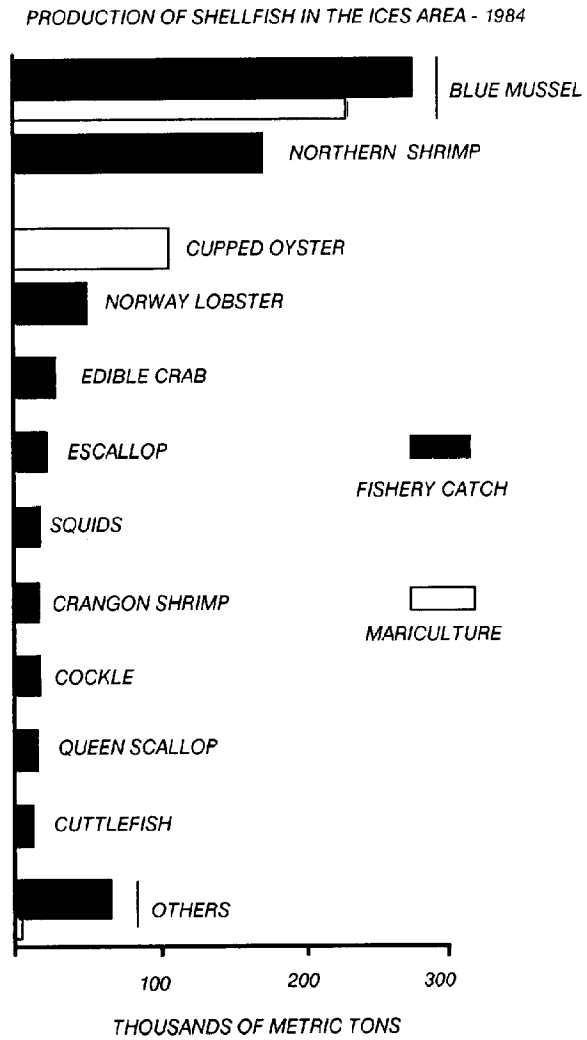

FIGURE 1. Landings and mariculture production of shellfish species from the ICES area in 1984. Data are for all invertebrates exclusive of seaweeds. Total fishery catch of shellfish was 682,000 mt, mariculture production was 341,000 mt.

(=Pandalus) shrimp were considered problematic in that by-catches of small finfishes were discarded from these fisheries.

Research in mariculture, sanitation and population dynamics of shellfish developed more or less independently during the 1930s and early 1940s. Numerous publications in the Journal du Conseil and elsewhere attest to the developing sophistication in methodology in these areas. However, it wasn't until the late 1940s that researchers were coming to a consensus that a united discipline of shellfisheries research was necessary within the context of ICES. A landmark special meeting was called in 1949 (Havinga[26]; Korringa[27]) during which all current aspects of shellfish research were discussed under the theme of 'Shellfish Investigations'. In his preface remarks, the convener, B. Havinga, first stated the case for shellfish research as a separate discipline in ICES by noting that in the past, shellfish research had not received due attention because in no country were shellfish the predominant fishery landings. Also, shellfish researchers rarely attended meetings of the Council because most investigators in the field were specialists rather than being generalists. He further pleaded the case for recognition of shellfish investigations by noting that the aggregate value of all countries shellfish landings in the North Sea area were roughly equivalent to that of the plaice, but that the research resources dedicated to plaice were much greater. Summarizing the current state of mariculture in relation to natural production, Havinga noted that 'While the oyster has proved to be an organism that is extremely sensitive to overfishing, nearly all the natural banks being extinguished by intensive fishing, artificial culture has provided a very efficient method of producing much larger quantities of oysters than has been possible from natural banks'. Given the current (1984) production of oysters from mariculture relative to natural production (Figure 1), Havinga's statement is as true today as nearly 4 decades ago. A few of the titles of papers from the 1949 shellfish meeting emphasize its multi-disciplinary nature: 'British oyster industry and its problems', by H.A. Cole, 'On crustaceans of commercial importance in Danish waters', by E.M. Poulsen, and 'Les huitres de cotes Francaise', by L. Lambert.

After the successful meeting of 1949, ICES established a formal Shellfish Committee, which met for the first time in 1951. Reports of the statutory meetings from 1951 - present show that research presented at the Shellfish Committee meetings has retained its diversity in interest. However, special meetings regarding shellfish, conducted since 1949, have been more topical, relating variously to mariculture, pollution and its effects, and natural history and population dynamics.

In 1954 a special meeting on 'Oyster and Mussel Culture' (Havinga[28]) was conducted to assess the current status of mariculture and was convened by the first chairman of the ICES Shellfish Committee, B. Havinga. This meeting is historically important since it was the only special session devoted exclusively to mariculture prior to the establishment of a formal Mariculture Committee within ICES.

The special meeting conducted in 1963 (Cole[29]) was devoted to 'Problems in the Exploitation and Regulation of Fisheries for Crustacea'. During this meeting numerous descriptive, analytical, and methodological papers regarding crustacean biology were presented. The period of the 1950s and early 1960s witnessed intensive research on a number of species including Norway lobster (=Nephrops), shrimps, and American and European lobsters, and much of this work was summarized and placed in context at the special meeting on crustaceans.

The special meeting of 1976 (Thomas[30]) is important not only since it was the first ICES meeting devoted to population dynamics of shellfish, but it was among the first international gatherings at which researchers discussed the unique life history and population dynamics characteristics of mollusks and crustaceans. Because of the growth, recruitment and spatial dynamics patterns exhibited by shellfish populations, the utility of models originally developed for finfisheries was seriously questioned. New methodological developments relating to the use of quantitative tools for designing fishery sampling, estimation of growth and mortality, and the calculation of yields were put forward. Perhaps the seminal paper of the meeting was the contribution by D.A. Hancock on 'Population dynamics and management of shellfish stocks', in which he contrasted shellfish and finfish population dynamics, noting at the same time the need for better quantitative studies of shellfish, but rejecting the universal application of finfish-derived methods.

Two subsequent special meetings conducted in 1979 (McIntyre and Pearce[31]) and 1980 (Stewart[32]) are notable not because of their concentration on shellfish issues **per se**, but rather because they attest to the diversity and intensity of contemporary work relating to the biological effects of contaminants and the status of research on fish and shellfish diseases, respectively.

The late 1970s and 1980s have seen a virtual explosion in the diversity and quantity of research directed to shellfish topics within the ICES arena. In the field of mariculture, studies of genetics and disease resistance, modern culture techniques, and increased interest in the effects of the use of non-indigenous species have proliferated. Significant in the studies of mariculture operations is the increasing awareness that intensive culture operations can impact greatly on local waters wherein such operations are conducted (Rosenthal et al.[33]), and that such operations may result in competition among cultured and natural populations for limited food supplies (Sauriau[34]).

Population dynamics studies on shellfish, at first based on careful investigations of the life histories of the animals, have been significantly aided by increasingly sophisticated techniques for the ageing of mollusks through the examination of shell microstructure (Ropes et al.[35]), and the use of radioisotopes to validate age determinations (Berthou[36]). For crustacean studies, the development of techniques for length-based assessment has significantly improved estimates of growth, mortality and recruitment. An important issue in the management of crustacean populations has been the testing and development of selective harvesting gear to reduce the impact of by-catches of small finfish in small-mesh shrimp fisheries. Multispecies assessments taking into account the trophic and fishery interrelationships among invertebrates and finfishes are in their infancy (Brander and Bennett[37], Anon.[38]).

Recent developments in the fields of contaminant assessment in relation to shellfish are documented elsewhere in this symposium.

These are but a few selected examples of the impact and diversity of shellfish research conducted by researchers operating under the ICES purview. The reader is encouraged to consult the various publications of ICES and elsewhere for a more comprehensive treatment of particular subject areas.

SPECULATIONS

The period of the 1970s and 1980s witnessed an unprecedented increase in the degree of specialization of research in the various disciplines of mariculture, contaminant assessment relating to shellfish, and the dynamics and regulation of natural populations of mollusks and crustaceans. Because of the degree of technical sophistication in these fields, researchers by necessity developed expertise of specific rather than general applicability. This specialization in research emphasis, however, belies trends that will likely determine the future of shellfish research in ICES. It is clear that management-related problems associated with 'traditional' specialties in shellfish research transcend any of these areas taken individually. Thus, for example, the questions of environmental effects of intensive mariculture will require research on new culture methods, biological oceanographic and contaminant evaluations, and population dynamics studies to evaluate 'optimal' densities of mariculture operations in relation to environmental constraints. Likewise, traditional population dynamics studies will to a greater extent rely on investigations of biological productivity and species interactions, since, in many cases, harvested shellfish stocks are food sources for exploited fish populations. Improvements in fishing technology will be important in minimizing harvesting interactions that are problematic for optimizing productivity from jointly harvested fin and shellfishes.

Underlying all these considerations is the fact that ultimately research on living marine resources will progress from evaluating the limits to increasing productivity of individual constituents (e.g. natural or cultured shellfish populations), to an holistic approach to optimizing ecosystem productivity for the totality of benefits to society. By all appearances coastal systems, particularly but not limited to the ICES area, have reached their capacity to generate production from both natural sources and from mariculture. The ability of coastal areas to absorb increased burdens of contaminants is likewise conjectural. The challenge for the future is to conduct multi-disciplinary studies aimed at understanding the impacts of management decisions regarding mariculture, pollution/contamination and harvesting of natural populations in the context of coastal ocean ecosystems. Current relationships among shellfish research programs within ICES (Figure 2) will, by necessity, be modified to accommodate research of a more interdisciplinary nature. The critical need at this juncture is a forcing function to bring the various specialties together to address these more integrative problems. Perhaps ICES will fill that need.

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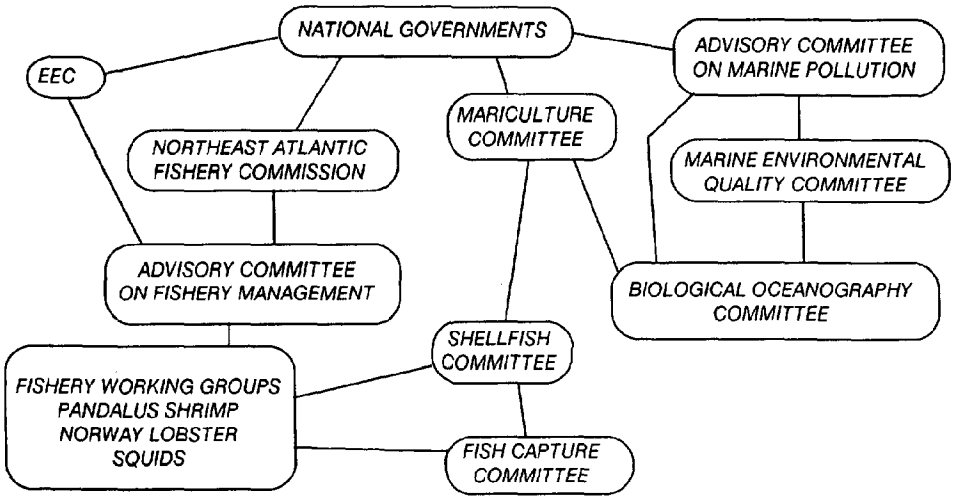

FIGURE 2. Relationshps among various working groups, standing committees, and fishery advisory and regulatory commissions dealing with shellfish issues in the ICES area. This diagram represents both formal and informal relationships among the various entities.

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THE ICES MARINE ENVIRONMENTAL QUALITY COMMITTEE (MEQC); ITS HISTORY AND ACTIVITIES

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ABSTRACT

This paper reviews the early history of pollution research and its consideration in management as accomplished within the Marine Environmental Quality Committee (MEQC) and predecessor units, International Council for the Exploration of the Sea. Recent issues and developments are discussed and used to illustrate the activities of the MEQC since 1975.

THE EARLY HISTORY

It is frequently stated that the International Council for the Exploration of the Sea (ICES) is the world's oldest international organization dedicated to the study and management of the world's oceans. The ICES started during a series of meetings held in the late 1890s, culminating in the first formal sessions of ICES in 1902. The Council was organized in response to a general feeling that the development of large trawling vessels, involving steam or diesel propulsion, and the use of the otter trawl had affected fish stocks. As was the case in the 1960s, in the middle of the 19th Century there was a "firm belief" in the ability of the seas to produce unlimited amounts of food stuffs. The effects of man, new harvesting techniques as one, however, led some scientists to believe that the thinking of the 19th Century was erroneous.

In his history of ICES, "Seventy Years Agrowing", Went[1] detailed the early meetings, including the North Sea Convention of 1882, and how these led to organizational meetings which gave birth to ICES. Much of the Council's early attention was given to overfishing and how it might be controlled. Relatively little thought was given to matters of pollution. The committee structure that was adopted at the first meeting of the Council, July 1902, did not indicates any large or immediate concern for matters of pollution or the environmental effects of man's activities. By the 1920s, however, papers had been published which were concerned principally with the effects of various forms of pollution. The tenth meeting held in Copenhagen in April 1912 resulted in plans concerned with the effects of pollution on salmon and their spawning grounds. During the so-called "Jubilee Year" of 1927 the matter of oil pollution was raised by Odon deBuen, Spain. The Council invited him to prepare a paper "embodying all the information procurable as to the ill affects of oil on fish and fisheries" to be given at future meetings. Subsequently several papers were developed, presented, and published in ICES Proceedings volumes.

In 1925 there was a resolution that a major reorganization should be made in the ICES structure. Indicated in the list of committees to be formed or added was the Hydrographical Committee. This committee was mandated to formulate programs which would be involved with the studies of the "hydrographical conditions, which might affect the life and movements of fishes." At this time in history the principal issues of pollution were not identified and no special responsibility to study pollution was given to <u>any</u> of the ICES standing committees. No doubt it was understood, even at this time, that pollution could be a problem and that there was a general concern. In October 1951 yet another scheme for the ICES Committee structure was developed. Again it included pollution related activities that might be relegated to the several full standing committees, not to any specific committee. Went[1] took note that as far back as 1931 France and its delegation had asked the Council to establish a committee to deal with the "sanitary control of mussels and oysters." The matter was left, however, for informal settlement amongst the delegates and others concerned.

During the May 1966 ICES meetings held in Edinburgh, a new structure for scientific committees was outlined, to be implemented on 1 November 1966. The new committee structure included one called the Fish Improvement Committee (FIC) which was to be concerned with, among other things, problems of pollution. Papers presented to the FIC up to 1975 frequently concerned topics having to do with aquaculture and artificial propagation. As early as 1971 there was concern about the overlap between the FIC and the Anadromous and Catadromous Fish Committee, as well as the Shellfish and Benthic Committee.

In 1975 a fair amount of the dialogue within the Fish Improvement Committee had to do with the establishment of a committee that would be concerned solely with the quality of habitats for

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the fisheries and shellfisheries. In 1978, the first meeting of the Marine Environmental Quality Committee (MEQC) took place in Copenhagen. The terms of reference for the MEQC suggested that this committee would have lead responsibilities for matters concerned with the sources, fates, and effects of pollutants. Moreover, the MEQC would have principal working groups which would report to it. While it was understood that certain pollution related issues might be dealt with by other committees, i.e., Hydrography or the future Mariculture Committee, most issues related to pollution and physical degradation of habitats would be the responsibility of the MEQC and its associated working and study groups.

Before going on with discussions about the activities of the MEQC, it should be noted that in 1971 the Council took under consideration the question of "international investigation of pollution of the North Sea and the wider aspects of pollution within the Councils' area". The Council decided that all necessary steps be taken to establish an "advisory committee" to provide scientific information and advice on marine pollution and degradation and its effects on living resources. Information and advice were to be directed to the member nations as well as several intergovernmental agencies or regulatory bodies having responsibilities for control of pollution. Moreover, such agencies could request advice from the ICES Advisory Committee on Marine Pollution (ACMP). It was noted that responsible standing committees within the ICES structure could be called upon by the ACMP to provide appropriate papers, advice, or plans necessary to the activities of the ACMP. Finally, because of these interests, Professor Cole (UK) that year gave a special lecture on "Marine Pollution and its Effects on Living Resources - the Role of ICES".

As will be seen in the following brief paragraphs, the future mission of the MEQC was well established in the 1960s and the consequences of its activities have been instrumental in establishing the courses of marine pollution studies world-wide.

THE RECENT HISTORY

The 1975 meetings of ICES were held in Montreal and the work of the then Fisheries Improvement Committee (FIC) largely centered on the report of the Working Group on Pollution Baseline and Monitoring Studies in the Oslo Commission and ICNAF areas. This working group had a responsibility to develop the strategy for a baseline monitoring program that would involve analyses for contaminant levels in fish from the entire area of interest to ICES. Moreover, the monitoring would include a baseline survey of metal levels in sea water in the ICES area. This latter activity was recognized as an extremely difficult task given the lack of interrelationships and intercalibration that might exist between the various participating laboratories. It was to be, however, one of the first truly international efforts of its type.

The working group was also to be responsible for reviewing all known inputs of pollutants to the area of interest. Given the foregoing mandates, the Working Group report to the 1975 meeting was accepted by the FIC and one of the world's larger marine monitoring programs commenced. In addition to the matter of long-term pollution monitoring, the Committee also was concerned about the issue of extraction of sands and gravels, especially from areas that might be important spawning grounds. Aggregate mining was then being done and proposed in important European and North American coastal waters and aspects of the issue were seen as deleterious to the fisheries.

A total of 45 papers was presented to the 1975 meeting. About half touched on issues of pollution and the remainder were concerned with shellfish and benthos, mariculture, and anadromous fish.

During the 1976 meetings additional progress was reported for the Working Group on Pollution and Baseline Monitoring Studies (WGPBM). It was recommended that studies should not necessarily be done only at the same reference sites but that special areas, i.e., "hot spots", should receive additional, more indepth treatment. It was during this Copenhagen meeting that a small study group reported on the feasibility of <u>biological effects monitoring</u>. While several national and international monitoring programs had been implemented, to this time none had emphasized looking at the effect of pollutants on the physiology, genetics, or biochemistry of "sentinel species". The early discussions and subsequent recommendations resulted in an international workshop on biological effects monitoring. This 1979 meeting was held at the Duke Marine Laboratory and resulted in a proceedings[2] which almost a decade later is still a principal source of knowledge on the subject.

It was during the 1976 ICES Statutory Meeting that extensive coverage was first given to oil spills and the effects of petroleum hydrocarbons on fisheries and supporting food chains. It was also noted that **atmospheric input** would be a significant source of toxic trace metals and other contaminants in the Firth of Forth and the North Sea in general. Several papers touched on trace metals, their distribution and abundance in organisms, their role in the physical habitat, and their possible effects on resources.

By 1977, the FIC gave considerable attention to **biological effects monitoring** and the use of pathological, physiological, and biochemical changes, and aberrant behaviors, as indicators of stress due to pollution. A special report was given on the US Ocean Pulse Program, a long-term monitoring program developed to assess the health of living resources. Numerous reports were forthcoming from the WGPBM which reported on levels of trace metals in selected fish and shellfish from the North Atlantic. The data in such reports became part of the aforementioned working group data holdings on pollution baseline

and monitoring studies. Spurred by several major oil spills, extensive discussions were held about how best to assess the effects of oil spills and blow outs, such as at well head BRAVO in the North Sea.

In 1976 and 1977 discussions were held to the end that FIC was to be divided essentially into the Mariculture and Marine Environmental Quality Committees. This move had the distinct advantage of concentrating presentations of all papers, reports, and activities in regard to marine pollution in a single committee. Prior to this time, papers on pollution could well appear at the Hydrographic, Fish and Benthos, Fish Improvement, and several of the Fish committees, per se.

It was during the 1978 session in Copenhagen that the fourth report of the Working Group on Marine Pollution Baseline Studies in the North Atlantic (WGNA) (a name change from WGPBM) was presented and discussed. By this time exercises concerned with the intercalibration of samples and analytical methods were being widely discussed and plans for future work developed. Oil pollution continued to be a major theme, with 13 papers presented. One of the main themes for the Committee was the report on use of bivalve mollusks in long-term monitoring, with special emphasis on the preliminary results from the "Mussel Watch Program". Five papers were given on relationships between pollution and fish diseases and other abnormalities. Likewise, the first reports from Mussel Watch were given and continued emphasis was placed on the use of biological effects monitoring.

In 1979 the meetings were held in Warsaw and the principal theme included information and reports on the introduction of exotic or nonindigenous marine organisms. Although there were 19 new papers on biological effects monitoring, one of the main thrusts of the meeting was environmental quality in estuaries and coastal waters. Ten papers detailed the status of habitat quality in estuaries along the coastline of the United States, from Maine to the Chesapeake Bay. These papers, and others, were later published in an ICES Cooperative Research Report[3]. A formal recommendation was made to the Council that member nations should encourage future reports on status of habitat quality or assessments of national estuaries. The Committee also had joint meetings with the Hydrographic Committee, with special emphasis on marine chemistry. This meeting was the scene for reports from the first meeting of the Marine Chemistry working group, one of the future dominant producers of water and sediment quality information for the ACMP and the MEQC.

All of the aforementioned "themes" have continued into the 80's. The work of the Marine Pollution Baseline and Monitoring in the North Atlantic Working Group has continued with its assignments now divided between the Marine Chemistry Working Group and the recently formed Working Group on Biological Effects of Contaminants, whose mission is to concentrate on biological aspects of marine pollution and marine pollution monitoring. Trend monitoring contaminants in biological tissues and the several physical compartments is now assigned to the Working Group on Environmental Assessment and Monitoring Strategies. A report on the Working Group on Biological Effects will be given during the present session. Committee emphasis has focused on determining sources and fates of contamination, as well as on the biological effects of individual contaminants on key target species.

It was during the 1983 meeting that the MEQC focused on plankton blooms and from these sessions the special ICES meeting on "The Causes, Dynamics, and Effects of Exceptional Marine Blooms" evolved. Also during the 1983 meeting, the first formal conceptualization of the precautionary approach occurred. Several scientists suggested that the world's oceans, especially coastal waters, were presently overloaded with wastes and it might be better to begin to protect the world's oceans at the expense of other habitats. This debate has continued to the present, with often very different views held by different scientists and nations.

Earlier, the WGNA had suggested a meeting to develop regional assessments. In the 1982 Statutory Meeting a paper[4] by J. M. Bewer et al was read and discussed in terms of providing the guidelines and protocols for preparation of regional assessments. During the 1983 meetings of ICES, the first such assessments were presented to the MEQC. These included overviews for and assessments of Massachusetts and Cape Cod Bays. At this time it was well known that Boston Harbor was heavily polluted and that pollutants were being exported to adjacent coastal waters. A large NOAA/EPA offshore assessment for the area(s) involved with the 106-mile sludge disposal site[5] was also reviewed and discussed as a paradigm for future assessments. Member nations were asked to develop assessments to be used in the management of fisheries habitats following the guidance given in the Bewer et al paper.

During the eighties the MEQC meetings regularly resulted in the preparation and presentation of fully three score papers. Interests have continued in many of the aforementioned areas but new issues and themes have emerged. These include the problem of floatable debris, especially various plastics, and the matter of diseases in fish that are induced by pollution.

The foregoing represents a necessarily brief sketch of what the ICES MEQC has been involved with the past decade. It is important, however, to note the foresight shown by this committee in terms of its various recommendations and products.

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THE ICES WORKING GROUP ON BIOLOGICAL EFFECTS OF CONTAMINANTS: A CASE STUDY

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ABSTRACT

The activities of the ICES Working Group on Biological Effects of Contaminants are representative of the responsibilities of the approximately 60 Working Groups established by the Council. The Working Groups address specific questions and problems referred to them by the ICES Subject or Advisory Committees. This Working Group develops and evaluates biological-monitoring techniques for monitoring marine pollution. It coordinates its activities with other ICES Working Groups including those concerned with pathology, marine chemistry, benthic ecology, and environmental assessment, and also works closely with other national and international organizations concerned with biological effects of contaminants; it has particularly close ties with the UNESCO Intergovernmental Oceanographic Commission.

INTRODUCTION

The International Council for the Exploration of the Sea (ICES) was founded in 1902 with eight member countries. Since that time membership has grown to eighteen countries bordering the Atlantic Ocean and adjacent seas. Although its specific statutes have changed over the intervening years, its main function has remained the same: to encourage research and study of the sea and to coordinate these investigations among its member nations. In 1964 the ICES mandate was redefined to promote and encourage research focused particularly on living marine resources, to draw up and organize programs required for this purpose, and to publish the results of these investigations. These goals remain essentially the same today, with an emphasis on the North Atlantic and its adjacent seas.

The administrative component of ICES, located in Copenhagen since its founding, is run by a General Secretary and a staff of about 20 people. The scientific component comprises a series of committees and their adjunct working groups. This paper describes the role and function of the scientific working groups. The Working Group on Biological Effects of Contaminants (WGBEC) will be used as an example; its function and operation is typical of the approximately 50 to 60 working groups active under ICES auspices at this time.

ORGANIZATION

Briefly, the organizational structure of ICES through which each working group operates is as follows:

Each member country appoints one or two delegates to the Council. Thirteen scientific committees and two advisory committes report to the Council and each working group operates under the advice and direction of one of the scientific committees. Each working group is formed to carry out specific tasks and studies for its parent scientific committee, and is composed of participants named by the member countries. Each country typically names one or two members to those working groups in which it has an interest. The chairman is confirmed by the Council and usually serves a three-year term. Each group functions as long as the parent committee requires its work.

The Working Group on Biological Effects of Contaminants functions under the direction of the Marine Environmental Quality Committee (MEQC). Although other committees deal with pollution issues as they relate to specific committee interests, the MEQC has the lead responsibility for investigation of sources, fates, and effects of contaminants in the marine and estuarine waters adjacent to ICES member countries.

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The MEQC works closely with the Advisory Committee on Marine Pollution, whose responsibility is to provide scientific information and advice on marine pollution and its effects on living resources, as well as advice on the control of pollution, to member governments and any interested intergovernmental bodies. The activities of MEQC are described by Pearce elsewhere in this volume.

The WGBEC had its origin within the Working Group on Marine Pollution and Baseline Studies in the North Atlantic (WGMPNA). That working group first met in 1975 and was formed to develop coordinated programs in the North Atlantic for investigating levels and trends of marine contaminants in water, sediments, and biological tissues, as well as the development of a monitoring program for biological effects of contaminants. The membership of that working group included both biologists and chemists.

In 1984 an ad hoc study group was assembled to formulate recommendations for a biological monitoring program. That study group met in Hirtshals, Denmark, in April of 1985 and recommended that a biological monitoring program be developed within the ICES community using proven techniques as well as those showing promise of detecting sublethal contaminant effects on marine animals. A close cooperation between ICES and the UNESCO International Oceanographic Commission (IOC) biological program on contaminant effects was strongly supported.

In 1986 the ICES Council accepted the recommendations of the Hirtshals Study Group and further recommended that the biological studies be separated from the chemical studies of the WGMPNA. The contaminant chemistry work, therefore, was transferred to the Marine Chemistry Working Group and the task of investigating and evaluating biological effects of contaminants and developing a coordinated biological monitoring program was given to a new working group - the Working Group on Biological Effects of Contaminants.

The preceding paragraphs summarize the position of a typical working group within the ICES structure and demonstrates the flexible nature of working groups; they are formed, evolve, are modified, replaced, and finally phased out as the needs of the ICES community change. For clarity and ease of reading, the WGBEC and its predecessor, the WGMPNA, will be refered to as the Working Group unless specific clarification is needed.

Although the WGMPNA had a broad mandate for contaminant monitoring in the North Atlantic, the following section will be limited to those activities that focus on biological aspects of marine pollution and marine pollution monitoring.

ACTIVITIES

The mandate given to the WGBEC by the Council best summarizes the scope of the activities of this working group:

1. To develop approaches and procedures for discrimination between biological effects induced by anthropogenic activities and the natural background incidence of abnormalities in fish and shellfish, and thus promote the development of reliable approaches and techniques for the detection and evaluation of the effects of contaminants in marine organisms.

2. To maintain close contact with the Intergovernmental Oceanographic Commission Group of Experts on Effects of Pollutants (GEEP) and other relevant bodies, to ensure that, where appropriate, ICES activities are coordinated with GEEP.

Cooperation between working groups plays an important role in ICES. The Working Group has been active in monitoring levels of contaminants in the flesh of fish and shellfish and has developed an extensive monitoring program in cooperation with the Marine Chemistry Working Group. The two working groups also sponsored intercalibration exercises for pollutants, especially PCBs, in biological tissues. An active cooperative study on the possible links between contaminants and diseases of marine fish and shellfish continues between the Working Group and the Working Group on Pathology and Diseases of Marine Organisms.

One of the most important ICES initiatives on the effects of contaminants on living marine resources was the Workshop on the Problems of Monitoring Effects of Pollution in the Sea, held in Beaufort, North Carolina in March of 1979. Although not sponsored by the Working Group, it was co-chaired by two Working Group members and has been the foundation of many of the investigations of the WGMPNA. The purpose of that workshop was to examine possible approaches to monitoring biological effects, to identify those that could be put to immediate use, and to make recommendations for the implementation of a major monitoring program in the North Atlantic using

selected biological effects measures. Seven areas of study were chosen for special attention: genetics, physiology, biochemistry, pathobiology, behavior, ecology, and bioassay. The recommendatons and conclusions were published in 1980 (1) in a volume still considered one of the very few comprehensive reviews of biological effects monitoring techniques.

During the early 1980's the Working Group recognized the need to test the recommendations of the Beaufort Workshop in a practical field situation so that those techniques, as well as other recently developed methods, could be tested on animals taken directly from a contaminated environment. A shipboard workshop was proposed as an initial test of these techniques. For a variety of financial and logistical reasons, a hands-on practical workshop was not undertaken until 1986, when the IOC Group of Experts on Effects of Pollutants (GEEP) sponsored a Workshop at the University of Oslo to test biological effects measurements. Animals collected from both clean and contaminated sites in the Oslo Fjord were examined by a variety of physiological, biochemical, cellular, histopathological, and ecological methods. In addition, marine animals were held in large mesocosms, dosed with a mixture of pollutants, and then examined using these same techniques. Several Working Group members were invited to participate in this very successful workshop. An evaluation of each technique as well as the results of the workshop have been prepared for publication (2).

Interest in a shipboard workshop has continued over the past several years; the success of the Oslo Workshop reinforced the desire of the Working Group to undertake an at-sea workshop. It was agreed that the Beaufort suggestions and the Oslo results would serve as the core around which to design an at-sea, hands-on, workshop.

In 1986 IOC and ICES recognized the common goals of their parallel working groups in the area of biological effects studies on marine animals and agreed to work together on complementary projects. Because only limited funds and personnel are available to be applied to the investigation of a complex and important problem, an official liason was developed between the two groups. The chairman of the ICES WGBEC was assigned as an observer for the activities of IOC GEEP and the chairman of the IOC GEEP was similarly assigned to the ICES WGBEC. This cooperation has reduced duplication of effort and has resulted in a stronger program for both groups, with the talents of two quite different groups working together in an area of common interest. A shipboard workshop, co-sponsored by both groups, is now in the planning stages; it will be held in the North Sea in April of 1990 using Federal Republic of Germany research vessels as well as a shore laboratory in Bremerhaven. This workshop will employ a variety of biological monitoring techniques at both contaminated and uncontaminated stations, and will work closely with the Benthos Ecology Working Group on benthic community studies. Moreover, IOC and ICES will cooperate in other biological effects workshops in the next several years. By doing so, we can take the years of laboratory experimentation on pollutant effects into the field in a meaningful attempt to relate field and laboratory observations.

Other areas of ICES/IOC cooperation include the development of biological-effects handbooks of methods and their evaluation, and the development of standardized tests that can be used in regional and multinational programs of biological monitoring of environmental contaminants. The need for inter-organizational and international cooperation in methods development and evaluation, in long-term data gathering, and in joint use is clear (3).

International organizations have a clear role to play in the development and implementation of monitoring programs that take advantage of biological measures of pollutant stress. The worldwide shortage of funds currently available for broad development of these programs necessitates increased cooperation and increased sharing of data and interpretations. It is also essential to apply the research findings from studies in one part of the world to potential pollution situations in other areas to avoid costly duplication of effort. The cooperative efforts of ICES, IOC, and other national and international groups thus will help to ensure that such programs become an effective reality.

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MODELING THE IMPACTS OF CSO TREATMENT ALTERNATIVES ON NARRAGANSETT BAY

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ABSTRACT

A laterally averaged channel hydrodynamics model and a pollutant transport model have been coupled to predict water quality resulting from combined sewer overflow (CSO) discharges into estuarine environments. The hydrodynamic component of the model system is driven by river and CSO flows plus the tide at the lower model boundary. It is based on the conservation of momentum and water mass equations. The pollutant transport model is based on the conservation of mass equation, modified to account for settling, decay and interactions between water quality parameters. The model system is applied to the Providence, Rhode Island, sewer system overflows which empty into the upper reaches of Narragansett Bay. Total coliform loadings from CSOs as they currently exist and as modified are simulated. The impacts on the water quality in the tributary rivers and Narragansett Bay are then examined.

1. INTRODUCTION

Narragansett Bay is one of the major saltwater resources on the U.S. East Coast, from both economic and aesthetic viewpoints. Surrounded almost entirely by the state of Rhode Island, its waters provide a livelihood and recreation for many people. The Seekonk, Moshassuck, and Woonasquatucket Rivers at its northern end are the major sources of freshwater entering the bay (Figure 1). The Moshassuck and Woonasquatucket Rivers join to form the Providence River which extends 12 km south to Conimicut Point. At Fox Point the Seekonk River also joins the Providence River. A hurricane barrier spans the Providence River north of Fox Point to provide protection to downtown Providence from flooding due to storm surges. The Pawtuxet River enters the Providence River at the Warwick/Cranston city line south of Providence.

Pollution in the Providence River and upper Narragansett Bay has long been recognized as the most serious water quality problem in Rhode Island (1). Sewage outfalls are a major source of pollution to this area. While the Providence sewage treatment system is capable of treating the regular (dry weather) load of sewage, the system overloads during severe rainstorms. During these times, flows from storm water, municipal sewage and industrial waste, all flowing in the same network of sewer pipes, exceed the plant capacity and the excess flow is shunted directly to the Providence River through 65 outfalls (2). Similar situations exist in other communities at the head of the bay and on the Seekonk River (Figure 1).

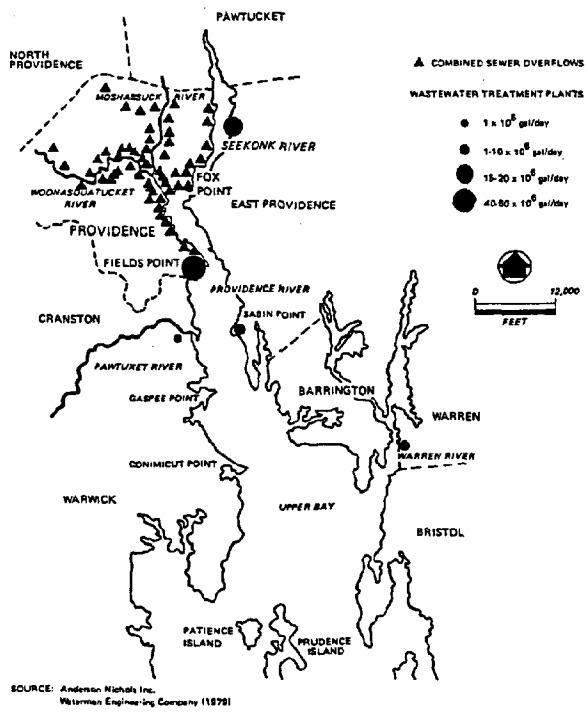

Figure 1. Upper Narragansett Bay point source discharges.

It has been proposed that the effluent from these numerous outfalls be collected into combined sewer overflow (CSO) areas and holding or treatment facilities be provided at these locations to improve the water quality in upper Narragansett

Bay. This study examines CSO impacts on the tidal portion of the rivers and upper Narragansett Bay north of Prudence Island, and examines the improvements in the bay's water quality to be expected if various CSO treatment strategies are implemented. An integrated hydrodynamics/water quality model system is used to quantitatively define water quality impacts.

2. THE WATER QUALITY MODEL SYSTEM

The water quality model system consists of two model components. The hydrodynamic model describes the circulation patterns in response to tide, wind, and density induced forcing. The pollutant transport (water quality) model predicts the spatial and temporal distribution of pollutants in the water column. It requires as input a definition of the current field from the hydrodynamic model plus estimates of the sources and sinks of the pollutant and the interaction of the pollutant of interest with other pollutants or organisms present in the receiving water.

HYDRODYNAMIC MODEL

The hydrodynamic model is based on the conservation of momentum and water mass equations. Since little variability is seen across the rivers, the full three dimensional equations are laterally averaged but retain their longitudinal and vertical variability. The standard approximations for estuarine flow are assumed: (1) the flow is incompressible, (2) vertical accelerations are negligible (hydrostatic), (3) density variations are important only when multiplied by gravity and (4) direct tide generating forces may be neglected. For the channels we assume that the cross channel variability is small and that the coriolis force is unimportant in the momentum balance. With these assumptions the laterally averaged governing equations are:

Conservation of mass

$$\frac{\partial \bar{u}bh}{\partial x} + \frac{\partial \bar{w}bh}{\partial z} = 0 \qquad (1)$$

Conservation of momentum

$$\frac{\partial \bar{u}bh}{\partial t} + \frac{\partial \overline{uu}bh}{\partial x} + \frac{\partial \overline{uw}bh}{\partial z} = - \frac{1}{\rho}\frac{\partial pbh}{\partial x} + h\frac{\partial}{\partial x}\left(K_h b\frac{\partial \bar{u}}{\partial x}\right) + h\frac{\partial}{\partial z}\left(K_z b\frac{\partial \bar{u}}{\partial z}\right) \qquad (2)$$

$$\frac{\partial p}{\partial z} = -\rho g \qquad (3)$$

where the overbar indicates a laterally averaged value and

- x,z = Cartesian coordinate system with x measured longitudinally, and z measured vertically upward from mean sea level (cm)
- u,w = components of the current in the x and z directions, respectively (cm/s)
- p = pressure ($g/cm\text{-}s^2$)
- ρ = density (g/cm^3)
- K_h = horizontal eddy viscosity (cm^2/s)
- K_z = vertical eddy viscosity (cm^2/s)
- g = acceleration of the earth's gravity (cm/s^2)
- t = time (s)
- b = channel width (cm)
- h = channel depth (cm)

The model consists of multiple channels with one or more upstream channels connected to a downstream channel. The upstream velocity and surface elevation needed for the downstream channel calculation are flux weighted averages of the upstream channel or channels.

The transformed set of governing equations for each channel, in concert with the boundary conditions, is solved by a semi-implicit, split mode finite difference procedure on a space staggered grid system (3,4). In essence the equations of motion are vertically integrated and through simple algebraic manipulation are recast in terms of a single Helmholtz equation in surface elevation. This equation is solved using a tridiagonal matrix solution technique to predict the spatial distribution of surface elevation for each channel. The solution is embedded in an iterative loop on all channels with iterations continuing until no change in elevation is seen in successive iterations.

POLLUTANT TRANSPORT MODEL

The pollutant transport model is based on the conservation of mass equation modified to account for settling, sources and sinks of material and interactions between water quality parameters. For the channels the laterally averaged pollutant transport equation is

$$\frac{\partial \bar{c}bh}{\partial t} + \frac{\partial \overline{uc}bh}{\partial x} + \frac{\partial \overline{wc}bh}{\partial z} = h\frac{\partial}{\partial x}\left(D_x b\frac{\partial \bar{c}}{\partial x}\right) + h\frac{\partial}{\partial z}\left(D_z b\frac{\partial \bar{c}}{\partial z}\right) + Sbh \qquad (4)$$

where the overbar indicates a laterally averaged value and

- c = concentration (MPN/100 ml)
- D_x, D_z = diffusion coefficients in the x and z directions, respectively (cm^2/s)
- S = source/sink term (MPN/100ml-s)

The source-sink term is presently formulated as a single or double stage decay, depending on the pollutant (e.g., fecal coliform, DO-BOD cycle). The term includes sources, growth and/or decay, settling, uptake, etc. to simulate the appropriate kinetics.

It has been assumed in the derivation of the pollutant transport equation that molecular diffusion is insignificant compared to its turbulent counterpart and that mass conserving estimates for the time averaged turbulent velocity field can be obtained from the hydrodynamic model. The form of the pollutant transport equation used

allows one to address an individual water quality parameter or the interaction between several interrelated parameters.

A simple forward-in-time centered-in-space explicit finite difference technique (5) is used to solve the mass conservation equation on the same space staggered grid system used in the hydrodynamic model. Concentration values are defined in the center of each grid cell.

3. APPLICATION OF MODEL SYSTEM TO STUDY AREA

The model grid system is shown in Figure 2. It consists of five linked channels: the Woonasquatucket, Moshassuck, Providence, and Seekonk Rivers, plus the upper bay north of Prudence Island. The Woonasquatucket, Moshassuck and Seekonk River channels represent only the tidal portions of these rivers with a dam being the upstream boundary of each.

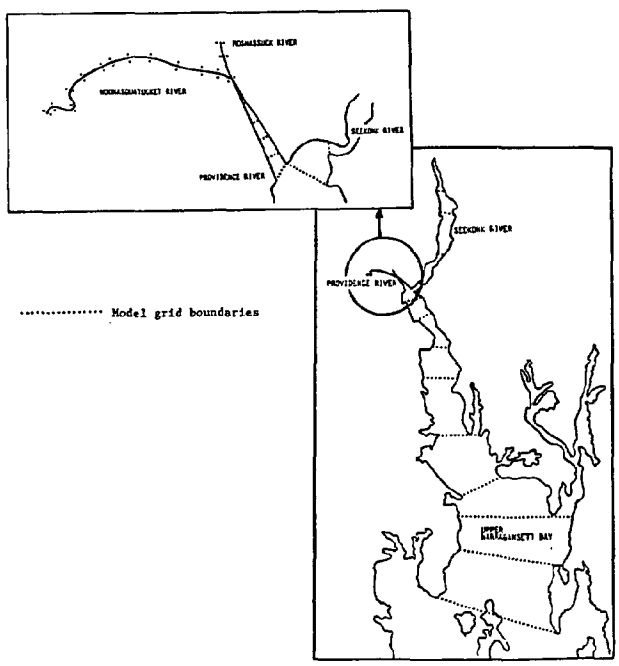

Figure 2. Model grid system.

The range of scales in the system varies widely. Flow in the Woonasquatucket River during dry weather is approximately 0.57 m^3/s while the tidal exchange at Prudence Island is approximately 3300 m^3/s. The Woonasquatucket River has typical depths of 90 cm and widths of 7 m while the Providence River and upper bay vary in width from 1 to 10 km and have a dredged shipping channel approximately 12 m deep. For model simulations, actual geometries of the rivers and bay were obtained from field measurements, nautical charts, and flood maps.

HYDRODYNAMIC MODEL

The hydrodynamic model was used to predict the spatial and temporal variation in the currents through the system. River flows into the area were either measured or estimated from historical data for low flow conditions.

The lower model boundary at Prudence Island was driven by an M_2 tidal height time series with an amplitude of 58.9 cm determined during field measurement programs. The M_2 constituent, with a period of 12.42 hours, was chosen because observations show that it is, by far, the strongest signal in the upper bay and Providence River. Other constituents, including those at diurnal, semidiurnal and higher frequencies contribute only variations, such as the spring neap cycle on the basic M_2 cycle.

Model predictions of tidal height and velocity were compared with observations for the Providence River. The modeled velocity amplitude of 2.7 cm/s compares well with observations of 3.0 cm/s for the M_2 constituent (6). The velocities lag the elevation by 3.0 hours which is typical for this type of estuary, while observations show a phase lag of 2.4 hours (7). The model predicts a phase shift of 17 min in the surface elevation between Prudence Island and Fox Point while observations indicate a phase shift of 26 min.

Previous analyses of field observations (6) have shown that local wind effects on the flows are minimal. Non-local wind forcing can impact the area by raising or lowering the water levels through storm surges but no significant surges have been observed during field programs. Both the local and non-local effects of the wind were thus excluded as driving forces.

The vertical velocity structure in the Providence River as measured from current meters has been shown to be minimal (6). North of the Hurricane Barrier no upestuary bottom flow has been noted. A vertically averaged approximation to the flow is thus reasonable. This, of course, implies that density induced flows are of secondary importance and can be ignored.

POLLUTANT TRANSPORT MODEL

The pollutant transport model was used to predict concentrations of fecal coliforms since this bacteria is a major problem in the upper bay. The Rhode Island Department of Environmental Management has closed the area north of Conimicut Point permanently and periodically closes the area between Conimicut Point and Prudence Island whenever rainfall exceeds 1.3 cm in a 24 hour period.

To examine the impact of fecal coliform loads on receiving water, the pollutant transport model was run using loading data generated by prior land and river based model applications to the various CSO areas (8, 9, 10). Coliform loading data for reference storms of 3, 6, and 12 month return

frequency were used. Loads from other CSO areas which have not been analyzed in detail were scaled from an earlier system wide study (11). The reference storms are synthetic design storms lasting 6 hours developed for the Seekonk River CSO study (8) and subsequently used for other CSO area studies.

Time series of CSO fecal coliforms for a typical CSO overflow are shown in Figure 3 for the 12 month storm. This case shows the loads for the overflows from the upper Woonasquatucket River CSO area entering the tidal portion of the Woonasquatucket River at the Rising Sun dam. The storm begins at hour 2 and lasts for 6 hours. The peak in flow and loads for the river occurs 3 hours after the storm starts. The simulated time series ends at hour 12 (10 hours after storm start) but since loads and flows are not yet at pre-storm levels, an additional 36 hours was simulated using linear interpolation from levels at hour 12 to pre-storm levels at hour 48. A two day recovery time was used since USGS records show such a response time for the Woonasquatucket River (10).

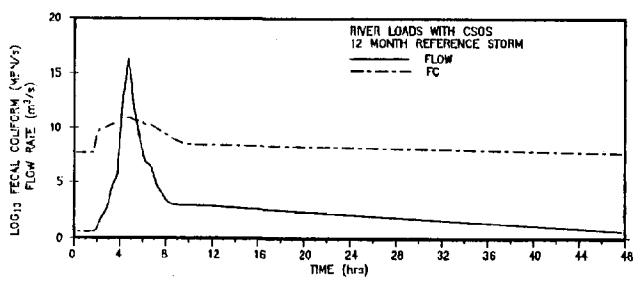

Figure 3. Typical time history of flow and fecal coliform loads in the upper Woonasquatucket River.

Typical model results are shown in Figure 4 for the time history of fecal coliform concentrations at various locations for the 12 month storm with loading from upper Woonasquatucket CSO sources. At Valley Street (Figure 4a) closest to the dam and the CSO area's overflows, the concentration rises quickly after the start of the storm at hour 2. A broad peak is seen during the storm. After the storm, concentration levels drop immediately and are almost at pre-storm levels within 12 hours. The load has stopped by hour 48 and a tidally induced variation in dry weather concentration is evident. The response at the Hurricane Barrier (Figure 4b) shows the tidal oscillations superimposed on the storm pulse throughout the simulation. The time scale has been expanded from 120 hours to 470 hours to show the system response in the upper bay area. The system returns to pre-storm conditions at the Hurricane Barrier in approximately 5 days. The time history at Prudence Island (Figure 4c) continues to show a phase lag in time of peak concentration and time to return to pre-storm conditions.

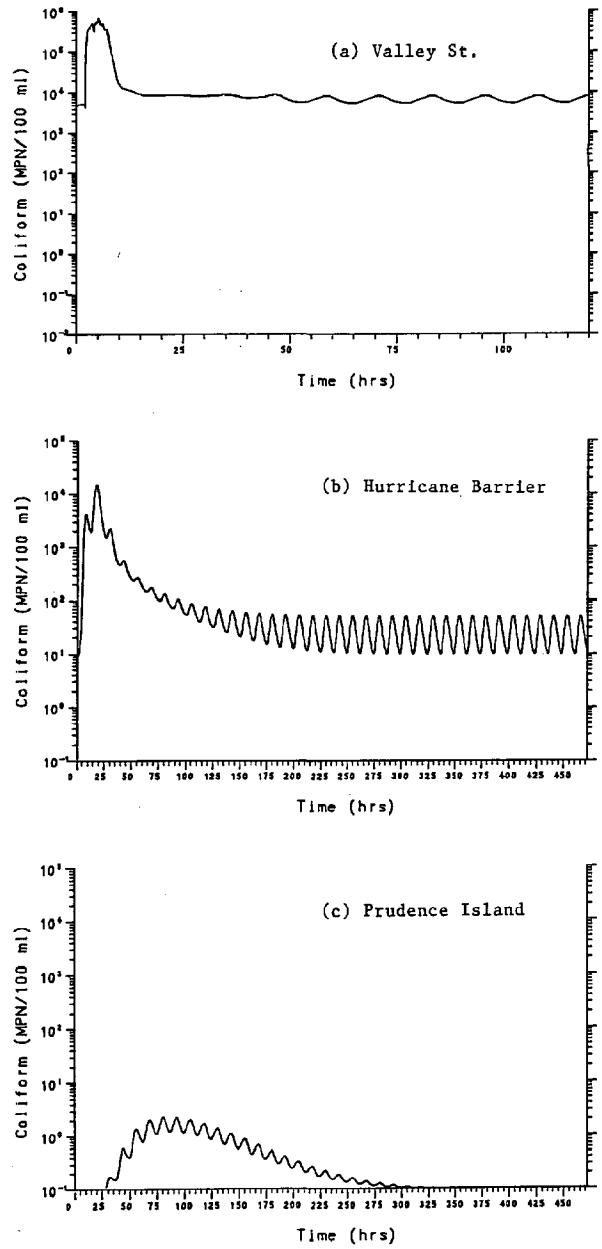

Figure 4. Model predicted time history of fecal coliform concentrations at various locations.

The maximum fecal coliform concentrations for the 12 month storm event as a function of distance downstream are shown in Figure 5. Four scenarios are shown. Scenarios 1 and 2 include all sources from the other CSO areas, rivers and sewage treatment plants, but in Scenario 2 the loads from the upper Woonasquatucket CSOs have been eliminated. The peak concentration occurs at the confluence with the Moshassuck River at 10^7 MPN/100 ml indicating that the upper Woonasquatucket CSO

loads are not the cause of the maximum calculated concentrations. In fact a comparison of Scenario 1 and Scenario 2 shows no difference below the confluence, only above. When only upper Woonasquatucket loads are assumed to enter the system (Scenario 3), the Valley Street concentration is the highest with a gradual decline in the river and then a steep decline from the Moshassuck River confluence to the Hurricane Barrier. Below the Barrier, gradual dilution continues. The same response for the case of upper Woonasquatucket C loads without CSOs (Senario 4) is evident with a one to two order of magnitude reduction in concentrations.

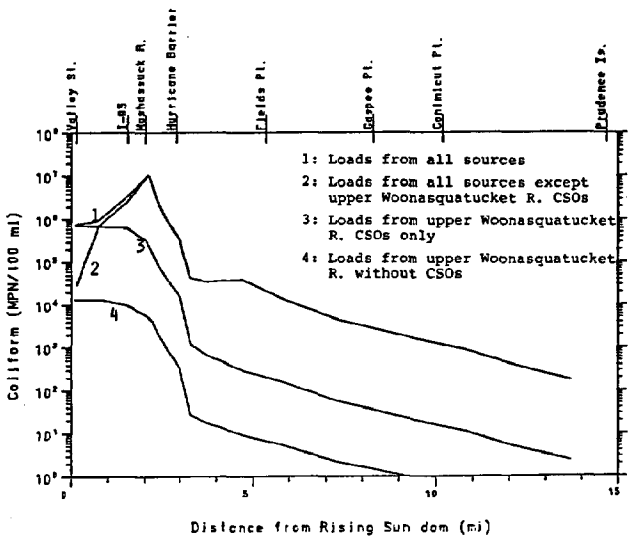

Figure 5. Model predictions of maximum fecal coliform concentrations in the study area for the 12 month reference storm.

4. CONCLUSIONS

A laterally averaged channel model system was applied to upper Narragansett Bay to investigate water quality resulting from fecal coliform loads entering the bay through CSOs, rivers and sewage treatment plants. Specifically, the improvement in water quality to be gained by eliminating the upper Woonasquatucket River CSOs was examined. When only coliform loads from the upper Woonasquatucket River were considered, elimination of the CSO loads resulted in a decrease in maximum fecal coliform concentrations by a factor of 100 in the Woonasquatucket River, a factor of 40 at the Hurricane Barrier and a factor of 25 at Gaspee Point. This reduction in concentrations was completely masked, however, when loads from other CSO areas were included in the simulations. Peak concentrations reached 10^7 MPN/100 ml at the Woonasquatucket/Moshassuck confluence (versus 10^6 MPN/100 ml and 10^4 MPN/100 ml when only Woonasquatucket loads with and without CSOs, respectively, were considered). Below the confluence the impact of the Woonasquatucket CSOs was indiscernible.

From these results it is evident that little improvement will be seen by eliminating upper Woonasquatucket CSOs. Other CSO area sources overwhelm the signal for fecal coliforms and so their control should be a greater priority.

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POLLUTANT LOADINGS TO THE NEW YORK BIGHT APEX

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ABSTRACT

Pollutant loading data obtained during the 1970's and 1980's for the Hudson-Raritan Estuary (HRE) and the New York Bight have been reevaluated. Annual inputs of up to 35 pollutants (major constituents, trace elements, synthetic organics, polynuclear aromatic hydrocarbons) carried to the Apex of the Bight via seven routes were estimated. Barging of dredge material and sewage sludge, and HRE outflow, accounted for more than 95 percent of the loadings of the 11 pollutants for which comprehensive estimates were possible. Dredge material barging was the largest source, contributing 30 to 83 (median: 56) percent of the total loading for these 11 constituents. HRE outflow contributed 13 to 45 (median: 27) percent, and sewage sludge barging contributed 3 to 24 (median: 16) percent. Moving the sludge dumpsite from 12 miles to 106 miles offshore appears to have decreased loadings to the Apex by less than 25 percent. Better estimates will require significantly improved monitoring of pollutants in barged dredge material.

INTRODUCTION

The marine ecosystem lying off the mouth of the Hudson-Raritan Estuary is known as the New York Bight. The inner section of the Bight that is most exposed to anthropogenic effects is known as the Apex of the New York Bight. The Apex is bounded by the Long Island (NY) coastline on the north, by the New Jersey coastline on the west, by latitude 40° 13'N on the south, and by longitude 73° 35'W on the east (Figure 1). It has an area of approximately 2000 km^2, about 5 percent of the 38,900 km^2 area of the New York Bight.

The Apex is a region of particular concern because of the large quantities of wastes that have been released to it during the last century. The routes of such input include net outflow from the Hudson River - Raritan Bay Estuary (across the "Transect" between the ends of Sandy Hook and Rockaway Beach), discharges from the Long Island and New Jersey coasts (municipal and industrial outfalls, gauged and non-gauged surface runoff, groundwater leachate), aerial (atmospheric) deposition, and dumping of barged wastes (dredged material, sewage or municipal sludge, acid waste, and cellar dirt or rubble). Effective and efficient management of such waste inputs to this marine ecosystem requires the estimation of average annual loadings via the various input routes for the individual pollutants of concern.

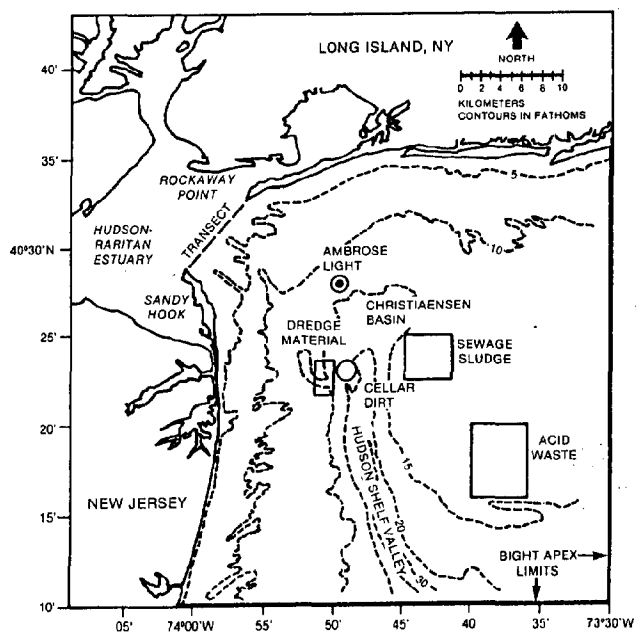

Figure 1. New York Bight Apex and historical dumpsites (After McLaughlin et al., 1975).

OBJECTIVE

The objective of this study was to compile and compare estimated annual loadings of pollutants released between the mid-1970's and mid-1980's via the various input routes to the New York Bight Apex, taking into account the estimated "filtering efficiency" of the Hudson-Raritan Estuary.

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BACKGROUND

The comparison conducted here is based principally on the results of the comprehensive pollutant input surveys reported for the New York Bight (Mueller et al., 1976; New York City Dept. of Environmental Protection, 1983) and the Hudson-Raritan Estuary (Mueller et al., 1982). However, these investigations suffered from a major oversimplification (clearly acknowledged by each report). This was the fact that no estimation was made for the "filtering" of pollutants (principally via removal to bottom sediments) as they passed through the Hudson-Raritan Estuary. Thus, that portion of a pollutant's annual loading to the estuary which is deposited to and accumulated in the bottom sediments of the estuary (at least until dredged) was erroneously included in the "estuarine advection" subtotal of the estimated total annual loading value for the Apex and the Bight. This caused the total loading value to be too high. In addition, the 1976 report of Mueller et al. included estimated inputs to the entire Bight, even though the major concern was the significance of the "controllable" inputs (e.g., barge dumping) to the Apex. Since the area of the Bight is much greater than that of the Apex, this also caused the estimated total loading of a pollutant (relative to concerns for the Apex itself) to be too high.

PROCEDURES AND RESULTS

Hudson-Raritan Estuary Advective Inputs

A mass balance approach patterned after that of Olsen et al. (1984) was used by Young et al. (1988a) to estimate the "filtering efficiency" of the Hudson-Raritan Estuary for particulate-associated pollutants such as trace metals, the higher molecular weight chlorinated hydrocarbons, (e.g., PCBs; DDTs), and petroleum hydrocarbons. Based on average sediment accumulation rates and pollutant concentrations, and assuming steady-state conditions, they estimated that approximately 60 percent of the loadings of such materials to the estuary obtained from Mueller et al. (1982) were removed to the bottom sediments. (In obtaining this estimate, Young et al. first assumed that 50 percent of the direct inputs to the East River by the six municipal wastewater treatment plants situated there were removed by tidal action to Long Island Sound. They also assumed that losses from the estuary due to volatilization were negligible.) Thus, they applied a median "transfer coefficient" value of 0.4 to these modified values for loadings to the estuary, to obtain estimated annual loadings of eight metals, PCBs and DDTs, and five poly-nuclear aromatic hydrocarbons (PAHs) via advection from the estuary to the Apex of the New York Bight. (Results of an independent budget by Connell, 1982, for petroleum hydrocarbons as a class also yielded a transfer coefficient of 0.4). Although use of this median value does not reflect the probable differences in transfer coefficients for various target pollutants based on their geochemical differences, it appears to be the best estimate obtainable from present data. Thus, here we have adopted this approximation, and have also applied it to the modified loading estimates for the estuary obtained from Mueller et al. (1982) for additional reasonably conservative pollutants (not considered by Young et al. owing to a lack of sediment concentration data). Because nutrients are highly non-conservative, they were not included in the mass balance approach. For the purpose of this survey, we have simply assumed that, to the first order, essentially all of the total nitrogen and total phosphorus net input to the Hudson-Raritan Estuary is carried across the Transect into the Apex. The resultant estimated annual Apex loadings from the estuary are listed in Table 1. Detailed information regarding the approaches, assumptions, and sources of data utilized in estimating net loading values from the Hudson-Raritan Estuary and the other routes of input to the Apex have been provided elsewhere (Young et al. 1988a; 1988b).

Long Island Coastal Inputs

Mueller et al. (1976) did not identify any direct industrial discharges from the Long Island coast into the waters of the Apex. However, they did identify four discharges of secondary-treated municipal wastewater (Bay Park, Long Beach, Freeport, Wantagh) with a 1972 total discharge rate of 85 million gallons per day (mgd) or 1.2×10^{11} liter/yr.

Because effluent concentration and loading values for most of the target constituents were either absent, estimated from other areas, or based on 1972 monitoring samples (often quite sparse), we have elected to use instead the more recent and comprehensive effluent concentration estimates for STPs in or near New York City (nationwide for the additional priority pollutants) reported in Tables VI-5 through VI-7 of Mueller et al. (1982). (We note that the estimated concentrations for "New York City Secondary Effluent" were the values selected from Table VI-5.) These concentration estimates were combined with the sum of the average effluent flow rates for the four STPs to obtain the loading estimates to the Apex from these STPs situated on the Long Island coast (listed in Young et al., 1988b).

Mueller et al. (1976) identified three surface runoff channels on Long Island discharging into the Apex via South Bay (E. Meadowbrook, Bellmore, and Massapequa Creeks), with a 1972 average flow rate of 19.5 cubic feet per second (cfs) or 1.74×10^{10} liter/yr. Because insufficient concentration data for the target constituents again were reported for these flows by Mueller et al. (1976), we have utilized the average concentrations reported by Mueller et al. (1982) for urban runoff from the adjacent New York Metropolitan Area (NYC 208 "separate" sites) to obtain the estimated loading values (listed in Young et al., 1988b).

Mueller et al. (1976) also estimated annual loading values for a few pollutants via groundwater transport from Long Island to the New York Bight. Because approximately one-third of the coastal extent included in this groundwater transport survey borders on the Apex, we assumed that 33 percent of the groundwater pollutant transport

values were applicable to our Apex inputs estimates. The resultant estimated pollutant inputs from the Long Island coast to the Apex are listed in Young et al. (1988b). The pollutant loading estimates for these three input modes have been summed to obtain the Long Island Coastal input values presented in Table 1.

New Jersey Coastal Inputs

Twenty of the STPs (coded M1 - M16 and M20 - M22a) on the northern New Jersey coast, identified by Mueller et al. (1976) as significant sources, discharge directly into the Apex. Seventeen discharge primary effluent (totaling 17.0 mgd or 23.4×10^9 liter/yr) and three discharge secondary effluent (totaling 5.4 mgd or 7.4×10^9 liter/yr). As was the case for the Long Island STPs, sufficient data were lacking to provide relatively comprehensive and up-to-date loading estimates. Since these STPs are situated in a relatively urbanized section of the New Jersey coast, we have again utilized the estimated effluent concentration values for the New York Metropolitan Area (if available, otherwise for 20 plants nationwide), reported by Mueller et al. (1982). The resultant estimated annual pollutant loadings via STP discharges from the New Jersey coast to the New York Bight Apex are listed in Young et al. (1988a).

No significant direct industrial discharges from New Jersey to the Apex were identified by Mueller et al. (1976). Regarding surface runoff inputs, we have estimated that an area of about 52 sq mi (135 sq km) drains from the New Jersey coast into the Apex. The major river in this area is the Manasquan R. (Mueller er al., 1976), with a 41 year average flow rate of 72.6 cfs (6.48×10^{10} liter/yr). Since this river drains an area of 43 sq mi (111 sq km), we have scaled up its flow rate by the factor 52/43 = 1.2 to obtain the estimated annual flow rate of 87.1 cfs (7.77×10^{10} liter/yr) for surface runoff from the New Jersey coast into the Apex. The same pollutant concentration estimates used for Long Island surface runoff were applied to this value to obtain Apex pollutant loading estimates for surface runoff from the New Jersey coast (Young et al., 1988b). No corresponding groundwater estimates are available, as Mueller et al. (1976) concluded that groundwater pollutant transport to the Bight from this coast was negligible. Our estimates of the New Jersey coastal inputs to the Apex obtained by summing the STP and surface runoff estimates are presented in Table 1.

Aerial Deposition Inputs

Although relatively few measurements of atmospheric pollutants have been made in the New York Apex or Bight, an extensive compilation of pollutant aerial deposition rates in downtown Manhattan has been provided by Mueller et al. (1982). Thus, in an effort to extrapolate these deposition rates to the Bight, surface air concentrations of three trace metals, made by Duce et al. (1975) at the Transect and at two sites in the Bight outside the Apex (Middle-Bight and New Jersey coastal), have been combined with corresponding data from the Manhattan Island site. This analysis showed that the most rapid decreases in air concentrations for the three metals (iron, lead, and zinc) occurs between the Manhattan Island and the Transect sites, with a much more gradual decrease occurring toward the edge of the Bight. Thus, the "application factor" used to extrapolate the Manhattan data to the Apex was estimated as follows. For each metal, we first averaged the value for the two areas beyond the Apex, and then obtained the average of this "outer zone" value and the Transect value to obtain an estimated average concentration for the Apex. This Apex average concentration then was divided by the corresponding value for Manhattan Island (M.I.) to obtain the application factor.

The application factors obtained for iron, lead, and zinc were 0.10, 0.17, and 0.15, with a median value of 0.15 (Young et al., 1988b). Combination of this factor with the Manhattan Island pollutant deposition values (Mueller et al., 1982) yielded the estimated average aerial deposition rates for the Apex presented in Table 1.

Barge Dumping Inputs

Historically, four major categories of wastes have been dumped from barges into the Apex of the New York Bight. These are (1) sewage (municipal) sludge, (2) dredge material (spoil), (3) acid waste, and (4) cellar dirt (rubble). The designated dumpsites for these types of barged wastes are shown in Figure 1. Santoro and Fikslin (1986) summarized the annual barge mass loadings of municipal sludge to the apex, and average pollutant concentrations in this sludge. The average annual value for the years 1982-1985 was 7470 + 340 (S.E.) English tons, or 6.8×10^9 kg/yr. Application of the average chemical constituent concentrations in ocean (barge) dumped sewage sludge from all plants for the period 1982-1985 provided by these authors yielded the conventional and trace metal loadings listed in Table 1. Concentration values used to obtain the loadings via such sludge for trace organics, beryllium and selenium (Table 1) were obtained from Fricke and Clarksen (1984). Estimated annual loadings for the target constituents via dumped acid wastes and dredge material were obtained from the technical information report prepared by New York Dept. of Environmental Protection (1983). These values also are listed in Table 1. (Loadings of these chemical constituents via barge dumping of cellar dirt are not reported here, as they are believed to be negligible compared to the other waste categories).

DISCUSSION

The estimated annual mass loadings of the target constituents via the seven input routes listed in Table 1 indicate that, for the chemical constituents considered here, the three dominant input routes to the Apex are (1) advection from the Hudson-Raritan Estuary, and barge dumping of (2) sewage (municipal) sludge and (3) dredge material (spoil). Thus, in obtaining the "Total Loading" values shown in the last column of Table 1, we have placed the sum of available data in a parentheses if loading data from one of these three dominant categories is missing. Further, if more than one

Table 1. Distribution of estimated annual pollutant loadings to the New York Bight Apex (approx. 1980). Parenthesis indicates that "Total" value does not include estimates for one of the three largest sources (H-R Estuary, Sewage Sludge, or Dredged Material). No value is listed if two or more loading estimates are lacking for these three sources.

Constituent	H - R Estuary	Long Is. Coastal	New Jer. Coastal	Aerial Deposit.	Acid Waste	Sewage Sludge	Dredge Material	Total
Suspended Solids (10^3 kg)	7.2×10^5	3.9×10^3	9.8×10^3	---	---	2.1×10^5	4.6×10^6	5.5×10^6
Oil and Grease (10^3 kg)	4.8×10^4	1.7×10^3	2.8×10^3	---	6.0	2.1×10^4	3.2×10^4	1.1×10^5
Nutrients (10^3 kg)								
Total N	1.1×10^5	2.0×10^3	1.5×10^3	4.3×10^2	---	2.2×10^4	---	1.4×10^5
Total P	1.4×10^4	2.6×10^2	2.7×10^2	2.9	---	---	---	---
Trace Metals (kg)								
Antimony	1.3×10^5	1.2×10^4	3.3×10^3	---	---	---	---	---
Arsenic	2.6×10^4	1.1×10^3	2.8×10^2	2.4×10^2	---	4.0×10^3	5.8×10^4	9.0×10^4
Beryllium	5.2×10^3	4.3×10^2	1.1×10^2	---	---	2.5×10^2	---	(5.9×10^3)
Cadmium	2.2×10^4	3.6×10^2	1.3×10^3	2.9×10^2	3.1×10^2	1.8×10^4	3.3×10^4	7.5×10^4
Chromium	2.8×10^5	2.3×10^3	3.4×10^3	1.7×10^3	1.4×10^4	2.1×10^5	6.4×10^5	1.2×10^6
Copper	4.4×10^5	1.3×10^4	1.4×10^4	---	4.8×10^3	5.0×10^5	1.4×10^6	2.4×10^6
Cyanide	1.0×10^5	6.1×10^3	2.6×10^3	---	---	9.1×10^4	---	(2.0×10^5)
Lead	4.0×10^5	6.2×10^3	2.7×10^4	2.5×10^4	2.1×10^3	3.5×10^5	8.5×10^5	1.7×10^6
Mercury	1.1×10^4	7.2×10	4.2×10	---	1.5×10	1.6×10^3	1.6×10^4	2.9×10^4
Nickel	2.3×10^5	5.8×10^3	9.6×10^3	2.6×10^3	---	5.7×10^4	3.4×10^5	6.4×10^5
Selenium	1.9×10^4	7.7×10^2	2.0×10^2	---	---	4.6×10^2	---	(2.0×10^4)
Silver	1.0×10^4	1.9×10^2	4.9×10	---	---	1.8×10^4	---	(2.8×10^4)
Thallium	4.0×10^4	4.1×10^3	1.1×10^3	---	---	---	---	---
Zinc	1.3×10^6	2.1×10^4	4.8×10^4	3.4×10^4	2.6×10^4	7.6×10^5	2.6×10^6	4.8×10^6

Table 1 continued.

Constituent	H - R Estuary	Long Is. Coastal	New Jer. Coastal	Aerial Deposit.	Acid Waste	Sewage Sludge	Dredge Material	Total
Chlorinated Hydrocarbons (kg)								
Aldrin	7.2 x 10	---	---	7.6 x 10	---	2.0	---	(1.5 x 10^2)
Gamma-BHC	3.4 x 10^2	7.0	1.8	3.6 x 10^2	---	4.1	---	(7.1 x 10^2)
Chlordane	3.1 x 10	1.2	0.3	2.0 x 10	---	6.4 x 10^2	---	(6.9 x 10^2)
DDT	1.4 x 10^2	5.7	2.6 x 10	1.3 x 10	---	5.5 x 10	---	(2.3 x 10^2)
Heptachlor	3.1 x 10^2	---	---	3.6 x 10^2	4.1	---	---	(6.7 x 10^2)
PCB	1.8 x 10^3	4.0 x 10	3.3 x 10	2.0 x 10^2	---	2.3 x 10^2	4.6 x 10^3	6.9 x 10^3
Pentachlorophenol	3.2 x 10^3	2.6 x 10^2	1.4 x 10^2	---	---	2.2 x 10^3	---	(5.8 x 10^3)
Phenol	9.6 x 10^3	2.2 x 10^2	2.5 x 10^2	---	---	4.1 x 10^3	---	(1.4 x 10^4)
Toxaphene	1.0 x 10^2	---	---	7.9 x 10	---	---	---	---
Polynuclear Aromatic Hydrocarbons (kg)								
Anthracene	4.4 x 10^3	---	---	---	---	---	---	---
Fluoranthene	7.2 x 10^3	1.6 x 10^2	7.2 x 10^2	---	---	---	---	---
Napthalene	4.8 x 10^3	4.8 x 10^2	1.3 x 10^3	---	---	---	---	---
Phenanthrene	2.9 x 10^3	1.3 x 10^2	4.5 x 10^2	---	---	1.2 x 10^3	---	(4.7 x 10^3)
Pyrene	5.6 x 10^3	---	9.3 x 10^2	---	---	1.4 x 10^3	---	(7.9 x 10^3)
Total PAH	---	---	---	5.0 x 10^3	---	---	---	---
Phthalates (kg)								
Bis (2-ethylhexyl)	4.4 x 10^4	3.0 x 10^3	2.6 x 10^3	3.6 x 10^2	---	1.8 x 10^3	---	(5.2 x 10^4)
Butyl Benzyl	6.0 x 10^3	1.3 x 10^2	2.8 x 10^2	---	---	---	---	---
Di-N-Butyl	7.2 x 10^3	5.4 x 10^2	2.8 x 10^2	3.6 x 10^2	---	---	---	---
Diethyl	2.8 x 10^3	8.1 x 10	1.2 x 10^2	---	---	---	---	---
Total Petroleum Hydrocarbons (kg)								
	1.3 x 10^7	---	---	---	---	1.3 x 10^7	---	(2.6 x 10^7)

Table 2. Distribution (percent) of annual loadings for constituents which include estimates for all three major input routes (Hudson-Raritan Estuary, Sewage Sludge, Dredge Material).

Constituent	H - R Estuary	Long Is. Coastal	New Jer. Coastal	Aerial Deposit.	Acid Waste	Sewage Sludge	Dredge Material	Col. (1+6+7) / Total
Suspended Solids	13.0	0.1	0.2	--	--	3.8	83.0	99.8
Oil and Grease	45.3	1.6	2.6	--	0.0	19.8	30.2	95.3
Arsenic	29.0	1.2	0.3	0.3	--	4.5	64.7	98.2
Cadmium	29.2	0.5	0.2	0.4	0.4	23.9	43.8	96.9
Chromium	24.3	0.2	0.3	0.1	1.2	18.3	55.7	98.3
Copper	18.6	0.5	0.6	--	0.2	21.1	59.1	98.8
Lead	24.1	0.4	1.6	1.5	0.1	21.1	51.2	96.4
Mercury	38.3	0.3	0.1	--	0.1	5.6	55.7	99.6
Nickel	35.7	0.9	0.1	0.4	--	8.8	52.7	97.2
Zinc	27.1	0.4	1.0	0.7	0.5	15.9	54.3	97.3
PCB	26.1	0.6	0.5	2.9	--	3.3	66.7	96.1
MEDIAN	27.1	0.5	0.3	0.6	0.2	15.9	55.7	97.3

of these dominant categories are not represented for a given constituent, no total loading value is calculated at all.

For only eleven of the target constituents were we able to obtain annual loading estimates for these three major input routes. Table 2 presents, for these eleven constituents, the percentage of the total loading carried via each of the seven input routes included in this study. It is seen that inputs to the Apex via Hudson-Raritan advection and dumping of sewage sludge and dredge material made up between 95 and 100 (median: 97.3) percent of the estimated total load for these "representative" pollutants.

By far the largest input route was ocean dumping of dredge material; percentage-of-total values ranged from 30.2 to 83.0 percent, with a median value of 55.7 percent. In view of the importance of this vector, it is unfortunate that the absence of chemical concentration data precludes meaningful loading estimates for more than two-thirds of the target pollutants surveyed here. The second largest input route is net advection from the Hudson-Raritan Estuary. Percentage-of-total values ranged from 13.0 to 45.3 percent, with a median value of 27.1 percent. Sewage sludge generally ranked third among the major input routes; contribution values ranged from 3.3 to 23.9 percent (median: 15.9 percent). Thus, the recent transference of the sludge dump-site from the "12-mile" Apex site to the "106-mile" offshore site (Suszkowski and Santoro, 1986) appears to have decreased inputs of monitored chemical pollutants to the New York Bight Apex by less than 25 percent. Finally, median percent loading values from coastal Long Island, coastal New Jersey, aerial deposition, and barge dumping of acid waste are each less than about one-half of one percent of the corresponding calculated total loadings. Thus, the fact that loading values for these routes often are based on earlier or incomplete surveys does not substantially weaken the principal conclusions of this survey.

CONCLUSIONS

Compilation of available data generally collected between the mid-1970's and the mid-1980's indicates that the largest source of chemical pollutants to the New York Bight Apex was the barge dumping of dredge material. The second largest source was advection from the Hudson-Raritan Estuary, even after accounting for the "filtering" effect via estuarine sedimentation. Barge dumping of sewage (municipal) sludge generally ranked third. Inputs from the Long Island and New Jersey coastlines, from aerial deposition, and from barge dumping of acid wastes generally were insignificant.

Regarding the eleven constituents for which loading estimates were obtained for the three dominant sources, sewage sludge contributed 3.3% to 24% of the total loading; the median contribution value was 16%. Thus, the recent transference of the sludge barge dumping from the Apex to the 106-mile dumpsite appears to have decreased the known chemical inputs to the Apex by less than about 25%. For the dominant input route (ocean dumped dredge material), concentration or loading data for less than one third of the target chemical constituents were located by this survey. Clearly a more accurate assessment of the relative importance of these input routes will require a substantial increase in the data base for chemical pollutants in dredge material.

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DESIGNATION OF AN OCEAN MINING STABLE REFERENCE AREA

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ABSTRACT

The scientific concept of Stable Reference Areas defined as reference areas for purposes of environmental and conservational assessment has been applied by NOAA and Ocean Mining Associates with OMA's "DELTA-GAMMA" USA-3 minesite in the manganese nodule province of the northeast equatorial Pacific Ocean. Two areas within the minesite have been proposed as environmental reference areas:

(1) An area of approximately 8400 sq. km. within DELTA-GAMMA has been selected by OMA as a provisional Preservational Reference Area where mining and mining impacts will not occur.

(2) An area of approximately 4600 sq. km. within DELTA-GAMMA has been selected by OMA as a provisional Impact Reference Area, which will be impacted by mining. NOAA is presently evaluating the proposal and tentative approval is forthcoming.

INTRODUCTION

In 1962, The Board of Directors of OMA's predecessor-in-interest, the Newport News Shipbuilding & Dry Dock Company ("NNS&DDCo"), mandated its Director of Research and Forward Planning to study the commercial potential of marine hard mineral resources. NNS&DDCo management had in mind both the assurance of company requirements for specialized steels and the potential for application of its skills in hydraulics, marine engineering and shipbuilding.

During the period 1962-68, NNS&DDCo's Research Department formulated and implemented a research and development ("R&D") program of marine surveying and ocean engineering in order to evaluate the technical and economic feasibility of mining marine manganese nodules.

In 1968, NNS&DDCo was purchased by Tenneco Inc. The marine hard minerals R&D program and its associated personnel, research vessel, patents, know-how, and other assets were transferred to Tenneco's newly organized, wholly owned subsidiary, Deepsea Ventures, Inc. ("DVI").

DVI moved to offices in Gloucester Point, Virginia, in 1970, and continued the marine hard minerals R&D program at increased scale and pace. Test facilities were established in Virginia, and ship operations were generally conducted from Pacific ports.

In 1974, OMA was organized to spread the costs and risks of the marine hard minerals R&D program. OMA has managed the program from 1974 to the present, using DVI as a service contractor, calling upon the OMA partners for funding and drawing upon partner affiliates for appropriate skills and facilities.

Ocean Mining Associates ("OMA") is a Virginia, USA, partnership organized for the purpose of evaluating the feasibility of mining manganese nodule deposits found on the seabed of the Pacific Ocean. OMA is owned in equal shares by domestic corporations owned or controlled by Enti Nazionale Idrocarburi S.P.A. (Italy), Societe Generale de Belgique S.A. (Belgium), The Sun Company (USA) and USX Corporation (USA).

RESOURCE BASE DEVELOPMENT

From 1962 to 1982, OMA and its predecessors-in-interest conducted more than 100 extended mid-ocean survey cruises aboard the company's 152-foot research vessel, R/V PROSPECTOR, and a number of chartered survey ships. These voyages were early concentrated primarily in the area between the Clipperton and Clarion Fracture Zones ("CC-Zone") of the northeastern equatorial Pacific Ocean.

This effort represented approximately 2,500 days at sea, with about 70% of that time spent productively on cruise-plan stations.

A variety of state-of-the-art deep seabed survey equipment was bought and, if not available, developed to gather and analyze geophysical and geotechnical data and samples. Many thousands of data points on nodule abundance and metal assay were derived from information gained by deployment of free-fall grab samplers, box corers and other nodule sampling devices.

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These data points are supported and supplemented by analyses of over 100,000 still photographs of the bottom and several thousand hours of towed-TV bottom observations. They are supplemented by data from SEABEAM, FADS (Finite Amplitude Depth Sounder), precision depth recorders, magnetometers and subbottom profilers representing tens of thousands of kilometers of ship tracks. In addition, OMA acquired many thousands of ship-log weather observations and a significant collection of micro-fauna samples and mega-faunal observations.

Ten years of such effort in the CC-Zone led OMA, in 1974, to publish notice of discovery of, and claim to, its chosen minesite (ILM,1975).
This public disclosure facilitated the identification and voluntary settlement of the half-dozen adequately asserted overlap claims made against OMA by commercial entities in the USA, France, Japan, and the USSR. These settlements are part of the subject matter of agreements and understandings between and among the governments of the USA, Belgium, France, the FRG, Holland, Italy, Japan, the UK, and the USSR (ILM,1984)(ILM,1987).

These settlements, and a further ten years of at-sea survey and analysis of the particular resource caused OMA to expand and amend its minesite, now known as "DELTA-GAMMA", the area of which is now contained within the amended coordinates of OMA"s Deep Ocean Mining License for Exploration at Site USA-3 (NOAA,1988).

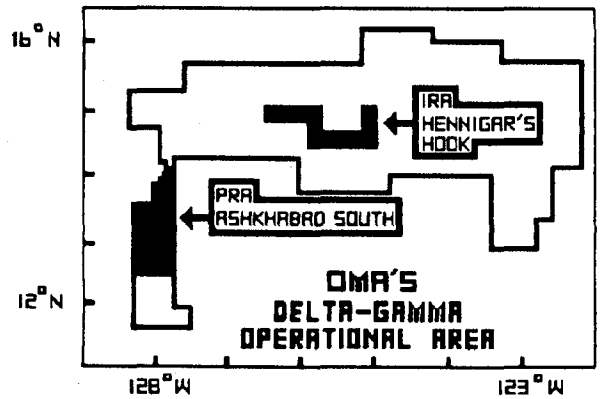
This license was issued to OMA by the National Oceanic & Atmospheric administration ("NOAA") on 28 August 1984 under the provisions of the Deep Seabed Hard Mineral Resources Act of 1980 (DSHMRA,1980).

DELTA-GAMMA is located in international waters some 3,200 kilometers west of Guatemala. The mineable terrain of interest in DELTA-GAMMA is found in depths of 4,200 to 4,800 meters in undulating valleys between roughly parallel ranges of hills trending North-South.

Steps, or small scarps, and small patches of boulders and rocks are occasionally encountered in these valleys. Nodules are found resting on soft sticky thixotropic clay that varies in surface shear strength, having a high shear strength gradient in the upper 30 to 60 centimeters.

The nodules have a specific gravity of approximately 2, and are typically ellipsoid or oblate spheroidal in shape. Their size ranges from sand-grain size to equivalent spherical diameters of 14 centimeters, with an average of 6.4 centimeters. Nodule abundance in surveyed areas of DELTA-GAMMA varies from 0 to 30 kilograms per square meter (wet weight in air), with an average of 10 kilograms per square meter. Abundance in the mineable terrain of interest in higher than that average.

The operational area of DELTA-GAMMA, excluding an area reserved to the USSR, encompasses about 150,000 sq. km. of seabed and contains two Stable Reference Area ("SRA") environmental sites; a Preservational Reference Area ("PRA") of 8,600 sq. km., and an Impact Reference Area ("IRA") of 4,600 sq. km., as follows (FIGURE 1).



Stable Reference Areas are to be used as reference areas for purposes of resource evaluation and environmental assessment of deep seabed mining. This requires the designation of appropriate areas to insure a representative and stable biota of the seabed (OPB/NRC). In the following sections, the history of the SRA concept is presented along with the implementation and application of the concept by NOAA and OMA.

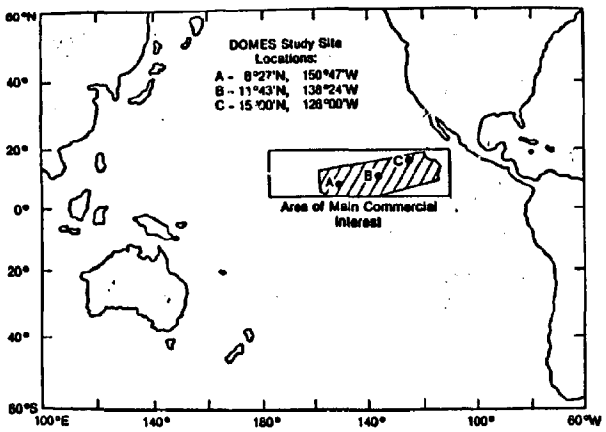
HISTORY OF THE STABLE REFERENCE AREA (SRA) CONCEPT

On 30 July 1970 a large tonnage of manganese nodules was test-dredged from the seabed in 2,400 feet of water on the Blake Plateau 150 miles off the Georgia-Florida coast. This historic "first" was accomplished after an eight year engineering development effort by Newport News Shipbuilding & Dry Dock Company and Deepsea Ventures, Inc. The dredging test utilized the 7,500 ton R/V DEEPSEA MINER I, a dry cargo ship, purchased and extensively converted by Deepsea for a 1/5 scale continuous mining "proof-of-concept" test of a seabed nodule collector and air-lift pumping system to be later deployed at far greater depths in the Pacific Ocean (Kaufman et al.,1971).

During these tests, a collaborative effort between Deepsea Ventures, Inc., and Lamont Doherty Geological Observatory was undertaken to determine the influence of ocean mining operations on the marine ecology, with specific concentration on the ecological impact, if any, of nutrient uplift and benthic sediment discharge at the air/sea interface (the "surface plume effect"). The results of this preliminary study, and follow-on reports, laid several questions to rest and pointed out the need for and direction

of further environmental research (Roels et al.,1972).

In response to industrial seabed mining exploration activity, the National Oceanographic and Atmospheric Administration ("NOAA") instituted in 1975 a cooperative NOAA/industry environmental research program, the Deep Ocean Mining Environmental Study ("DOMES") project. The DOMES project involved a five year study of a 13 million square kilometer area of the Clipperton Clarion Fracture Zone ("C-C Zone") of the east central Pacific Ocean (FIGURE 2), and the potential effects of ocean mining effects on the marine environment therein. The final DOMES Report issued in 1981 (DOMES,1981).



The DOMES area was selected by NOAA with the help of OMA, OMI, OMCO, and KCON, the four domestic deep ocean mining consortia. Three specific representative study sites within that area were designated by NOAA as loci for future ocean mining environmental research, captioned DOMES Sites A, B, and C. DOMES Site C was in OMA's published claim area, later NOAA Exploration License Area USA-3 ("DELTA-GAMMA"). To provide focus for site-specific Environmental Impact Statements, the DOMES area was later reduced to a smaller "area of main commercial interest".

DOMES consisted of two phases: DOMES I to characterize the region environmentally, and DOMES II to monitor the effects of industry pilot-scale equipment tests therein. The specific objectives of DOMES were to develop:

(1) environmental baselines (biological, geological, physical, chemical) at the three sites chosen as representative of the range of environmental parameters likely to be met during mining,

(2) predictive capabilities, to identify potential environmental effects of nodule recovery, and

(3) an information base, to prepare environmental guidelines for government and industry.

The DOMES project showed that many of the activities which initially raised concerns about deep seabed mining were unlikely to have significant adverse impacts on the environment, but that there were three potentially adverse effects which needed to be studied further, as follows:

(1) effects of the nodule collector on benthic life in and near the mining tracks,

(2) effects of the benthic (bottom) plume on benthic life, and its food supply, away from the mining activity, and

(3) effects of the surface plume on fish larvae.

The DOMES report and its associated scientific literature served as the technical foundation of a substantial number of subsequent environmental studies and Federal actions.

During the course of the DOMES research, OMA tested its mining system at 1/5 scale and full depth at its DELTA-GAMMA mine near DOMES Site C. These tests comprised four separate test campaigns of the 20,000 ton R/V DEEPSEA MINER II, a converted ore carrier. The tests culminated on 10 November 1978 in a final mining run of approximately 20 hours of continuous mining at 15,000 feet, during which approximately 400 tons of nodules were collected and air-lifted to the ship as various system performance envelopes were explored. These tests proved that the OMA engineering concepts worked at their mid-Pacific Ocean site of intended application (Kaufman et al.,1985).

During these tests NOAA placed scientist observers, or monitors, aboard the R/V DEEPSEA MINER II to observe the mining tests and the attendant discharge phenomena. Additionally, scientists aboard the NOAA vessel OCEANOGRAPHER observed the test and sampled its surficial plume. Several years later, the Scripps Institution of Oceanography initiated a study of the test equipment tracks, the resulting sediment plumes, and the effects on benthic macrofauna. These observations, and similar observations made during tests by other domestic ocean mining consortia, led to useful findings regarding both surficial and benthic plumes. However, the findings were of limited utility only, due to the lack of opportunity to observe sustained operations (Ozturgut et al.,1981;Spiess et al.,1987).

In the light of on-going ocean mining activities in the US, France and Japan, at least one international organization, the International Union for Conservation of Nature and Natural

Resources ("IUCNNR"), early recognized the need for a program to set aside seabed reference areas to facilitate environmental monitoring of commercial mining operations. In 1978, at Ashkhabad, USSR, the IUCNNR General Assembly resolved as follows (IUCNNR, 1978, 81, 84):

"The (IUCNNR) General Assembly....: URGES all nations engaged in, or considering, deep seabed mining activities to:

(a) precede commercial mining operations by commissioning a comprehensive ecological survey to determine the impact of such mining activity:

(b) designate appropriate areas of the deep seabed as baseline reference areas and resource zones in which no mining will be allowed;

(c) designate the size and shape of such area or areas to ensure that their stability will be maintained; and

(d) establish guidelines for scientific research to ensure minimum disruption of the natural state of such areas."

The US Congress became aware of the IUCNNR resolutions at an early date. At the time, domestic ocean mining legislation was being crafted based upon the legal theory that ocean mining is a legitimate exercise of the freedom of the seas doctrine, which doctrine imposes duties as a corollary of the rights so asserted. As a result, Section 109 (f) of the Deep Seabed Hard Mineral Resources Act of 1980 ("DSHMRA") contained a requirement that the US government seek to establish internationally recognized Stable Reference Areas ("SRAs") in the CC-Zone in which no mining can occur. Recognizing that the SRA concept required balance so as not to encourage politically inspired moratoria or unreasonably exclusionary set-asides, Congress provided that the SRA requirement shall not be construed as an authority to withdraw substantial portions of the DOMES area (DSHMRA,1980).

At the UN level, however, the IUCNNR concept fell upon less fertile ground. Part XI ("the Area") of the 1983 UN Conference on Law of the Sea ("UNCLOS") was negotiated in the 1970's to regulate deep seabed mining, applying the politicized solutions of the 1960's to the hypothetical problems of the 1950's. It should be no surprise that the text of Part XI, finalized in 1980, bears little relevance to present (or past) realities and contains no mention of the IUCNNR Stable Reference Area concept or its functional equivalent.

Noting this, the IUCNNR tried again. In its 1981 General Assembly resolution, IUCNNR specifically called upon UNCLOS's Preparatory Commission ("PrepCom") to develop and implement the concept. Failing to detect any responsive movement upon the part of PrepCom in the next three years, the IUCNNR General Assembly, at its 1984 Meeting in Madrid, resolved with continuing vigor (but more precision) as follows:

> "The (IUCNNR) General Assembly....: RECOMMENDS that the Preparatory Commission adopt at the earliest opportunity draft rules, regulations and procedures which adequately reflect the concept of protected areas and other appropriate environmental measures."

As of 1987, PrepCom was awash in draft rules. However, there was no indication that any PrepCom draft rule yet addressed the environment or responded to ten years of persistent IUCNNR resolutions on the subject (PrepCom, 1987).

To be fair, UNCLOS gave no mandate to PrepCom to draft environmental regulations or to incorporate the stable reference area concept into its resource management scheme. It is unreasonable then to expect PrepCom to do so; bold UN organizations do not flourish. However, this revealed lack of vision in Part XI, and related institutional inflexibility, can only serve as an excellent example of why there is good reason to sever Part XI from the otherwise equitable and widely accepted provisions of UNCLOS. Meanwhile, modern solutions to current deep seabed mining problems must be sought elsewhere.

Under the authority of DSHMRA, the Administrator of NOAA set up the Office of Ocean Minerals and Energy (now the Ocean Minerals and Energy Division of the National Ocean Service, NOAA, US Department of Commerce) which, in 1981, requested the assistance of the Ocean Policy Board of the National Academy of Science's National Research Council ("OPB/NRC") to evaluate the scientific validity of the SRA concept, and to recommend a cost-effective implementation strategy. The resulting study report, issued in 1984, concluded that the SRA had two purposes:

(1) to serve as preserves to ensure (maintenance of) a representative and stable biota of the deep seabed, and

(2) to be used as a reference zone or zones for purposes of resource evaluation and environmental assessment of deep seabed mining (impacts).

The OPB/NRC panel of experts concluded that the concept as outlined by IUCNNR in 1978 only had scientific validity if two areas were established; one in which to study impacts and the other to serve as a preserve. The panel

stated its belief that existing knowledge was insufficient to allow immediate designation of SRAs, but urged "provisional" designation of such areas as early as possible to provide the loci for further necessary research and to aid in the definition of criteria for final designations (OPB/NRC,1984).

Based upon the OPB/NRC study, NOAA accepted the scientific validity and the utility of the two-area SRA concept by incorporating such concept in proposed Commercial Regulations published in 1987. These regulations would require designation of both preservational and impact monitoring sites prior to issuance of any commercial ocean mining permit, and monitoring of such sites thereafter (NOAA Regulations,1987).

OMA believes that early establishment of preservational and impact reference areas in its ocean mining License Area DELTA-GAMMA will aid in its planning for initial mining operations and future environmental monitoring, if established according to scientifically valid criteria. Additionally, it is our belief that the earliest provisional approvals will substantially aid NOAA's efforts to establish such criteria for final establishment and approval of such areas, if applied in an objective manner to achieve a valid scientific experiment.

Accordingly, OMA has petitioned NOAA to approve, on a provisional basis, two reference areas within its license area; one area of 8,400 square kilometers for use as an interim preservational reference area, and the other of 4,600 square kilometers to serve as an interim impact reference area. Upon provisional approval by NOAA of each such reference area, proprietary data associated with such area would be released to NOAA for verification and use by NOAA in making findings and judgments leading to final designation of such areas (and final approval of OMA's mining permit, when and if appropriate).

The locations of these two proposed reference areas in DELTA-GAMMA are shown in FIGURE 1. The total area encompassed within these reference areas aggregates to approximately 13,000 square kilometers, or about 5,000 square miles. For purposes of comparison, this is roughly the size of the state of Connecticut and is a bit larger than the island nation of Jamaica.

OMA's environmental reference area proposals attempt to hew to the spirit of the IUCNNR resolutions, the letter of the DSHMRA provisions, the direction of the proposed commercial regulations, and the detail of the OPB/NRC findings and recommendations set forth as follows:

1. **OPB/NRC Findings**
   SRA concept scientifically valid only with impact and preservational areas; PRA to be located to ensure biota not affected; IRA to be located close to mining.

   OMA Proposals
   Agreed & incorporated

2. **OPB/NRC**
   Small-scale resuspension experiment required (highest priority research need).

   OMA
   OMA IRA includes location of NOAA experiment planned early 1989. Data offered.

3. **OPB/NRC**
   Divide CC-Zone into 9 "characteristic environments", each with 1 PRA; modify if indicated by further data.

   OMA
   OMA feels PRA areas may be consolidated in certain circumstances. Provisional area boundaries should be responsive to new data.

4. **OPB/NRC**
   Map drift of bottom waters so PRAs are placed "upstream" of mining.

   OMA
   Multi-layer current and sediment excursion data needed. "Core" of PRA is well within outer limit. Current meter to be deployed in PRA by NOAA in 1989.

5. **OPB/NRC**
   Use future mining tests to tracksediment redeposition to determine PRA separation criteria.

   OMA
   This is why OMA proposes an interim or provisional designation. See # 8 below.

6. & 7. **OPB/NRC**
   Encourage Industry to disclose data and (data and samples, study existing photos and samples, and use ships of opportunity, for cost-effective inventory of benthos to aid in PRA designation.

   OMA
   OMA has data and samples showing biota (already furnished).

8. **OPB/NRC**
   Make initial designation of provisional PRAs as soon as possible, using data from # 2, 4, 5 and 7 above.

OMA
This is the purpose of OMA's proposals.

9. **OPB/NRC**
Designate permanent PRAs upon issuance of first Commercial Permits using data from # 2, 5, 6 and 8.

OMA
OMA may wish earlier issue, if possible.

10. **OPB/NRC**
Continue long term monitoring of selected PRAs.

OMA
OMA has no present comment.

11. **OPB/NRC**
Designate one IRA per Permit at time Permit is issued; shape and size designed to maximize potential of experiment.

OMA
OMA feels designation should be earlier, if requested by license holder. OMA's proposed PRA is so shaped and sized, subject to verification and change by NOAA if future research so warrants.

12. **OPB/NRC**
Promote international consultation to maximize data collection and to minimize conflict.

OMA
OMA agrees.

13. **OPB/NRC**
Committee did not address issues associated with processing at sea.

OMA
OMA does not contemplate such practice in its approved exploration plan.

1. **OMA PRESERVATIONAL REFERENCE AREA PROPOSAL**

OMA's formal proposals to NOAA took the form of letters setting forth OMA's selection of two areas, one as a candidate preservational reference area and the other as a candidate impact reference area. Relevant excerpts from these proposals are set forth as follows:

....This proposal is made at this time in the belief that early designation of OMA's PRA best meets the needs of commercial planning, basic science, and public policy. This action was contemplated in our Exploration Plan, does not affect OMA's License Area, Logical Exploration Unit, ownership or capabilities, and thus is not an application for amendment of our license. We understand that any NOAA approval of our designation under present circumstances may be tentative in nature, but trust that permanent status will be forthcoming in time to provide predictability to OMA's exploration phase planning for at-sea commercial recovery operations. Also, we believe that this proposal could serve as the catalyst for, and nucleus of, a constructive, cooperative program of research applicable to much of the CC-Zone nodule province. Additional benefits to industry, the Nation, and the international community would accrue should such a research program acquire multinational participation. We solicit an appointment in your offices at a time convenient to you to begin these consultations relating to our planned license activities."

NOAA responded to the above proposal by noting its consistency with the approach NOAA is pursuing for monitoring the environmental effects of deep seabed mining, and by stating that it would be beneficial to pursue the proposal and the potential for designation of the proposed reference area (NOAA Federal Register Notices,1988).

This NOAA response, and subsequent consultations, prompted OMA to supplement its PRA proposal as follows:

"....As stated in our 19 October 1987 proposal, once the PRA is so approved, we will provide the proprietary data in the area, which derives from a broad spectrum of commercial sources and includes:

(a) results from more than 300 free-fall grabs, box cores and dredge hauls, including abundance estimates, 5-metal assays, and pulps for a majority of samples,

(b) bathymetric data for a significant portion of the PRA,

(c) data regarding nodule concentration and size, and obstructions along specific tracks, extracted from more than 100 nautical miles of video observations.

As you have been informed, the PRA is classified by OMA as a characteristic mining area in accordance with criteria established by OMA to identify future subareas with acceptable topography, soil mechanics, and nodule abundance/assay to qualify as component mining areas in a commercial mining plan. The only OMA criteria in which the PRA is marginal is that of total extent of the mineable resource; a contiguous area encompassing roughly 1/3 of the total PRA contains nodules of acceptable abundance and assay in what we have judged in a preliminary way to be acceptable terrain (more

detailed bathymetry of mining plan areas being a future exploration need). It thus ranks below other larger mineable OMA subareas which, collectively, are considered sufficient to meet the needs of any OMA 20-year mining plan.

According to our data, the PRA mineable resource is effectively surrounded by PRA terrain that lies well below several OMA criteria. It thus seems eminently qualified as the core of a preservational reference area. In addition, the PRA is in relatively close proximity to several larger mineable areas, sharing with those areas all characteristics except abundance above the commercial threshold. A caveat is necessary; the OMA criteria mentioned above do not include judgments related to biological populations. While we have insufficient data to indicate that the biota of the PRA is characteristic, we have no data to the contrary.

That the proposed PRA is of characteristic quality in economic and geological terms is confirmed by the fact that every known nodule mining operator who explored there ultimately claimed all or part thereof. These claimants included OMA, OMI, OMCO, KCON, IFREMER, DORD, and YUZHMORGEOLOGIYA. In fact, the PRA was the area most overlapped in the conflict resolution process embracing the RSA, the FSA, the SSA, and recent understandings concerning the USSR areas of interest in the C-C Zone.

We are aware that the emerging stable reference area concept also contemplates the utilization of an impact area to complete the data required to judge the scale of the impact of human activity in virgin territory. Accordingly, we are preparing a proposal which will set forth a further environmental monitoring site in the OMA operating area to be dedicated as an interim impact reference area, taking into account prior NOAA activity in the OMA license area and our planning for mining activities under a Permit. It is our view that with these two approvals in hand the monitoring and research plans will be greatly facilitated."

On 16 May 1988 NOAA designated the proposed PRA as an environmental monitoring site and solicited expressions of interest from the public (NOAA FEDERAL REGISTER NOTICES, 1988). As of 1 August 1988, two other US consortia, OMCO and KCON, have agreed to contribute additional contiguous area as part of a larger Preservational Reference Area. To confirm the multi-consortia sources of area contributions as well as to honor the 10th anniversary of the 1978 meeting of IUCNNR, which first articulated and endorsed the Stable Reference Area concept, we refer to the "USA Provisional Preservational Reference Area" as ASHKHABAD SOUTH.

2. OMA IMPACT REFERENCE AREA PROPOSALS

During April and May of 1988, NOAA and OMA entered into consultations regarding the selection by OMA of an interim, or provisional, Impact Reference Area ("IRA"). NOAA pointed out that its proposed commercial recovery regulations listed two criteria for selection of an IRA.

(1) The area should be representative of the environmental characteristics of the site, and

(2) It should be located in a portion of a Permit area tentatively scheduled to be mined early in the Permit term.

After consultations on the subject, NOAA and OMA agreed that:

(1) The IRA should be sized and shaped to be proximate to, and to include portions of, at least two potentially early mining blocks to facilitate examination and/or monitoring of areas being mined, or mined out, or dusted with sediment,

(2) It should not lie exclusively within a previous test area, although it could contain a test area,

(3) Its boundaries should be somewhat flexible to ensure that a dusted area just outside would not be excluded from examination, and

(4) Its location, size and shape should be selected by the licensee/permittee, taking into account (1) to (3) above.

On the basis of these consultations, OMA submitted the following formal proposal of an impact reference area to NOAA, excerpted below:

".... OMA herewith requests further consultations with your offices with the objective of early designation of an area of approximately 4,629 square kilometers within DELTA-GAMMA to be reserved as a Provisional Interim Impact Reference Area ("IRA"). This proposal is a supplement to our proposal dated 19 October 1987 to designate, on a provisional basis, a Preservational Reference Area. It is intended to flesh out our environmental monitoring site proposals to you to aid in the establishment of criteria and locations for a scientifically valid interim Stable Reference Area(s) in OMA License Area DELTA-GAMMA, and to facilitate timely governmental research programs and industrial planning for environmental monitoring therein. Said proposed IRA HENNIGAR'S HOOK is representative of the environmental characteristics of DELTA-Gamma and portions have been tentatively scheduled to be mined early in the Permit term. HENNIGAR'S HOOK contains the following categories of sub-areas:

(1) NOAA's "DOMES SITE C", in which NOAA and academia have conducted, and plan

further, nodule related environmental research,

(2) areas including or impinging upon OMA's "TEST SITE", which:

(a) OMA utilized to conduct multiple tests modelling a commercial nodule mining ship and system in all principal respects,

(b) NOAA and academia have become quite familiar with, having monitored test operations and measured post-test impacts therein,

(3) area(s) proximate to and impinging upon at least one other potential OMA early mining site, and

(4) additional area shaped so as to have a high probability of containing at least some "downstream" area (ie; area swept by currents originating in any nearby early mining site selected by OMA).

At the date of this writing (1 August 1988), NOAA is considering the designation of the proposed IRA as an additional OMA environmental monitoring site. To minimize the potential for confusing OMA's Stable Reference Areas, the "OMA Provisional Impact Reference Area" is referred to as HENNIGAR'S HOOK. The hook is for capturing elusive mining impacts and constructive participants in the process of implementing the Stable Reference Area concept.

SUMMARY

OMA is not an environmental society. It is a marine mining R&D company attempting to create efficient technical assets and to marshal a business and regulatory environment that will impose the lowest level of investment risk during future commercial operations. Early implementation of a carefully crafted stable reference area program, in association with reasonable monitoring obligations, appears to offer substantial advantages in assuring that environmentally responsible operations will yield the minimum of costly future "surprises".

This will be true, however, only if the further development of the SRA concept is exposed to the earliest and broadest scientific enquiry and an absolute minimum of industrial, bureaucratic, and political bias. Accordingly, the process of establishment of the first "provisional" SRAs must be clearly understood by industry, government, and public interest groups to be a classic scientific experiment. As such, all parties engaged in development and implementation of the SRA concept must be careful to avoid the introduction of bias into the experiment. Should the data or conditions be deliberately skewed, or the "moratorium tendency" introduced into the process, the concept will lose utility. The victim would be the possibility for cooperation, constructive consensus and useful results.

If NOAA can institute a procedure by which concerned scientists may participate with government and industry in the identification of the characteristics implicit in provisional designation of preservational and impact reference areas, the result will be:

(1) the design of a new, valid and defensible resource management tool (the SRA concept) to assure environmentally responsible domestic government policy and actions,

(2) the creation, through early participation, of a broad consensus to support such concept, policy and actions,

(3) the provision to industry of a predictable and reasonable set of environmental guidelines and obligations upon which to base present planning and future operations, and

(4) the availability of an economically rational, environmentally responsible resource management tool for consideration by other nations and international institutions concerned with "shared" resources.

REFERENCES, ABBREVIATIONS, AND ACRONYMS USED

AFERNOD: Formerly, the French deep seabed mining entity, now IFREMER.

AMR: A West German deep seabed mining entity.

C-C ZONE: The seabed area between the Clipperton Fracture Zone and the Clarion Fracture Zone of the northeast equatorial Pacific Ocean.

DEEPSEA VENTURES, INC.: Service contractor to OMA.

DELTA-GAMMA: OMA's minesite in the C-C Zone, NOAA Deep Ocean Mining Exploration License Area USA-3.

DOMES, 1981: The Deep Ocean Mining Environmental Study, a long-term environmental research program funded by NOAA. The final DOMES report was published as Volume 3, No. 1/2, Marine Mining Journal (1981), Crane, Russak & Company, Inc., 3 East 44th Street, NYC, NY, USA, 10017. A compendium of over 150 individual domestic environmental research projects and reports funded by NOAA and supporting the DOMES report or building upon its data and results may be

obtained from the Ocean Minerals and Energy Division, OCRM, NOAA, US Department of Commerce, Room 704, 1825 Connecticut Ave., NW, Washington, DC, USA 20235.

DORD: The Japanese deep seabed mining entity.

DSHMRA, 1980: The Deep Seabed Hard Mineral Resources Act of 1980, US Public Law 96-283, 30 USC 1401.

FSA: The Final Settlement Agreement, a private overlap settlement signed among OMA, OMI, OMCO, KCON, AFERNOD, and AMR on 18 May 1983.

IFREMER: The French deep seabed mining entity.

ILM,1975: International Legal Materials, "Notice of Discovery and Claim of Exclusive Mining Rights, and Request for Diplomatic Protection and Protection of Investment by Deepsea Ventures, Inc.", 14 ILM 51 (1975).

ILM,1984: "Provisional Understanding on Deep Seabed Matters", 23 ILM 1354 (1984).

ILM,1987: "Agreement on the Resolution of Practical Problems with Respect to Deep Seabed Mining Areas, and Exchange of Notes", 26 ILM 1502, (1987).

IRA: Interim Impact Reference Area.

PRA: Interim Preservational Reference Area.

IUCNNR, 1978, 81, 84: The International Union for Conservation of Nature and Natural Resources, Gland, Switzerland. The IUCNNR is an independent, non-profit, international, natural resources-oriented organization with a General Assembly of members, and a permanent secretariat. At the time its 1984 General Assembly resolution was passed, IUCNNR had 501 members from 114 countries, in three categories: 57 nations; 123 government agencies; 315 non-governmental organizations; 6 non-voting affiliates.

Kaufman et al., 1971: R. Kaufman, J. Latimer, "The Design And Operation Of A Prototype Deep-Ocean Mining Ship"; Proceedings of SNAME Annual Meeting, Honolulu Hawaii, USA (25 May 1971), Society of Naval Architects and Marine Engineers, 74 Trinity Place, NYC, NY, USA 10006.

Kaufman et al., 1985: R. Kaufman. J. Latimer, D. Tolefson, S. Senni, "The Test And Operation Of A Pacific Ocean Deep-Ocean Mining Test Ship: R/V Deepsea Miner II"; Proceedings of the 17th Annual Offshore Technology Conference, Houston Texas, USA (6 May 1985).

KCON: The Kennecott Consortium, a US seabed mining consortium.

NOAA Federal Register Notices, 1988: National Oceanic and Atmospheric Administration, "Deep Seabed Mining; Approval Of Revisions To Mine Site Areas And Publication Of Revised Coordinates"; Federal Register, Vol. 53, No. 42, Pgs 6858-9, Thursday, 3 March 1988; "Deep Seabed Mining; Designation Of Deep Seabed Mining Environmental Reference Area"; Federal Register, Vol. 53, No. 94, Pgs 17237-8, Monday, 16 May 1988.

NOAA Regulations, 1987: National Oceanic and Atmospheric Administration, "Deep Seabed Mining; Regulations For Commercial Recovery And Revision Of Regulations For Exploration; Supplemental Proposed Rule"; 15 CFR Part 971; Federal Register Vol. 52, No.177, Monday, 14 September 1987.

OMA: Ocean Mining Associates, a US seabed mining consortium.

OMCO: Ocean Minerals Company, a US seabed mining consortium.

OMI: Ocean Management, Inc., a US seabed mining consortium.

OPB/NRC, 1984: Ocean Policy Board, Commission on Physical Sciences, Mathematics, and Resources, National Research Council; "Deep Seabed Stable Reference Areas"; National Academy Press, Washington, DC (1984).

Ozturgut et al., 1981: E. Ozturgut, J. Lavelle, R. Burns, "Impacts Of Manganese Nodule Mining On The Environment: Results From Pilot-Scale Mining Tests In The North Equatorial Pacific"; Chapter 15, Marine Environmental Pollution, 2, Dumping and Mining, R. A Geyer (Ed.) Elsevier Publishing Company, Amsterdam, Netherlands (1981).

PrepCom, 1987: Preparatory Commission for the International Sea-Bed Authority and for the International Tribunal for the Law of the Sea, "Statement By The Chairman Of The Preparatory Commission"; UN Document LOS/PCN/L.54/Rev. 1 (4 September 1987). In the nature of UN documents, what is not said is frequently more important than what is said.

Roels et al., 1972: O. Roels, A. Amos, "Environmental Impact Of Mining Tests"; Manganese Nodule Deposits Symposium/Workshop, Honolulu, Hawaii (16 October 1972).

RSA: The "Reciprocating States Agreement" (Provisional Understanding Regarding Deep Seabed Matters), signed among the governments of the USA, UK, Canada, Belgium, Italy, France, Japan and the Netherlands on 3 August 1984.

Spiess et al., 1987: F. Spiess, R. Hessler, G. Wilson, M. Weydert, "Environmental Effects Of Deep Sea Dredging"; (unpublished) NOAA Contract No. 83-SAC-00659, NTIS Accession No. PB 87-138319/AS (1987).

SRA: Stable Reference Area, a new concept to serve as a tool for resource management and environmental protection.

SSA: The Supplementary Settlement Agreement, a private overlap settlement signed among OMA, OMI, OMCO, KCON, AFERNOD, AMR and DORD on 15 December 1983.

UNCLOS: The Third United Nations Convention on the Law of the Sea, opened for signature at Montego Bay, Jamaica on 10 December 1982, UN Publication Sales No. E.83.V.5.

YUZHMORGEOLOGIYA: The USSR deep seabed mining entity.

REGIONAL GEOLOGIC FRAMEWORK OF THE NORPHLET FORMATION OF THE ONSHORE AND OFFSHORE MISSISSIPPI, ALABAMA, AND FLORIDA AREA

By

Robert M. Mink[1], Bennett L. Bearden[2], and Ernest A. Mancini[3]

ABSTRACT

Numerous hydrocarbon accumulations have been discovered in the Norphlet Formation in the onshore and offshore Mississippi, Alabama, and Florida area. Petroleum traps are salt anticlines, faulted salt anticlines and extensional faults associated with halokinetics. Reservoirs include eolian dune, interdune, wadi and marine sandstones. Source rocks for the Norphlet hydrocarbons are Smackover carbonate mudstones. Hydrocarbon types are oil, condensate, and natural gas. Evaluation of the geologic information along with the hydrocarbon data from the Mississippi, Alabama, and Florida area indicates that three Norphlet hydrocarbon trends (oil, oil and gas-condensate, and deep natural gas) can be identified. These onshore hydrocarbon trends can be projected into the Alabama and Florida state waters and Mobile, Pensacola, Destin Dome, and Apalachicola Areas in the Central and Eastern Gulf of Mexico. Substantial reserves of natural gas are present in Alabama state waters and the northern portion of the Mobile Area. Significant accumulations of oil and gas-condensate may be encountered in the Pensacola, Destin Dome, and Apalachicola Areas.

INTRODUCTION

The first discovery of hydrocarbons in the Upper Jurassic Norphlet (fig. 1) was in 1967 at Pelahatchie field in Mississippi (fig. 2). In 1979, natural gas was discovered offshore in Mobile Bay in the Jurassic Norphlet Formation. These discoveries led to active leasing and drilling programs in the onshore Mississippi, Alabama, and Florida areas and in adjacent offshore areas. To date, 35 Norphlet fields have been discovered in the onshore and offshore tri-state area with production established from eolian dune, interdune, wadi, and marine reservoir facies. The more recent offshore discoveries in the Norphlet have emphasized the importance of understanding the regional Norphlet geologic framework of the Alabama coastal waters area and adjacent federal waters area. Identification of the Norphlet hydrocarbon, structural and stratigraphic trends in the onshore tri-state area of Mississippi, Alabama, and Florida is critical to the projection of these Norphlet petroleum trends into the Eastern and parts of the Central Gulf of Mexico regions.

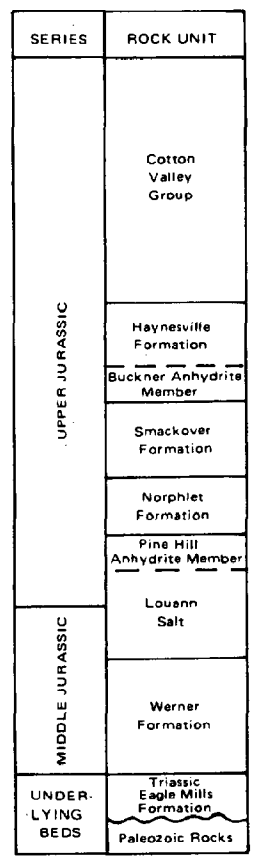


Figure 1.--Generalized Jurassic stratigraphy of the study area.

[1]State Oil and Gas Board of Alabama.
[2]Geological Survey of Alabama.
[3]University of Alabama and Geological Survey of Alabama

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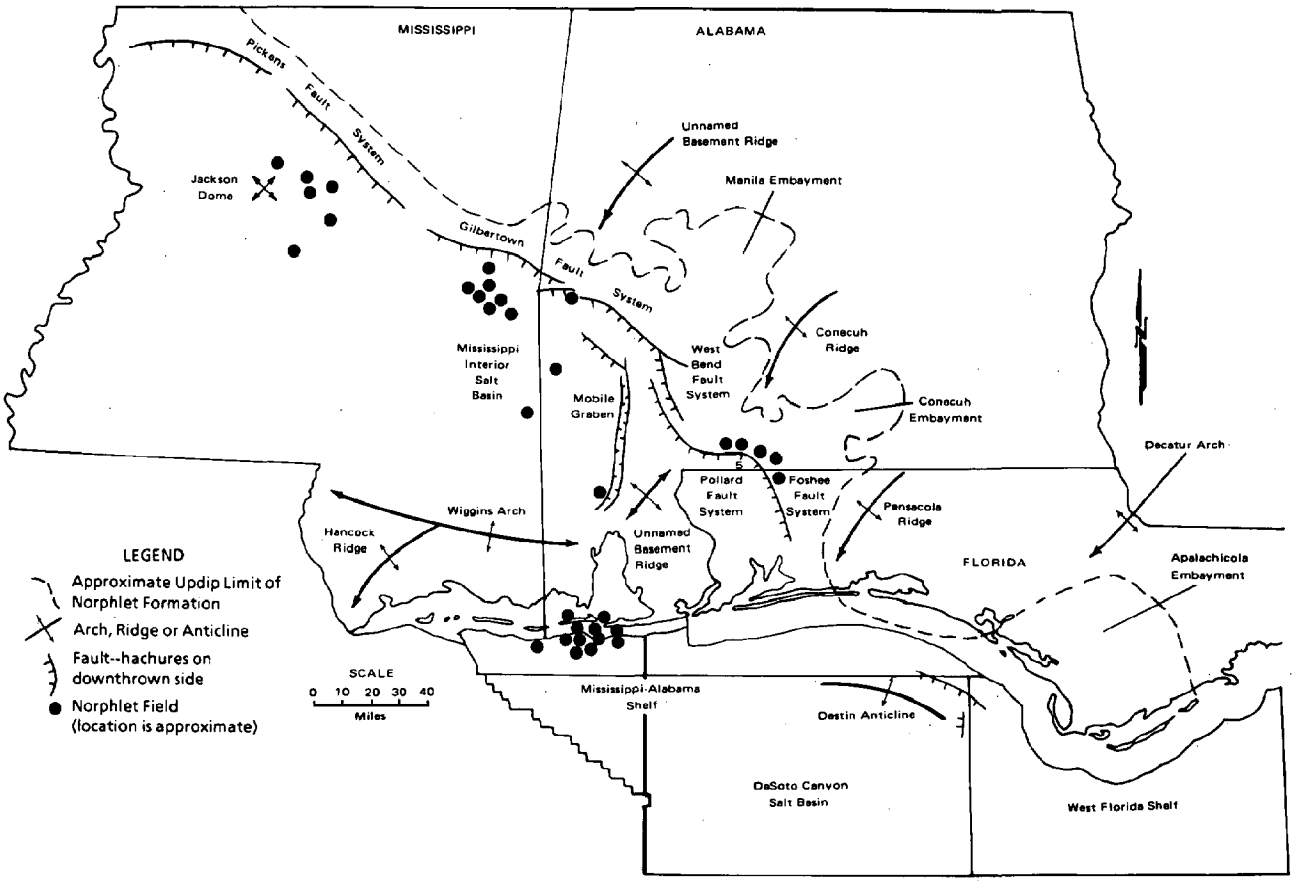

Figure 2.--Regional trend map of Norphlet fields.

STRUCTURE

The northern Gulf basin extends from DeSoto Canyon to northern Mexico and is composed of a broad wedge of Mesozoic and Cenozoic strata that accumulated almost continuously from Jurassic time to present.[15] The northern Gulf basin is that part of the Gulf region that is roughly outlined by the updip limits of Jurassic sediments and ranges in extent from east Texas to northwest Florida.[18, 2, 19] Along the inner regions of this basin from Alabama to southwestern Texas, updip members of Mesozoic and Cenozoic strata rest unconformably on complexly faulted and folded Paleozoic rocks of the Ouachita-Appalachian system.The most common structural styles in the northern Gulf region are normal faults, extensional faults associated with salt movement, salt diapirs and syndepositional growth faults. Normal faults in the region typically exhibit down-to-the-basin displacement and in the Jurassic strata may have angles of 45° to 70°.[2]

The most pronounced structural system of the northern Gulf region is a group of related faults, typically referred to as the regional peripheral fault trend,[15] which rims the Gulf basin and corresponds approximately to the updip limit of Louann Salt deposition in the region. In Mississippi, Alabama, and Florida the faults that comprise this trend include: (1) the Pickens-Gilbertown-West Bend systems of eastern Mississippi and southwestern Alabama, which roughly border the edge of the Mississippi interior salt basin; (2) the Pollard-Foshee systems of southern Alabama and panhandle Florida; and (3) related faults in the Pensacola, Destin Dome and Apalachicola Areas (fig. 2). A similar but unrelated fault group, the Mobile Bay fault trend is present in Mobile Bay and offshore Alabama.[3]

The present day Mississippi-Alabama shelf lies in offshore Louisiana, Mississippi, Alabama and western Florida and, according to Martin,[15] is separated from the Texas-Louisiana shelf by the Mississippi Delta and adjoins the West Florida shelf along an arbitrary boundary that extends from the southeastward bend of the shelf break to the shoreline near Pensacola, Florida. The Mississippi-Alabama shelf is characterized by pronounced relict topography and a gentle gradient.[15]

Large paleohighs are found in the northern Gulf region of Mississippi, Alabama, and Florida, including the Wiggins arch and Conecuh ridge systems in southeastern Mississippi and southwestern Alabama, and the Pensacola ridge in northwestern Florida (fig. 2).[33, 5, 9] In addition, the Appalachian structural trend had a significant influence on the distribution of Jurassic sediments and served as a major source area for Jurassic clastic sediments.[31]

The widespread Louann Salt created a complex network of structures in the northern Gulf region. These salt-related structures include salt pillows and diapirs, growth faults, extensional fault systems related to salt flowage, and graben systems caused by salt movement adjacent to a stable basement. The updip regional peripheral fault trend that rims the northern Gulf basin is the result of salt flowage. Grabens similar to the Mobile graben of southwestern Alabama (fig. 2) are associated with this fault trend. Numerous anticlines and faulted anticlines related to the movement of thick salt are located downdip of these extensional fault systems. The structural fabric of most of the northern Gulf margin is largely the result of salt flowage.[15]

In the offshore panhandle Florida region, the most pronounced structural elements are the Destin anticline and the DeSoto Canyon salt basin (fig. 2). The Destin anticline is thought to be related to a deep-seated salt feature.[25] The DeSoto Canyon salt basin lies on the western edge of the West Florida Slope. This salt basin is characterized by numerous salt piercements.
Based on analyses of selected seismic lines, the authors interpret a major fault system north and northeast of the Destin anticline in the Pensacola, Destin Dome, and Apalachicola Areas. This fault system is interpreted to be an extension of the regional peripheral fault trend that occurs along the approximate updip edge of deposition of Jurassic strata in the northern Gulf rim.

STRATIGRAPHY

The Jurassic stratigraphic section in the study area consists of over 4,000 feet of clastics, carbonates and evaporites.[29] One group and five formations comprise the Jurassic section and are, in descending order, the Cotton Valley Group, Haynesville Formation, Smackover Formation, Norphlet Formation, Louann Salt and Werner Formation (fig. 1). Basal Jurassic sediments unconformably overlie either clastics of the Triassic Eagle Mills Formation or igneous/metamorphic Paleozoic basement rocks. Eagle Mills sediments fill Late Triassic grabens in the northern Gulf rim. These grabens are probably related to the continental rifting of the Gulf of Mexico.[24, 26] Jurassic formations in the study area are known only from the subsurface. These formations range in age from Callovian (Middle Jurassic) to Tithonian (Late Jurassic) according to Imlay.[10]

The Norphlet Formation of Late Jurassic (Oxfordian) age[10] unconformably overlies the Louann Salt, the Werner Formation, Eagle Mills Formation (Triassic) or undifferentiated basement rocks of probable Paleozoic age. The Norphlet in the study area ranges in thickness from 0 (updip limit) to possibly as much as 1,000 feet in the Mississippi interior salt basin. The Norphlet is overlain by the Smackover Formation. The Norphlet Formation has a gradational or abrupt contact with the overlying Smackover Formation.[14] In some areas the Pine Hill Anhydrite Member of the Louann Salt underlies the Norphlet Formation.[21, 22, 14]

Badon,[14] Wilkerson,[32] Pepper,[23] and Mancini and others[14] recognize four lithofacies within the Norphlet Formation, and these are a discontinuous and localized basal shale, an updip conglomeratic sandstone, red beds, and an upper quartzose sandstone (Denkman Sandstone Member of Tyrrell[30]). The basal shale has a discontinuous distribution in the study area. The conglomeratic sandstone occurs along the updip margins of the region. The red beds extend downdip into the inner margins of the salt basin and embayments of the region and the quartzose sandstone lithofacies occurs in the downdip and central parts of the salt basin and embayments in the study area.

The Norphlet was deposited in several distinct environments, which include alluvial fan and plain, wadi, eolian, intertidal, and beach to shoreface.[1, 28, 32, 23, 14] The conglomeratic and red bed lithofacies were deposited in alluvial fan and plain and wadi environments. The shale lithofacies is representative of lagoonal or mudflat deposition related to a Louann sea. The quartzose sandstone has been interpreted as inland and/or coastal eolian dune deposits.[1, 32, 23, 12, 13] The uppermost sandstone beds represent marine beach-shoreface deposits.[28]

The area in and around the study area contains southward projections of features of the Appalachian ridges. Features associated with Norphlet deposition include the Wiggins arch, the Conecuh ridge and the Pensacola ridge. These paleohighs were probably of importance during Norphlet time in that they provided local sediment sources and influenced Norphlet deposition and sedimentation.[28, 32, 27]

The sequence of deposition of the Norphlet and associated facies would include accumulation of intertidal shale in isolated lagoons or bays along an emerging shoreline, followed by Norphlet sandstone accumulation initiated with the uplift and erosion of the Appalachian system. Conglomeratic sandstones were deposited in alluvial fans while red beds accumulated in alluvial fan and plain and wadis. Sand from these environments was transported toward the coast across a desert plain. Subsequent reworking of this sand led to the Norphlet dune and interdune facies. A marine transgression initiated in Late Norphlet time resulted in the reworking of underlying sediments. The marine transgression continued into Smackover time.

Excellent ancient analogs for the mode of deposition of the Norphlet Formation are the Permian sandstones of the North Sea[7, 8] and of Scotland.[6]

PETROLEUM GEOLOGY

Norphlet petroleum traps in the onshore and offshore tri-state area of Mississippi, Alabama, and Florida are principally structural traps involving salt anticlines, faulted salt anticlines, and extensional fault traps associated with salt movement along the regional peripheral fault trend[17]. Stratigraphy plays an integral part in the formation of Norphlet petroleum traps, as is evidenced by the existing fields and recent Norphlet discoveries.
Thirty-five Norphlet fields have been established and since 1967 have produced more than 54 million barrels of oil and condensate and 317 billion cubic feet of gas. The Norphlet productive trends (fig. 2) occur along the rim of the regional peripheral fault trend in the central Mississippi interior salt basin,[11] along the Mobile graben, and in the offshore Alabama area. The most important petroleum exploration play in the Norphlet is the prolific deep gas trend of Alabama state waters and adjacent federal waters. In 1979, Mobil discovered the Lower Mobile Bay-Mary Ann field with the drilling of the Block 76 No. 1 well (fig. 3), which tested 12.2 million cubic feet of gas per day from the Norphlet. Since the discovery of this field, 11 other Norphlet fields have been established in Alabama state waters and in adjacent federal waters. Recoverable reserve estimates for Alabama state waters alone range from 4.93 to 8.12 trillion cubic feet of gas.[17] The large natural gas fields in the offshore Alabama region are similar to the Viking gas field in the United Kingdom portion of the North Sea, as described by Gage.[7]

Along the regional peripheral fault trend several fields have been established including the Flomaton, Sizemore Creek, and Chavers Creek fields. The petroleum trapping mechanism at Chavers Creek field is an elongate, faulted salt anticline associated with the Pollard-Foshee fault system. The Flomaton field consists of a low-relief, faulted salt anticline downthrown to the same extensional fault system.

In the Mississippi interior salt basin, the Copeland field is an excellent example of a salt anticline in the Norphlet Formation. Along the Mobile graben, the Hatter's Pond field in Mobile County is representative of prospective traps involving salt movement along the west side of the graben system.

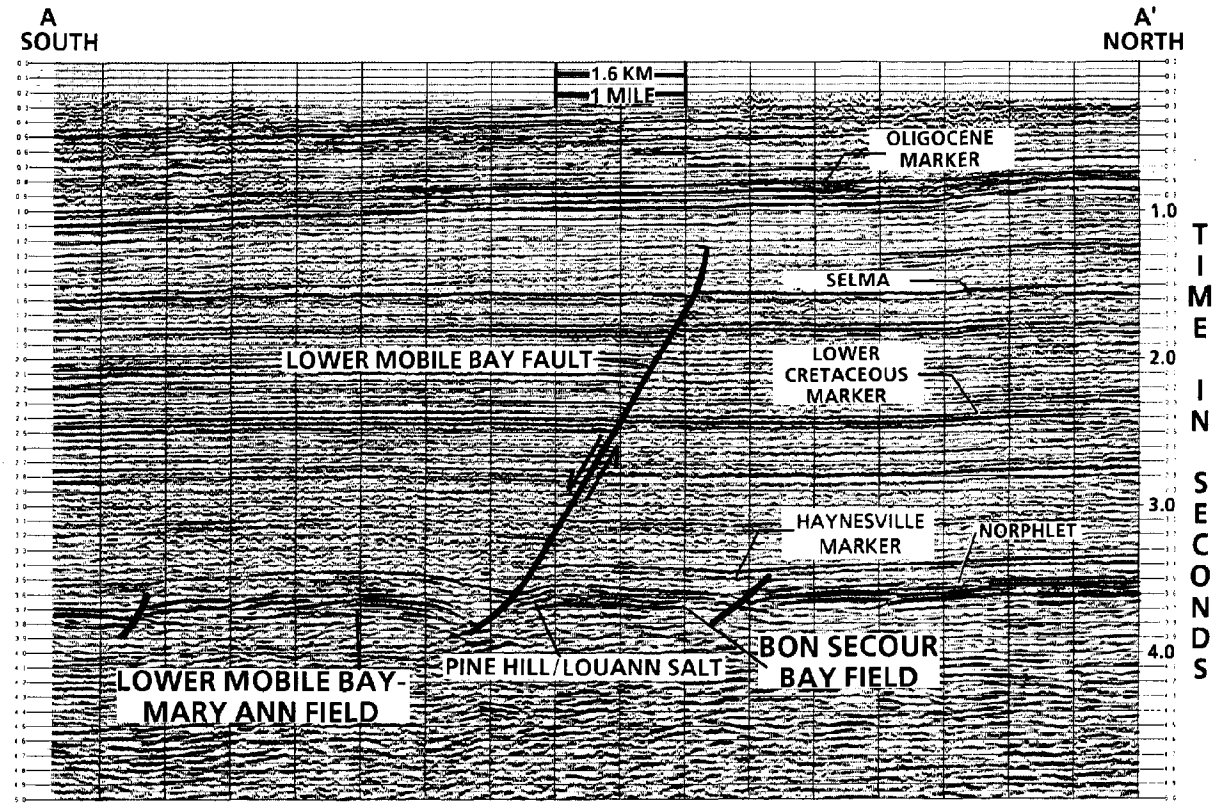

Figure 3.--Typical seismic profile for offshore Alabama. Interpretation by Bennett Bearden (line courtesy of Geophysical Service, Inc. (GSI) - reprinted with permission).

The primary Norphlet reservoir in the study area is the Denkman Sandstone Member, with principally eolian, marine and wadi lithofacies being productive. Porosity in the wadi and dune sandstones is principally intergranular porosity. Porosity in the Norphlet averages approximately 10 percent, while permeability ranges from 0.5 to over 100 millidarcies. The Norphlet marine sandstones typically have lower porosity preserved because of the presence of high percentages of calcite and silica cements.

Smackover algal carbonate mudstones are the source rocks for the Norphlet hydrocarbons.[4, 14, 20] Geothermal anomalies may affect the maturity of the source rocks.[34]

NORPHLET HYDROCARBON TRENDS

Three Norphlet hydrocarbon trends can be identified in the study area. An oil trend and oil and gas-condensate trend are defined by existing onshore Norphlet fields in the tri-state area. A deep natural gas trend is defined by the Lower Mobile Bay-Mary Ann field and other deep gas fields in Alabama state waters and the adjacent federal waters area.

The oil trend is located updip from the regional peripheral fault trend. Salt-related structures are the trapping mechanisms found in this trend. Norphlet fields have been established in the trend with oil being the principal hydrocarbon produced. The projection of this trend into federal waters (fig. 4) extends into the eastern portion of the Pensacola Area, the extreme northeastern corner of the Destin Dome Area, and the northwestern corner of the Apalachicola Area. Although the potential for Norphlet hydrocarbon accumulations in the federal waters portion of the oil trend appears to be relatively high, onshore data evaluated for this study suggest that the amount of reserves is possibly insufficient to justify offshore development.

Substantial Norphlet production has occurred from fields in the oil and gas-condensate trend. This trend is located downdip of the regional peripheral fault trend and most, if not all, of the productive structures are related to salt movement. Oil, condensate, and natural gas are all produced from Jurassic fields in this trend. The projection of this trend into federal waters (fig. 4) would be into the central part of the Pensacola Area and the northwest quarter of the Destin Dome Area. The potential appears to be high for significant Jurassic hydrocarbon accumulations in the federal waters area included in the oil and gas-condensate trend.

The Norphlet deep natural gas trend appears to be concentrated in the Alabama state waters area and the northeast and north-central portions of the Mobile Area. The Lower Mobile Bay-Mary Ann and other deep Norphlet gas fields have been established in this trend. The deep natural gas trend appears to have the highest potential in the Norphlet Formation in Alabama state waters and the northern portion of the Mobile Area.

SUMMARY AND CONCLUSIONS

Study of the available stratigraphic, structural, and hydrocarbon data for onshore and offshore Mississippi, Alabama, and Florida areas demonstrates that these data can be used to establish a regional geologic framework for the Norphlet Formation for the onshore tri-state area and for the state coastal waters and adjacent federal waters areas. Establishment of a regional Norphlet geologic framework along with interpretation of the hydrocarbon data for the tri-state area indicates that at least

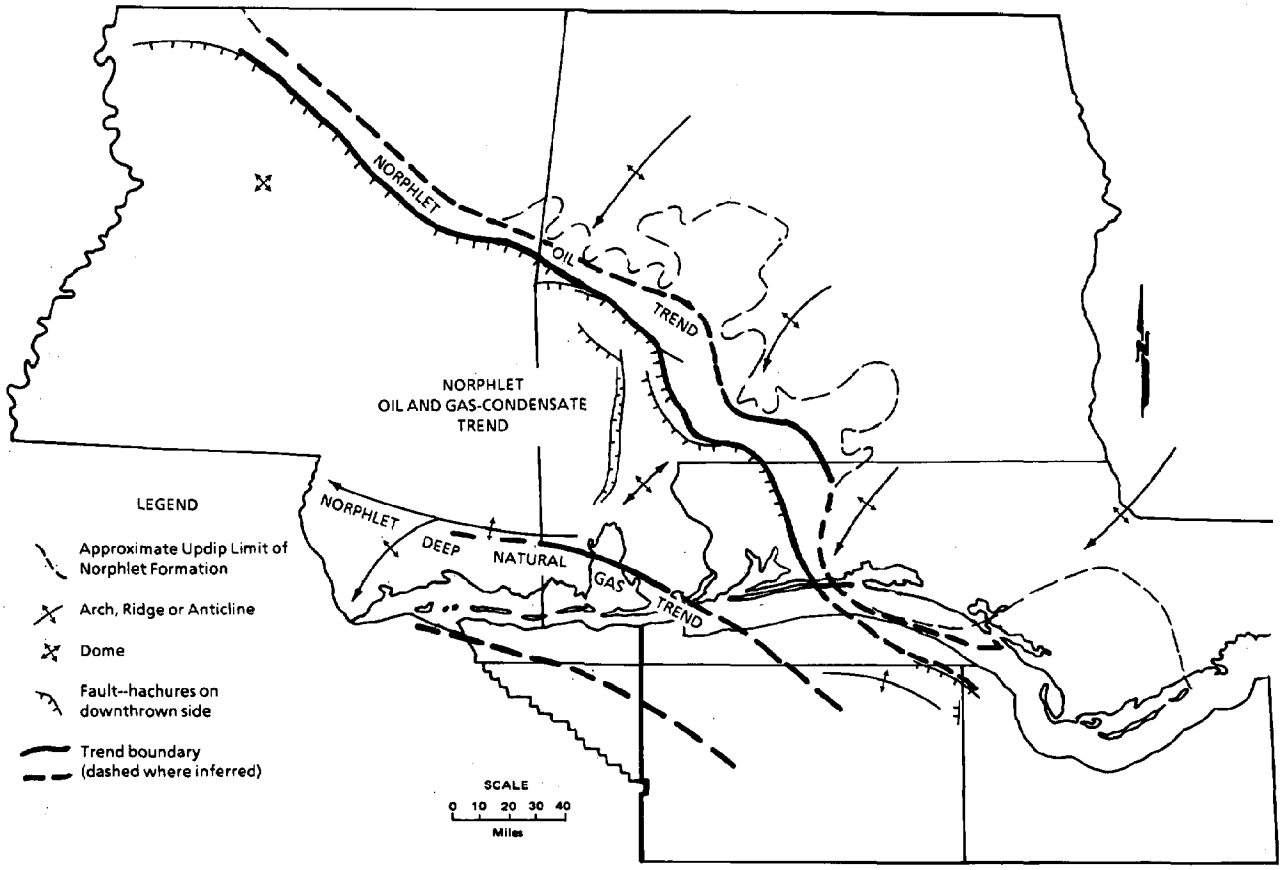

Figure 4.--Norphlet hydrocarbon trends.

three Norphlet hydrocarbon trends are present in the region. An oil trend is located onshore north of the regional peripheral fault trend and extends into the offshore area north of the Destin anticline. An oil and gas-condensate trend has been delineated onshore between the regional peripheral fault trend and the Wiggins arch and extends into the offshore area of the Destin anticline and north of the DeSoto Canyon salt basin. A deep natural gas trend occurs in the Mobile Bay area and extends into the offshore area in the Mobile Area. The oil and gas-condensate and deep natural gas trends appear to be prospective for Jurassic hydrocarbons in state coastal waters and federal waters areas of portions of the Central and Eastern Gulf of Mexico. Substantial natural gas reserves are present in the Alabama state waters area and the northern portion of the Mobile Area, and significant accumulations of oil and gas-condensate may be encountered in the Pensacola, Destin Dome and Apalachicola Areas.

ACKNOWLEDGMENTS

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AVAILABILITY OF MINERALS OFFSHORE VIRGINIA

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ABSTRACT

Offshore Virginia, linear shoals represent potential supplies of sand and possibly placer minerals. If additional exploration proves the deposits favorable, their availability will be determined by various factors: geological setting, mining systems, the environment, multiple uses, and market economics, each with the potential to affect development. Based on available information, the area has favorable mineral potential. Mining systems capable of developing the deposits exist; system selection would be based on deposit characteristics and the environment. Multiple-use factors including fisheries and marine sanctuaries, military, recreation and commercial shipping will present issues but could be accommodated by agreements between the concerned parties. The cost of bringing the minerals to market and the price the market (local for sand, international for placer minerals) will support are critical factors in determining overall feasibility.

INTRODUCTION

Since the establishment of the U.S. Exclusive Economic Zone (EEZ) in 1983, a variety of efforts and studies have been initiated that reflect the increased interest in offshore mineral resources. Within the Federal sector the Minerals Management Service (MMS) has created the Office of Strategic and International Minerals to assure a focused and coordinated marine minerals program within the EEZ. We have aggressively pursued a customized regulatory regime under the OCS Lands Act in order to facilitate State involvement and commercial ventures. A number of cooperative State-Federal task forces have been organized to evaluate resource potential, economic feasibility, and environmental impacts.

Several studies have been published while others are underway. At MMS' request, the U.S. Bureau of Mines conducted two reconnaissance studies in 1987 relating to EEZ minerals potential -- one focused on sand and gravel, the other on heavy minerals. A comprehensive report by the Congressional Office of Technology Assessment (1986) examined the status of knowledge of the mineral resources within the EEZ, assessed the technology, and identified pertinent issues.

In view of this interest, the linear shoals offshore Virginia should be considered as potential sources of sand and possibly other minerals. Reconnaissance has indicated significant concentrations of heavy mineral placers associated with the sand. Availability, however, will be determined by factors pertinent to development, including geology, mining systems, the environment, multiple uses and market economics. Consideration of these factors will be necessary on the site, local and regional scale.

DISCUSSION

Geological Setting

Sand and placer minerals located offshore Virginia are part of the linear shoal field extending along the shallower portions of the continental shelf seaward from the coast to about 75° 30' W. and from about 37° 00' to 37° 30' N. The shoals are part of a sand terrace dominating the bottom topography and forming an extensive topographic high on the

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shelf. Williams (1986) indicated that the shoals associated with prominent capes, regions of abundant sand, show potential for exploration. One such prominent shoal area is located approximately 9 miles off Cape Charles, Virginia. Regionally, the topography is low relief with water depths increasing seaward to a maximum of 60 feet. Petrographic analysis of sediment samples from over 675 square miles of continental shelf indicated that the mean grain size range from fine (0.125-0.25 millimeters) to very fine sand (0.062-0.125 millimeters) with an average mean grain size corresponding to fine sand. Analysis of sedimentological parameters characterized the sediments as well sorted and relatively homogeneous (Rowland, 1977).

Shoals can be divided into two classes: shoreface-connected and isolated. Shoreface-connected shoals are topographically related to the shoreface and are generally shoreward of the 30-foot isobath. These shoals are part of the shelf-shoreface sedimentary system.
Isolated shoals show no apparent connection to the shoreface but are responsive to the modern hydraulic regime. If located below the wave-base, as is common, isolated shoals are relict geomorphic features. As such, relict shoals may have potential for development with minimal impact to the shoreface sedimentary system. This is a critical consideration for any proposal pertinent to mining of the continental shelf.

Interest in the shoals focuses on their potential as sources of sand and minerals, such as ilmenite, epidote, staurolite, garnet, magnetite, and zircon. As early as 1972, reconnaissance offshore Virginia north of the Chesapeake Bay (Fig.1) indicated that extensive sand bodies contained heavy minerals of possible economic value. Offshore sediment samples have shown higher concentrations of heavy minerals than the areas to the south and only slightly less than the richer onshore areas of South Carolina. Additional evaluations will be required, but preliminary indications merit further exploration. Potentially economic concentrations of minerals have been located in the shoal field off Smith Island, Virginia, by Grosz and Escowitz (1983) and Berquist and Hobbs (1985).

Atlantic shelf shoals commonly contain millions of cubic yards of sand, much of which appears suitable as borrow sources. Resource estimates for specific shoals can vary significantly based on the assumptions, sampling, and methodogy (Williams, 1986). Thus, specific resource estimates are premature; however, the potential appears favorable based on the available data and geological analogies show favorable potential.

Mining Operations

Mining operations would be similar to others conducted for beach nourishment and those conducted for offshore mining in other countries, including Japan and the United Kingdom. Offshore mining in Japan produces 60-70 million tons of sand and gravel per year, 20 percent of the total production (McKelvey, 1986). The United Kingdom produced about 15 percent of its domestic supply of sand and gravel from the offshore in 1980 (Tinsley, 1983).

Mining systems would employ either of two basic dredging color types: mechanical or hydraulic. Mechanical dredging excavates and lifts the material to a ship by buckets or in a clam-shell type device. Bucket ladder dredges are

efficient for operations containing boulders, clays, and debris; however, such operations can generate substantial turbulence can be generated during operations. Bucket ladder dredges have been used for offshore mining of gold and tin (Cruickshank, 1987). Hydraulic dredges lift material as a sediment-water slurry to the ship. Development of cutterheads and submersible pumps has significantly extended both operating capability and depth range. Cutterhead suction dredges excavate compact, granular materials from water depths of less than 100 feet. Suction hopper dredges have been used in water depths of up to 120 feet, and newer models have depth ranges of up to 150 feet (Cruickshank, 1987). Dredging technology exists for operations in at least 300 feet of water. Water depths offshore Virginia are well within the capabilities of operational dredges.

In recent years, antiturbidity overflow systems have been developed in Japan. Such engineering systems can significantly reduce the amount of water column turbidity generated from dredging operations. Thus, using such a system could reduce environmental concerns associated with operations.

Environment

Environmental considerations encompass a range of interrelated factors. The Eastern shore of Virginia is part of an extensive barrier island and wetland system. Barrier islands are dynamic geomorphic features constituting an important segment of the coastal zone system. Changes in the coastal zone will alter the associated natural processes, and subsequently, the characteristics of the estuaries and wetlands (Leatherman, 1982). For example, intense coastal urbanization in the vicinity of Ocean City, Maryland and Fenwick Island, Delaware, has had documented impacts on the coastal and shoreface sedimentary systems (Dolan and others, 1980). In selecting shoals as candidates for mining, an analysis of the particular shoal to the shoreface sedimentary system is necessary (Rowland, 1984). Impacts as a result of dredging could result from: (1) changes in the wave-base by seabed alteration, (2) changes in the composition of the bottom sediments, and (3) increases in water turbidity.

Research by the U.S. Army Corps of Engineers, the British government, and coastal scientists is being conducted into the effects of dredging in shallow water. Based on the British experience, dredging has not instigated significant changes in water depths of greater than half a wave length, or more than one-fifth the length of extreme waves. In the United Kingdom, dredging in waters over 60 feet generally receives routine approval. Between 30 and 60 feet, a detailed study and site-specific information are required, but for operations proposed for water depths of less than 30 feet substantial studies are required (Drinnan and Bliss, 1986).

Sediment resuspension near bottom can also occur as the mining operation traverses the deposit. Lifting sediment to the surface discharges sediments throughout the water column. Increased turbidity could result not only at the site but possibly throughout the area. Coastal and continental shelf dredging resulted in sediment plumes that have been visible often up to 3 miles and up to 12 miles in extreme cases (DOI, 1974). A major impact of

a sediment plume is modification of the depth of light penetration into the water column. Suspension of the fine-grained sediments can affect the gills and ability of indigenous fish to navigate. Dispersion by surface currents and currents in the water column can affect the larvae and juvenile stages of shell and finfish. Migration routes of sea turtles, porpoises, and finfish can be affected by increased water turbidity if turbidity remains for an extended period of time. Over the larger areas, turbidity may be more significant than the disturbances at the activity site. Life cycles are affected by the texture, composition and stability of the substrate. Many benthic fauna have restricted ecological niches; local communities cannot survive in a severely disturbed area.

Seabed sediment texture and composition are vital as variability caused by erosion or additional accumulation of fine-grained sediment can impact the total local population. But, disturbances in the bottom characteristics may not necessarily be permanent. Dredges leave undisturbed areas of sea floor between tracks that may serve as source areas of repopulation. In a channel near Le Harve, France, recolonization occurred rapidly after dredging (McKelvey, 1986). Additional research is necessary to focus on the aspects of dredging, including studies of the succession patterns of various benthic species.

Multiple Uses

Potential multiple-use conflicts exist between local military operations and offshore mining. Langley Air Force Base conducts a variety of missions off Virginia. At the mouth of the Chesapeake Bay, Norfolk and Virginia Beach constitute the home port for the U.S. Navy's Atlantic and Mediterranean fleets. Norfolk Naval Air Station has extensive air operations in the area with approximately 116,000 flights annually. Other large naval installations in the area--Oceana Naval Air Station and the Little Creek Amphibious Base--conduct exercises outside the Chesapeake Bay. Also, nautical charts identify places of undetonated explosives in the area. Four such places are apparent on navigation charts, two of which are situated in what is considered the shoal area.

Onshore, the Wallops Island missile testing range serves as a base for launching weather balloons and rockets. The Wallops Island-NASA Warning Area extends offshore for nearly 80 miles across the continental shelf. Military and commercial "precautionary areas" and navigation "traffic separation zones" are indicated on U.S. Coast Guard navigation charts and in the Notice to Mariners, a weekly publication of the Defense Mapping Agency Hydrographic Center.

Marine sanctuaries are designated around distinctive marine resources whose protection and use requires comprehensive, geographically oriented planning and management. A number of marine sanctuaries exist along the barrier islands of Virginia including some in proximity to the linear shoals. For instance, at Cape Charles, the Fisherman's Island beach area is designated as a sea turtle nesting area. Habitats of endangered species and the potential impacts to those sites would necessarily be addressed before offshore mining begins.

Recreation on the continental shelf and the adjacent coastal areas is important to the public and to local and State revenues. Coastal

States, including Virginia, commit large expenditures to such activities as boating and fishing. Coastal waters--those within 3 miles of the shoreline--comprise one of the most intensively used areas for outdoor recreation. In 1982, Atlantic coastal counties invested heavily in outdoor recreation; $48.7 per capita, nearly $27,000 per square mile, was spent by public agencies along the Atlantic coast (NOAA, 1986). Coastal recreation as a component of the American lifestyle has been to an extent studied by the NOAA, Offshore Assessment Division. However, more regional and specific assessments will be required to provide information for strategies on using the near shore, especially the impact from mining operations.

The Chesapeake Bay entrance and approaches are among the most heavily traveled in the world providing access for commercial shipping to Hampton Roads. Shipping lanes are indicated on the NOAA bathymetric charts and are updated periodically in the Notice to Mariners.

Market Economics

Market economics is a consideration influencing and influenced by the other development factors. A deposit must be determined to be economically attractive in order for development to occur either onshore or offshore. Sand is a relatively low-value, high-volume commodity. Thus historically, deposits have been located and developed in close proximity to the market. Generally, the market is established first, creating a need for discovery and development of a local sand supply. In the absence of a local supply, transportation costs become prohibitively high.

Economic factors pertinent to comparison of offshore with onshore sources are (1) local market conditions, (2) exploration costs, (3) mining and processing costs, and (4) transportation costs. A detailed economic feasibility study would be required before development of the deposits. For instance, often marine exploration and initial capital investment costs would be expected to be higher compared with similar onshore costs, but the efficiencies associated with dredging operations and the low costs associated with barge transport could offset those costs (Economic Associates, 1986).

The potential market of the offshore sand exists as Tidewater, Virginia, a metropolitan area incorporating Norfolk, Virginia Beach, Chesapeake, Portsmouth, Hampton, and Newport News. Significant urban and industrial growth in this area over the last decade has resulted in a population in excess of a million, a viable multifaceted local industrial base, and an increasing demand for sand. Pending specific market feasibility studies, information indicates possible economical viability for the offshore deposits based on market proximity and relatively inexpensive and efficient barge transportation.

Additionally, the potential may exist for the development of the associated heavy mineral placers as a co-product. If the placers are found to occur in sufficient quantitites and are developed as a co-product of the sand for national or international markets, the economic development potential would be greatly enhanced for the shoal field.

ASSESSMENT

Preliminary information indicates a strong geological potential for the linear shoals as sources of sand and possibly placer minerals. However, resource estimates for individual

shoals or for the resource area are premature. Additional exploration and resource evaluation are needed to assess the mineral resource potential.

Assuming traditional exploration methods indicate the linear shoals as viable targets, other geological factors will require consideration including: (1) geomorphic and oceanographic changes resulting from excavation and (2) sediment texture alterations resulting from settling of suspended material. Information pertinent to those considerations could be obtained by site-specific studies using existing geological and oceanographic information and by the development of a geological, mineral, and engineering data base.

Existing mining systems can operate in the water depths and under the physical conditions of offshore Virginia. Existence of the technology is not the question, but rather, there is a choice of systems to be employed. Selection of a system would be an engineering decision based on factors such as sediment characteristics and environment. Environmental analysis should examine processing and material handling and whether the material will be processed at sea or onshore and if the sand and heavy minerals will be mined as co-products.

Various studies have examined offshore processes and potential impacts associated with offshore activities. The Department of the Interior in 1974 prepared a draft environmental impact statement on Outer Continental Shelf mining. In 1979, the Department of the Interior also prepared a program feasibility document examining a variety of issues and site-specific marine mining possibilities. Although valuable contributions, these efforts were not of the scope required before development of offshore mineral resources in the late 1980's. Historically, most offshore environmental studies have focused on oil and gas leasing activities and ocean dumping. Despite the great amount of environmental data, certain of the data may not be directly pertinent to offshore mining activity. Differences in data collected for offshore oil and gas and that required for marine mining result from differences in the minerals and between the types of operations. Variances also exist among the individual minerals and between their associated geological and physical environments. For example, the polymetallic sulfide deposits of the Gorda Ridge and the sand deposits off Virginia illustrate the often radical differences between offshore mineral deposits and settings.

If economic feasibility and commercial interest exist, comprehensive study of the environmental effects of offshore mining would be beneficial on a mineral-and site-specific basis. Such a study could be analogous to Project NOMES, which examined potential environmental impacts associated with offshore sand mining in the nearshore continental shelf. Project NOMES examined the impacts from hydraulic dredging at a sand and gravel site in Massachusetts Bay (Padan, 1977).

Nearly two-thirds of the Atlantic commercial fish and shellfish are estimated to be estuarine dependent during some stage of their development (Department of the Interior, 1988). The area is within the nation's largest commercial fisheries (blue crabs, menhaden, oysters and bluefish) and is in proximity to the habitats of certain endangered species (the Sea Turtle, Bald Eagle, and Delmarva Fox). Issues pertinent to the

interaction between fisheries, sanctuaries and mining operations include: (1) the impact of noise and (2) interference between the fishing and mining activities and with biological resources. The magnitude of such issues remains to be determined, but experience developed from the offshore oil and gas and commercial fisheries could form the basis for mitigation. For example, since May 1, 1988, North Carolina shrimp trawlers 25 feet or more in length are required to use approved turtle exclusion devices (TED's) on shrimp nets. Costing about $100 each, TED's provide an escape path for sea turtles captured in the shrimp nets. This demonstrates the level of interaction possible and sometimes required by multiple-use interests.

Because of the deposit locations, mining operations would be expected to minimally impact military surface ship operations. Military ship traffic areas are identified on the navigation charts and published in the Notice to Mariners. In the vicinity of the potential mining sites, conflict between the military ships and the mining operations could be expected to be small and resolvable. Previous cooperation between the military and the Department of the Interior with the offshore oil and gas activities would form the basis for resolution, possibly by prelease and postlease stipulations.

Recreation activities in the vicinity constitute a potential multiple-use conflict with offshore mining. Coastal activities are generally in the category of surf fishing and beachcombing. Related are the aesthetic or scenic values associated with this area. The impact to recreation in the immediate vicinity would depend on the scale of the proposed mining operation. At sea level, visibility is 12 miles; thus, it would be reasonable to assume that mining operations would not be visible or be barely visible from the Virginia shoreline. Anticipated heights of the mining vessel would be approximately 30 feet above the water surface.

Offshore recreation would be affected by mining operations to a limited extent. However, to the degree possible, mining operations could accommodate such activity by posted warning and restricted areas. An educational and public information program on offshore mining would be necessary to minimize the potential conflicts with recreational activities (Cruickshank, 1988).

Potential sites are outside the commercial shipping lanes; as a result, mining operations would not be expected to require alteration of shipping lanes. Marine mining activities would slightly increase the volume of traffic into Hampton Roads; however, the increase would be expected to be small relative to the total ship traffic. The nature of the increase would be a function of the type of mining systems employed, that is, the number and type of dredges and barges.

CONCLUSION

Deposits of sand, possibly with valuable placer minerals, exist off the coast of Virginia as linear shoals. Development potential appears favorable, pending further economic feasibility assessment and resource evaluation. The minerals associated with the sand include concentrations of ilmentite and zircon. If present in sufficient quantities, they could be considered

by-products from mining the sand. Current dredging technology could be employed for the marine mining, assuming favorable mineral evaluation and environmental analysis.

Prior to development, however, additional investigations are needed on the following geological topics: (1) impacts to the shoreface sedimentary systems, (2) impacts of dredging on local geomorphology, and (3) reclamation. Environmental issues related to the effects of mining would include: (1) impacts from increased and sustained turbidity, (2) the potential for recolonization including ecological successions, and (3) impacts on the biota of altered sediment texture.

Offshore and coastal regions of Virginia are areas of varied multiple-use activities: marine sanctuaries, commercial fisheries, military operations, recreation and commercial shipping. Conflicts may be anticipated but should be resolvable. The extent of specific measures necessary for resolution remains to be determined. However, at this time, multiple-use activities do not appear to be exclusionary to mining. Experience of the Department of the Interior with offshore oil and gas programs and with commercial fisheries in other areas could be expected to provide the foundation for resolution.

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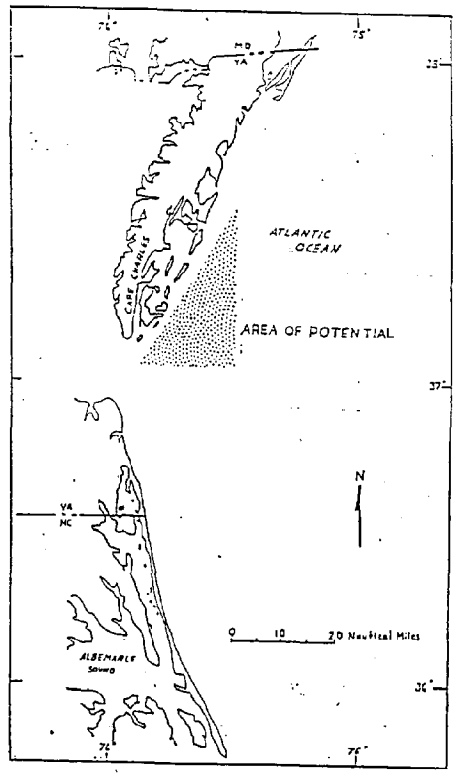

Figure 1. Area of Potential Off Virginia

OCEAN MINING: AN OPPORTUNITY FOR PUBLIC-PRIVATE PARTNERSHIP

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Ocean hard mineral mining has represented an area of potential economic interest and development for the U.S. over the past 30 years. Its successful development within the U.S. EEZ will require the conciliation of potentially conflicting ocean uses: economic development on the one hand, and the protection of existing ocean uses and the environment on the other. A public-private partnership structure is suggested as a vehicle for the successful resolution of these issues.

Introduction

Ocean hard mineral mining has been an area of developmental interest within the U.S. over the past 30 years. With the discovery of manganese nodules on the deep ocean floor, and the subsequent formation of several consortia for the exploration and development of these mineral deposits in the 1960's and early 70's, interest in the practical economic potential of ocean minerals assets has remained in a prominent position in the ocean policy of the U.S.. Under the Carter Administration, this interest among others motivated the U.S. to work closely with the Law of the Sea Treaty organization. Under the Reagan Administration, this same interest was one of the key reasons cited by the U.S. in refraining from signing the Treaty and for the later declaration by the U.S. of its own Exclusive Economic Zone, in March of 1984.

The idea of seabed mineral mining still excites the ocean community, but the reality is that few practical immediate opportunities appear to exist at this time. The number of opportunities is not zero, however. In several cases, potential hard mineral assets lie within the U.S. EEZ. The development of these potential assets could be an important factor in strengthening coastal region economies. At the same time, these same potential developments are viewed by many as a risk to other ocean uses and to the regional coastal environment. The resolution of these issues must inevitably involve the effective cooperation of both public and private sector parties.

This paper reviews these ocean hard mineral opportunities, and suggests that the formation of public-private partnerships may constitute the most appropriate and effective path to their development within the U.S.. The views expressed are entirely those of the author, and result from his work, and that of his associates, in their work to establish practical ocean mining operations.

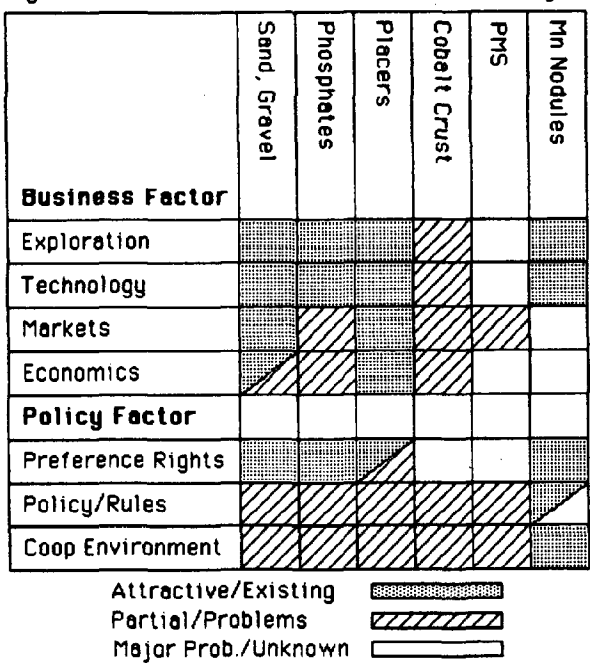
Status of Ocean Mining in the U.S.

There are currently six active or potential ocean mining areas of interest to the U.S. economy at the present time:

- Sand and Gravel
- Metal ore bearing placers
- Phosphates
- Cobalt rich crusts
- Polymetallic sulfides (hydrothermal)
- Manganese Nodules

The first three in the list are essentially shallow water coastal deposits and, as might be expected, these are the areas in which there are current practical operations. The last three areas are still either in the exploration phase, or are awaiting a more suitable economic environment, or both. This situation is briefly summarized in Figure 1(Wenzel[1]). Referring to Figure 1, it is suggested that in the case of the three shallow water mineral areas, the exploration of known deposits is within the capabilities of technology, and is either completed or

Fig. 1 Ocean Hard Minerals Development & Policy



defineable for deposits suspected but not yet characterized. The technology for recovery for these minerals areas is well in hand. Markets for these minerals are in most cases practical and in some cases attractive. The placer minerals of ilmenite, chromite, precious metals, and gemstones, all have a reasonable economic value, as do most sand and gravel deposits and some phosphates, depending upon transportation costs and local markets.

Most of these shallow water minerals are supported by a working set of development regulation and policy within the U.S. and State waters (in the U.S. jurisdiction, the States control the seacoast waters - the Territorial Sea - out to three miles from land). Development lease agreements can be established with the appropriate State or Federal jurisdiction. As an example of new policy, the State of Oregon has recently developed provisions for granting right of preference at the State level during the exploration phase. The establishment of such leases does pose problems, both environmental and in policy, and is most successfully undertaken under the situation of a "cooperative environment" between the developing interests and the public sector.

In the deep ocean area, there are more problems, and much less likelihood of near term economic development, even though some of these resources may be vast in extent and may hold valuable minerals even in todays rather weak market. Referring again to Table 1, the manganese nodules have themselves been rather thoroughly explored and characterized as a deposit. The technology for their recovery is reasonably in hand. Demonstration mining units have been build and tested. Interestingly enough, under the U.S. Deep Seabed Hard Minerals Act, the exploration preference rights have been well established for this particular mineral deposit in U.S. law. Policy and rules for the most part tend to favor development and a reasonably cooperative policy and viewpoint exists for the development of this resource within the U.S.. Unfortunately, the current world market is such as to preclude any practical investment in the development of the nodules[2].

The cobalt rich crusts, which have been of great interest in the Pacific, and which are well represented within the U.S. EEZ areas of the Central and Northern Pacific (around Hawaii, for example), have recently received a significant amount of exploration and are moderately well characterized. The technology for their efficient extraction has not yet been developed, although the general techniques for their recovery and processing are understood[3]. World markets for the principal metals, and the economics of their recovery, even for the valuable cobalt content, do not now appear to be such as to encourage private investment in extensive characterization and development. In addition, no suitable basis for establishing preference or claim rights for these deposits under the exploration phase has yet been developed by the U.S..

The relatively recent discovery of polymetallic sulfide deep ocean hydrothermal deposits has attracted attention in part because of their high concentrations of metals such as copper, tin, silver, and zinc. Only the first stages of exploration have been completed. New technology is required for the complete characterization of these deposits, as well as for any potential recovery operations. The economic practicality of these deposits is as yet largely unassessed. The recovery costs have not yet been determined, nor can they be until these deposits are more fully characterized. Again, there is at the moment no basis for an assertion of claim during exploration within U.S. law.

In summary, in the area of deep ocean deposits, there may be expected to be a continuation of research and exploration within the U.S. EEZ areas , but no near

term economic development and little privatly funded characterization. The picture in the shallow, coastal waters, is quite different. There are, and have been, profitable commercial enterprises operating on these types of minerals, and this type of development will continue, but increasingly under a more careful and often more demanding level of control by State and U.S. Federal agencies. The shallow water deposits are found in both State and Federal waters and these jurisdictions are often overlapping. Therefore, the establishment of an effective interface between State and Federal jurisdictions represents one of the more difficult and pressing problems for commercial development.

Incentives for Coastal Ocean Hard Mineral Development

Within the U.S., there has been a continuing search by the ocean hard minerals community for an appropriate way to encourage private sector participation in the exploration and development of promising mineral resources on the ocean floor. The current and seemingly chronic U.S. trade deficit argues for the development of more exportable resources. In addition, with a tightening Federal budget, the individual States are feeling the pinch in terms of fewer Federal dollars to support State and local needs. Since most of the shallow water ocean mineral assets of the U.S. lie at least partially within State territorial waters, the coastal States might look upon the development of these assets as a valuable additional source of income. Finally, many coastal regions around the U.S. have only a narrow economic basis, and would benefit from the development of an additional industry.

Against these incentives, however, lie a set of problems which appear to be common to all coastal developments. These are the perceived risks of such development to the environment and what might be termed the "lifestyle" of the coastal community. In many coastal areas of the U.S., any development at all is often seen as an encroachment on the current environment. In many cases, this has led to a confrontation of interests which is often resolved in the courts, at least temporarily, in the form of an injunction against continuation of the project, until studies can be made and the claims and concerns of other ocean users resolved in the context of the judicial system. This very risky and expensive process and its prospect is often a very effective deterrent to project initiation.

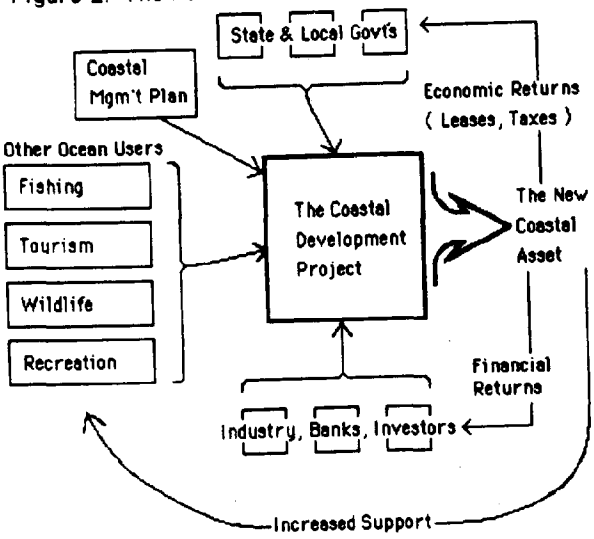
The primary incentive for private sector participation and development remains that of potential financial reward commensurate with the risk of development. In the case of ocean hard mineral development, and especially in the area of exploration and characterization so necessary for undertaking any developmental investment, the resolution of these real and perceived high risk areas will be an essential element in the development of sufficient incentives to encourage effective private sector investment. New methods are needed by which these high risks might be reasonably reduced or resolved.

The Public-Private Partnership Concept

Many U.S. coastal States and local governments are now entering into the development of comprehensive planning for the well thought out and integrated use of coastal ocean assets which, under State and Federal jurisdiction, belong to all. The Pacific coast States are now all engaged in such planning efforts. These activities were pioneered by the Gorda Ridge Task Force, formed in 1985 at the request of the concerned States at the behest of the U.S. Department of the Interior. The latest and most comprehensive activity of this type has been the establishement by the Oregon State Legislature[4] of an Ocean Resources Management Task Force for the creation of an integrated Ocean Resources Management Plan, initiated by Governor Goldschmidt in late 1987. Although in many cases in the past such planning efforts have been established as a reaction against untoward development, the more recent efforts, including the Oregon project, are toward the intelligent management of these coastal assets to realize their maximum benefit for all coastal ocean user interests through a balancing of risk, investment, and economic value.

This approach suggests the concept of a partnership between the State, local, and (where appropriate) Federal governments, the private sector development interests, and the ocean user communities. This concept, which has been encouraged under the policies of the current U.S. administration and the U.S. Department of Commerce[5], is suggested in Figure 2.

Figure 2: The Public-Private Partnership Concept



As suggested by Figure 2, under a comprehensive coastal management plan, and the interested support of industry, investors, and the banking community, a coastal development project is formulated, with the overall State and local government social and economic development objectives in view. The other ocean users are coupled into the project through such means as advisory councils, informal planning sessions, and as actual participants in the project itself. It is important that delegates of these other ocean users will have participated in the writing of the ocean asset management plan itself.

This team then works together to develop and execute the coastal development project. If the private sector provides the funding, the project must necessarily be designed to provide an adequate return on investment to justify the risk undertaken by the private sector investors. Joint funding, or sometimes sole funding, may also be provided by the Sate, local, and Federal governments. Wherever possible, it is highly desirable to involve the State and local colleges and universities. These can be sources of needed technical support and also provide a highly trustworthy source of balanced risk/benefit analysis, which will be an important element in assuring the other ocean users that their interests will not be unduly put at risk through the new project. The special studies of environmental impact on the affected region can often be most convincingly done by these academic institutions, and by such State agencies as the fish and wildlife service, the environmental protection and land conservation agencies, and interested technical and environmental research organizations.

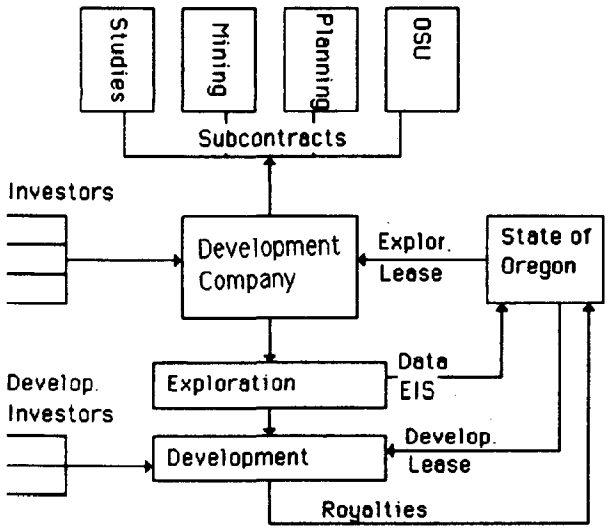
The "bottom line" point of the partnership approach to coastal project development is that of recognizing the complex nature of the public and private ownership and use of coastal assets, and the need to provide an effective means of incorporating the perceived interests and needs of this ownership as an integral part of the developmental project. In a very real sense, from the private sector standpoint, this approach is needed to assure the existence of a cooperative environment in which the investment in the new asset is to be made. This is a highly important factor in the reduction of perceived risk to the private investment community.

The Oregon Black Sand Placer Project as an Example Partnership

Development of placers along the Pacific coast of the U.S. has so far been limited to gold and platinum group metal (PGM) placers, primarily in Alaska. Coastal placer tracts in the Nome area, for example, are currently being worked by chain bucket dredges, with some economic success. The presence of gold in the black sands associated with the northernmost California coast, and the southern third of the Oregon coast has been known for a long time. Gold Beach, Oregon got its name from the early gold placer operations in the late 1800's there. These sands also contain important amounts of chromite and ilmenite (titanium). During World War II, the deposits on land (beach placers now above sea level due to coastal uplifting) were mined successfully for chromite. This mining continued until the early 1950's when the U.S. strategic stockpile purchases were terminated. The limited extent of the land deposit, and the lower price of chromite ore on the world market did not support continuation.

These black sands have been the subject of extensive surface (halo) exploration by the Oregon State University (OSU) School of Oceanography and by others over the past 25 years. A body of knowledge has been built up which now permits the definition of a detailed plan to explore and fully characterize the deposits[6]. Working with the State of Oregon over the past six years, the writer and his associates have been developing a plan (Figure 3) for the cooperative establishment of a project to fully explore and

Figure 3: Oregon Black Sands Development



characterize these deposits which would merit private sector investment and support.

Referring to Figure 3, a development company has been established, which is proposed as a vehicle for private sector investment. This joint venture would subcontract the bulk of its work, initially exploration and associated studies. The plan includes work by a major State university (OSU), to perform many of the exploration activities needed to characterize and understand the deposits as potential mine sites. The development company expects to respond to a competitive colicitation by the State for a cooperative exploration lease, which, under a new and unique Oregon law[7], provides for a right of preference in converting the exploration lease to a developmental lease. In return, as a partner, the State receives data in the public domain from the exploration upon which to base its development decision and the preparation of a development environmental impact statement.

Upon the determination that an economic deposit in fact exists, under the terms of the exploration lease the joint venture and its owners have rights of preference for development (akin to staking a mining claim). Upon the further determination by the State that the plans and techniques for such development will not have an undue impact upon other coastal ocean users, the State is empowered to grant a development license to the joint venture. In turn, the joint venture, under the terms of the development lease, could proceed with the development itself, sublicense the development to a mining operator, or sell the development lease, as a means of achieving an early return for its exploration investors. Upon commencement of the actual mining operation, the State receives royalties (as well as taxes) upon its operations. Assistance to the programs of other ocean users affected by or partners with the project can also be derived from the mining returns. All of these factors, of course, have to be considered in determining the overall economic feasibility of opening and operating the mine, once a suitable deposit has been located and characterized. This is the principal objective of the exploration program.

At this time, the joint venture has been established, the appropriate authorities have been identified and established by the State of Oregon, and a comprehensive coastal resources management plan is under development by the Ocean Resources Management Task Force, with a schedule for completion which provides that this plan will be in place in time to be used as a reference in any exploration or developmental lease entered into by the State. So far, the process has been working well, and excellent open relationships have been established between the project and other concerned ocean user groups. The writer and his associates believe that this approach will be an increasingly important one for all major coastal development projects, of which the Oregon black sands exploration and development is but one example.

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RECENT NONENERGY MINERAL ACTIVITY IN THE ATLANTIC OUTER CONTINENTAL SHELF

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ABSTRACT

Large deposits of sand and gravel, phosphate, titanium-rich heavy minerals, and manganese in the Atlantic Outer Continental Shelf (OCS) are available as future alternatives to onshore mining and importing. Several new developments concerning nonenergy minerals have taken place on the OCS during the last 2 years. These include seabed prospecting by industry, establishment of two Federal-State Task Forces to assess the likelihood of offshore mining, and release of studies on the economic feasibility of mining offshore North Carolina and Georgia. Although there are currently no commercial mining operations on the Atlantic OCS, sand is being commercially extracted from channels in New York Harbor, and it is dredged in State waters periodically for beach nourishment projects.

INTRODUCTION

The Atlantic OCS has large deposits of a number of mineral resources including sand and gravel, phosphate, manganese, calcium carbonate, ilmenite and other heavy minerals (figure 1). Sand and gravel deposits are nearly ubiquitous in the Atlantic, but the higher quality, cleaner deposits tend to occur north of New Jersey in glacial sediments. Inferred resources of 7.5×10^{11} cubic meters of sand have been estimated for the U.S. Atlantic continental shelf by Duane and Stubblefield.[1] Heavy minerals occur in older beach and strandline deposits in which extensive reworking of the sand has concentrated the heavier sand grain constituents. These deposits are known to exist in a number of places on the Atlantic OCS, but the most favorable sites are those offshore New Jersey, Virginia, and Georgia. Estimates of heavy minerals on the Atlantic OCS are about 1.3×10^9 cubic meters.[2] Phosphate deposits are known to exist offshore from North Carolina to Georgia and possibly even to Florida. Phosphate resources are estimated to be as high as 10 $\times 10^9$ tonnes offshore North Carolina[3] and at least that much offshore Georgia and South Carolina. Manganese occurs both as nodules and thin crusts in the Blake Plateau, and estimates range from 186×10^6 to 628×10^6 tonnes of ore.[4]

MINERALS EXPLORATION ACTIVITY

Two mining companies, DuPont and Associated Minerals, explored for heavy mineral deposits offshore Georgia in 1986. This involved gathering geophysical data and obtaining and analyzing core samples primarily for titanium-bearing minerals such as ilmenite, rutile, and leucoxene. In addition, there has been continuing low-level exploration and research on Atlantic OCS minerals by the U.S. Geological Survey (USGS), several universities, and a few State geological surveys. Recently, several cores obtained by the U.S. Navy for platform sites offshore of Georgia were analyzed for mineral content by the USGS and State of Georgia. These cores showed that the Middle Miocene phosphate-bearing sediments were richer and more widespread than previously thought.[5] Such efforts are resulting in the establishment of a sizeable offshore minerals database that will be of great importance in evaluating these deposits in the future.

NORTH CAROLINA TASK FORCE

A joint North Carolina-Federal Task Force was established in March 1986 to examine the likelihood of mining offshore phosphate deposits. The task force contracted a geologic, engineering, and economic study of the North Carolina continental shelf area, which was completed in December 1987. The study[3] addressed the potential size of the phosphate resources, the technology needed to extract and process the resources, the present and future phosphate markets both in the United States and the rest of the world. It also made discounted cash-flow economic analyses for a hypothetical mine site in Onslow Bay, North Carolina. The study estimated that as much as 99 billion tonnes of phosphate ore lie beneath the North Carolina continental

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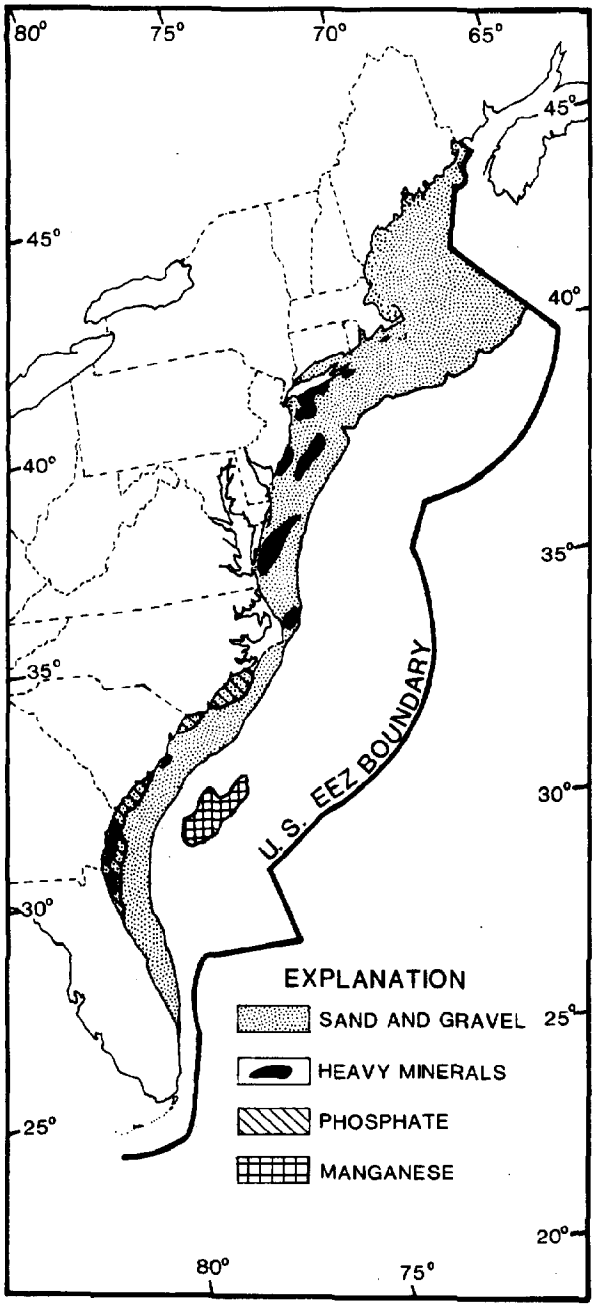

Figure 1. Location of major marine mineral deposits in the Atlantic OCS.

shelf, of which there are probably over 10 billion tonnes of recoverable concentrate averaging 7.3 percent P_2O_5. However, these estimates were based only on shallow drilling and ocean bottom sampling; deeper drilling will be needed to prove that these deposits contain reserves. Optimistically higher world phosphate prices and relatively low operating costs could result, according to the study, in a hypothetical, economically favorable mining operation in the late 1990's. The study determined that dredge mining would be more economically attractive than borehole mining. However, by assuming much higher phosphate prices in the next century, the study claims that borehole mining could become economically feasible. Borehole mining is far less disturbing to the ocean bottom than dredge mining. It provides a superior alternative for mine waste disposal and would allow mining areas where the overburden is too thick to excavate by dredging.

GEORGIA TASK FORCE

Organized in July 1986 by the State of Georgia and the Minerals Management Service in response to the mineral exploration activity offshore Georgia, the Georgia-Federal Task Force directed a study by an industry consultant of the geology, technology, and economics of mining phosphate and heavy minerals offshore. The study[6] identified a hypothetical mine site for phosphate about 6 miles east of Savannah Harbor and a similar site for heavy minerals about 30 miles southeast of Savannah Harbor. Similar to the North Carolina report, the study concluded that phosphate prices must rise from the current \$22-\$30/tonne to \$35-\$42/tonne for offshore mining to be profitable. Heavy mineral prices would have to rise from an average price (for five different mineral commodities) of \$127/tonne to at least \$152/tonne to economically mine these minerals offshore. Phosphate mining is considerably more capital intensive than heavy mineral mining both in processing and disposing of waste materials.

NORTH ATLANTIC SAND AND GRAVEL

Near future offshore mining activity for sand and gravel is most likely to take place in the North Atlantic. This commodity is already being shipped great distances by land into the major northeastern metropolitan areas and serious consideration is being given to importing it from Canada and Europe. Large quantities of sand and gravel occur less than 30 miles offshore of New York, Boston, and Norfolk. The only offshore commercial sand and gravel mining operation on the Atlantic coast is in New York Harbor. Here, a company is dredging the ship channel and processing the material for construction aggregate. Also, a number of coastal communities dredge sand from State waters for beach restoration or nourishment.

SUMMARY

Other areas of future potential for Atlantic offshore mining are Virginia (heavy minerals), New Jersey (sand and gravel and heavy minerals), and Florida (sand and gravel, carbonate sand, and heavy minerals). As onshore reserves are depleted and land-use pressures halt development of new mine sites, the offshore deposits will become increasingly important in maintaining domestic production of these minerals.

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EVENTS OF THE SUMMER OF '87

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ABSTRACT

In the summer of 1987 the shorelines of New Jersey were beset by a number of unusual environmental events. These included the beaching of dead and dying dolphins, unusually large amounts of debris washing ashore, and perceptions that the coastal zone was polluted and unsafe for swimming. A Blue Ribbon Panel was commissioned to study the events; its conclusions and recommendations are given.

INTRODUCTION

During the summer of 1987 the New Jersey shore was visited by numerous events that had untoward consequences. Large numbers of marine mammals, especially bottlenose porpoises, were washed onto the beach; more often than not these large animals were dead or dying. At the same time many beaches were found littered with debris of unknown origin. The floating and beached wastes consisted of garbage, wooden debris, petroleum contaminants, and various hospital wastes. Finally, measurements were made which occasionally indicated that bacterial contaminants existed in coastal waters and hence there was concern about the safety of swimming.

These various events were reported widely in the local and national newspapers as well as on local and regional radio and television. Merchants, resort owners, marina operators, and commercial and recreational fishermen were particularly vocal about the reported events. The New Jersey Department of Environmental Protection (DEP) frequently came under fire for not being able to evaluate fully the situation, or for not doing something.

In most instances, there was relatively little that could be done immediately. Like many marine scientists, the personnel of the New Jersey DEP understood fully that the debris could have come from literally hundreds of sources, including many from out-of-state. While marine mammals, including porpoises and whales, are quite large and fairly commonly sighted, and continue to be of interest to the public, relatively little is known about their biology, and very little is known about their diseases or the causes of disease in such animals. Although routine monitoring of the New York Bight has been done by state, local, and federal agencies, in recent years shortages of personnel and funds for monitoring studies have resulted in a relatively low level of monitoring activity. Consequently, sources and fates of pathogens and toxic substances, and their effects, are still poorly known in the overall New York Bight.

In late 1987 the Commissioner of the New Jersey DEP, in response to the events of the summer of 1987, decided to commission an independent Blue Ribbon Panel which would review what had transpired the past summer, evaluate the relative importance of the various events, and provide advice to the State as to what had happened and what could be done in the future to ameliorate such events and their effects.

THE FINDINGS OF THE BLUE RIBBON PANEL

The Panel, consisting of over a dozen scientists, managers, and citizens from various agencies and backgrounds, met early in January 1988 to develop the thrust of the studies to be done. It was decided early-on that the Panel would review to the degree possible all information related to the events of the summer of 1987, look at various generic studies that might relate to such events, commission certain independent investigations and analyses, and, based on these, develop syntheses which would allow conclusions to be reached and recommendations to be made.

During the second meeting of the Panel, public hearings were held in Asbury Park and Atlantic City so that the concerned citizenry, political entities, scientists and managers, and local business leaders could bring to the attention of the Panel their various views on the events. Several hundred individuals participated in these hearings. Following the hearings, and between major meetings, the Panel continued to work on an intersessional basis. Studies and reviews were done in regard to water and contaminant movement as they might be related to wind direction and strength. Public health officials considered the matter of debris on the beaches and its possible relationship to contagious diseases. The general matter of water quality and its relation to local surface drains and industrial and domestic

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outfalls were reviewed. Full consideration was given to the relevance of the events of the summer of 1987 and effects on living marine resources.

The four subsequent meetings and numerous ad hoc gatherings provided an opportunity for thorough discussions of the issues and for the interrogation of State officials who had been or continued to be involved in matters relating to the summer of 1987.

From the meetings and associated studies and seminars, the Panel reached specific conclusions, developed a series of recommendations to be considered by Commissioner Dewling, Governor Kean, other state officials, and the public, and incorporated these in a Report[1]. The conclusions in the Report are as follows:

o Stranding and Deaths of Marine Mammals: The hypothesis that the deaths of the bottlenose dolphins could be attributed to pollution in the New York Bight or New Jersey coastal waters during the summer of 1987, was not supported by evidence presented to the Panel.

o Water Quality: The Panel concurred with the public and the DEP that problems with coastal water quality are of the utmost importance and must continue to receive the attention of local, state, and federal agencies. Closures of shellfish beds for harvest, occurrence of fish diseases such as finrot, and the accumulation of chemicals such as PCBs and dioxins in fish and shellfish are indicators of persistent water quality problems in the New York Bight, especially the nearshore waters.

o Waste Disposal: The Panel realized the importance of this issue and concluded that there are many sources and many ways of reducing the amount of wastes deposited into the marine environment. The evidence suggested a need for enforcement of existing regulations and for far more concern by local governments and the citizenry in regard to beach management.

o Hospital Wastes: Hospital-type wastes including syringes, I.V. bags, and gauze dressings were reported to be part of the beach litter during the summer of 1987; the Panel, with appropriate public health input, concluded that it is virtually impossible for a person to contract AIDS or other diseases through any form of beach litter subjected to ocean conditions for several days.

o Ocean Dumping of Sewage Sludge: Ocean dumping occurred in coastal waters for over a half century at the "12-mile site" within the New York Bight Apex. There continues to be great concern about ocean disposal of sewage sludge at the "106-mile site" beginning in 1987. The Environmental Protection Agency (EPA) designated the 106-mile site for disposal of sewage sludge for a period of 5 years, ending in 1991. The EPA may redesignate the site provided that the effects of such dumping are deemed acceptable.

o Floatables: Floatables were deemed highly visible and unacceptable. Reports of "garbage slicks," plastic floatables, and tar balls are not unique to New Jersey and are a worldwide problem. A review of research papers and reports indicated that floatables and beach litter have multiple sources, including: refuse resulting from beach use; combined sewage outfalls; poorly managed landfills; materials jettisoned from small and large vessels; and oily substances which originate from industrial sites, roadways, and airports, as well as railways and vessels. The Panel concluded that far higher volumes of floatables existed in the New York Bight and coastal waters than in many other coastal areas. The way to reduce floatables is to control them at their source.

o Ocean Disposal of Contaminated Dredged Materials: Feasible alternatives to present disposal practices of contaminated dredged materials include: borrow pit disposal, capping, use of dredged materials for sanitary landfill cover, and containment islands. The Panel concluded that implementation of alternative methods for the disposal of contaminated dredge materials will have great bearing on the improvement of coastal water quality.

o Industrial Waste Pretreatment: The Panel concluded that a technologically sound, comprehensive, and strictly enforced pretreatment program is absolutely essential for short- and long-term improvement of water quality along the coast of New Jersey. It is important that the wastes reclaimed by pretreatment be reused, recycled, or disposed of in an environmentally safe manner.

o Variability in Natural Processes: The Panel concluded that acts of nature played a major role in the events of 1987. Wind patterns during the summer of 1987, were different from the patterns generally observed from 1948-1986. These patterns intensified the garbage and other waste washup problems on beaches during 1987.

o Consumption of Seafood: The Panel recognized that persistent water quality problems affect the perceived wholesomeness and quality of some fish and shellfish. There is no evidence to suggest that the events of 1987 contributed to these problems. The DEP has comprehensive monitoring programs in place; the Panel made recommendations aimed at improving these programs and improving the quality and abundance of fishery resources in New Jersey.

o Enforcement: The Panel concluded that the present enforcement of existing conservation and environmental laws and regulations is inadequate to ensure protection of public health, as well as that of marine and coastal resources.

o Education: One of the elements missing from the New Jersey DEP's existing programs is a coordinated, highly visible effort to educate citizens about coastal issues and to increase public participation in the regulatory process.

This program should include information on development, pollution, and resources as well as potential solutions to major problems in this important zone.

o Development: The Panel regarded the rate and type of construction and coastal land use as the most critical issues facing New Jersey. The density of development and the intensity of land and water use along the islands, bays, and estuaries of New Jersey place exceptional pressures on aquatic ecosystems and the living resources. The issues often revolved around waters and their uses but the solutions must be found on land.

o DEP Coordination: The Panel believed that the DEP should more carefully coordinate its several activities related to coastal issues.

o Coastal Commission: Although the Panel was not asked to review specific proposals for a coastal commission, it recognized that some of the recommendations that follow can be addressed by the proposed coastal commission.

o Research: The Panel recognized that there must be a coherent, state or interagency supported ocean research and monitoring program to achieve an understanding of complex ocean and estuarine systems. Such an understanding is essential to a future multiple-use management strategy.

The recommendations developed in relation to the conclusions of the Panel touched on aspects of development, water quality, coastal ocean public health issues, control of litter and hence floatables, enhancements of fisheries resources and their habitats, increased enforcement of regulations, increased education at all levels of society, and coordination of activities to improve the wellbeing and usefulness of the coastal zone. Page limitations prevent listing the recommendations in detail. The following are, however, some of the more important highlights of the Panel's recommendations:

o The density of development on the coast should be lowered. Future development must be limited to areas presently providing adequate infrastructure, utilities, and services. New growth should not occur in undeveloped, environmentally sensitive areas.

o Local zoning ordinances must be sensitive to environmental values and strictly enforced to control urban sprawl.

o Direct runoff of contaminant and debris laden waters into coastal waters should be prohibited and prevented.

o The DEP should work toward improving public systems designed and implemented to control pollution caused by land development.

o The DEP must work with the appropriate agencies and industry to reduce or eliminate the problems caused by outfalls that combine sewer and storm water runoff, i.e., combined sewer outfalls.

o The DEP must consider the development of alternatives to ocean dumping and make appropriate recommendations to communities and agencies which use dumping.

o The Panel highly recommends that the State address the problems of continued release of toxic chemicals into the coastal environment by improving research, monitoring, permitting, and enforcement components of its existing industrial waste pretreatment program.

o The Port Authority of New York and New Jersey must take a vigorous leadership role in the planning of future dredged material disposal facilities and sites.

o Consideration should be given to expanding the number of variables monitored and to developing a more statistically sound sampling program.

o Data management systems for monitoring should include adequate quality assurance/quality controls.

o The state and Federal agencies must develop monitoring criteria for unreasonable degradation that are agreed to, published, periodically reviewed and updated, and enforced.

o The DEP must continue to improve its monitoring programs for toxic chemicals in marine organisms and for microorganisms in shellfish and habitats.

o It must be required that sanitation (toilet) facilities be located at beaches in sufficient numbers to handle all beach users.

o The DEP in coordination with the counties and Department of Health as well as the U.S. EPA should continue beach monitoring efforts at crowded beaches, for bacteria and other indicator organisms.

o Lifeguards, beach administrators, and beach cleaning personnel should be educated by State officials (DEP and DOH) prior to the bathing season in regard to issues concerning public health and water quality issues.

o The DEP must require an increase in the number of vessel sanitary pumpout stations in the backbays and estuaries.

o The DEP must work with the legislators and sewerage authorities to improve operation and maintenance of all sewage treatment plants.

o The DEP must continue to develop and enforce statewide standards for municipal public works activities such as drain cleaning and street sweeping; storm drains must have trash collectors.

o The DEP and the Attorney General must continue to work with the State of New York and New York City to improve solid waste handling practices at transfer points within N.Y.C.

o The DEP and the Attorney General must work toward increasing penalties, and strengthening and enforcing the littering laws.

o The DEP or local agencies should provide sufficient litter containers and trash receptacles, and litter control grants (under strict regulations and guidelines) should be made available to municipalities.

o Manufacturers of packaging, and especially floatable products, should be encouraged to develop alternatives.

o The DEP should continue to support an aggressive recycling program for glass, cans, and plastics.

o The majority of the Panel believed that having a container deposit bill will reduce the amount of litter on the beaches.

o The DEP must commit sufficient financial resources for research in shellfish contamination to determine the most effective strategy for preventing both potential public health risks and resource degradation.

o The Panel recommended that a thorough review of all State of New Jersey environmental and conservation laws be undertaken and provisions made for more stringent interpretation, stiffer penalties, and timely judicial processing.

o Building upon the Environmental Education Act of 1971, the DEP should initiate a program with the Department of Education to educate all citizens about ocean issues.

o The DEP should institute a position in the Commissioner's Office for a Coastal Activities Coordinator and an Advocate.

o The Coordinator would be responsible for preparing an annual agenda for ocean research which would assist the DEP to achieve its mission.

The reader can see that the Panel stressed the importance of enforcement, education of the general citizenry, future monitoring and research, and the necessity somehow to manage development in the future so that it will have minimal effects on coastal resources and other uses of the coastal zone. Of special note is the recommendation to regulate or license development so that it occurs in areas already developed and serviced with proper infrastructure, including roads, high levels of sewage treatment, and mass transport systems. The Panel recognized that while the issues develop in aquatic habitats and involve fish and people, solutions can only be found in limiting development and managing habitats on the land mass.

Without limits on development and without proper management of terrestrial habitats it will be impossible to prevent continued degradation of riverine, estuarine, and coastal habitats and the many amenities associated with them.

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IMPACTS AND IMPLICATIONS OF THE SUMMER OF 1987, NEW JERSEY FLOATABLE INCIDENTS

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ABSTRACT

The New Jersey coastal area suffered from a number of cascading pollution incidents during the Summer of 1987. The various incidents are described and observations are made on the resultant public policy initiatives, the implication for the shore economy, and the need to focus on long term solutions.

The events along the New Jersey coastline during the Summer of 1987 have set the stage to bring ocean pollution to the forefront as one of the preeminent environmental issues facing the Nation. The coastal waters of the New York Bight have long been plagued with anthropogenic inputs such as floatables, nutrient enrichment, and contaminated water in the surf zone. Prior to 1987, coastal pollution was of local concern and lacked national significance. However, on August 13, 1987 a 75 mile long slick of refuse, timbers, and hospital waste washed ashore on New Jersey's premier beach communities. The insult of syringes, hypodermic needles, blood bags, and bandages was repugnant to the beachgoers, public officials and the community at large. This event, in combination with the concurrent dolphin deaths and beach closings attributed to bacterial contamination, galvanized the public's disgust with ocean pollution and catapulted the issue into the national limelight.

Initially, the public response was to seek out and prosecute the individuals responsible for this despicable act. When a "smoking gun" could not be identified, it became more apparent that the region's waste disposal practices, or lack thereof, were largely responsible for the hospital-like waste in the coastal ocean.

The floatable incidents of 1987 mark a turning point in our resolve to improve the health of the ocean. But is it possible to eliminate or reduce ocean pollution without first solving the myriad of problems associated with management of waste streams on land? The New York Bight directly or indirectly receives pollution resulting from the day-to-day activities of over 20 million people.

During the summers of 1987 and 1988, veteran beachgoers in New Jersey and on Long Island have noted that the water in the surf zone has never been so filthy. A valid question is why now, why not five, ten, or twenty years ago? The States of New York and New Jersey and the federal government have recently taken a number of actions designed to improve water quality in the Bight and in the Hudson-Raritan Estuary. For example:

- New York City has eliminated the discharge of 225 mgd of raw sewage by placing two new sewage treatment plants on line.

- All of New Jersey's coastal sewage treatment plants are now operating at a secondary level of treatment.

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- Sewage sludge disposal has been relocated from the Bight Apex (12-mile Site) to a new site off of the Continental Shelf (106-mile Site).

- The cyclical nature of dredging has resulted in a significant downturn in the volume of dredged material being disposed of in the ocean over the past several years.

- All but one industrial permittee has phased-out ocean disposal of waste materials.

Other factors have not changed substantially in recent years. The region's storm drains, combined sewers, and overland drainage have not been radically altered. As a society we continue to produce solid waste, litter at will, and use fertilizers and pesticides without hesitation. Non-point sources of water pollution are now being recognized as a major contributor to coastal and estuarine water quality degradation. But these factors in themselves don't explain why our beaches have suddenly turned filthy.

Probably the best explanation of the current state of affairs is the variability in natural processes. Dr. Lawrence Swanson will shortly present a paper on the meteorological conditions which lead up to the garbage and medical waste washups on the New Jersey Shore during the Summer of 1987. In previous work he concluded that ..."During summer months prevailing winds have a pronounced effect on the distribution and fate of floatables"[1] It is interesting to note that during the Summer of 1988, New Jersey's beaches have been relatively free of floatable incidents while New York City, Long Island, and even New England beaches have taken a beating from washups of medical wastes.

Wind patterns and other meteorological conditions cannot be legislated. However, there has been heightened political interest in responding to the coastal incidents of 1987. Over one hundred bills and resolutions were quickly introduced into the New Jersey legislature. Governor Thomas H. Kean proposed a 14-point Action Plan to Preserve New Jersey's Ocean and Beaches. Hearings were held and bills introduced in Congress. The New Jersey Department of Environmental Protection and the New Jersey Attorney General's Office took steps to learn about the nature of the floatables problem and take corrective actions to minimize similar ocean incidents in the future. Some of the legislative proposals were farsighted and necessary, others sought a "quick fix" based on an oversimplification of the problem.

On balance, the legislative process seems to be working well by providing the regulatory agencies with the tools necessary to address a complex set of issues. Existing regulatory and resource management programs as well as the initiation of lawsuits have also been utilized to protect the coastal ocean from further degradation. The following is a list of significant actions which have been taken since the Summer of 1987:

- The Commissioner of the NJ Department of Environmental Protection formed a Blue Ribbon Panel to report on the ocean incidents of 1987. In May of 1988, the Panel issued a report, State of the Ocean. The Report provided an independent scientific viewpoint on the incidents and made many far ranging recommendations. Dr. Jack Pierce served as the Panel's chairman (Dr. Larry Swanson also served as a panel member).

- In November 1987, New York City entered into a consent agreement with the State of New Jersey to improve its management practices with respect to solid waste which could end up in a waterway.

- State legislation was enacted to beef-up New Jersey's Marine Police.

The emphasis of the legislation is to establish a presence in the Port of New York/New Jersey for the purpose of surveillance and enforcement against marine polluters.

- State legislation was enacted to make intentional dumping of materials in coastal waters a criminal offense in New Jersey.

- State legislation was enacted to prohibit New Jersey communities from the disposal of sewage sludge in the ocean after March 17, 1991.

- The United States Senate ratified MARPOL Annex V which will prohibit overboard disposal of plastics from ships in international waters and strictly regulate other forms of solid waste disposal by ocean going vessels.

- Federal legislation was enacted to implement MARPOL Annex V, require EPA to study methods to reduce plastic pollution, and have EPA prepare a New York Bight Restoration Plan.

- The EPA Administor selected the New York - New Jersey Harbor for inclusion into the National Estuary Program. A Management Conference will be convened to develop a Comprehensive Conservation and Management Plan.

In addition to the above, there are a number of pending State and Federal legislative initiatives designed to reduce ocean pollution, especially floatables. These include:

- legislative proposals to track medical waste so as to ensure proper disposal

- federal prohibition of ocean disposal of sewage sludge after 1992.

- legislation by the State of New Jersey to expend $125 million to upgrade stormwater management systems in coastal areas and correct combined sewer overflows in urban communities within the Hudson Raritan Estuary.

The ocean incidents of 1987 have had a devastating effect on the State of New Jersey. Coastal tourism and recreational activities along the coast contribute between $7-8 billion to the State's economy each year. Tourism has become the State's number one industry. There is no absolute method to estimate the economic losses attributable to pollution, beach closings, or the current negative image of the Shore. In 1988, merchants and businessmen estimate that business is off by as much as 30%. Although the downturn in the shore economy is primarily the result of continued coastal incidents and media "hype", many other factors can influence a person's decision to spend a day or a week at the shore. The high cost of summer rentals, traffic congestion, crowds, or poor weather are but a few factors that are taken into consideration.

The events of 1987 could have easily been forgotten in the public's mind if it were not for the medical waste and the resulta : fear that swimming could lead to illness or disease. Medical waste has tarnished the image of the Shore, and more importantly, the image of the entire State. The citizens of New Jersey take great pride in the beautiful beaches of the New Jersey Shore. The State has worked hard to reverse a once negative image. Now, those relatively few incidents, many of which have been overexaggerated, have done untold damage by violating the State's greatest natural resource.

Unfortunately, the prospect of economic recovery for the Shore in 1989 and the following years rests more with the variability of natural processes

than by the legislative juggernauts in Trenton, Albany, and Washington, DC. Tracking medical waste through a manifest system or imposing criminal sanctions for improper disposal does not get to the heart of the problem. Very simply the New York Metropolitan area has run out of adequate facilities within reasonable distances to dispose of or recycle all types of solid waste. What will New York City do when the Fresh Kills Landfill runs out of space? Virtually all of the solid waste produced in Northern New Jersey is trucked to out of State landfills. The likelihood for new facilities being sited and on-line is not encouraging at this time. Community resistance and the not-in-my-backyard syndrome have delayed much needed resource recovery plants on both sides of the Hudson. The prospect of siting incinerators for infectious medical wastes and municipal sewage sludge is equally dim.

The floatables that washup on our beaches are simply the artifacts of a society that has not come to grips with the management of all types of wastes. The ocean will become free of pollution only when the people of the region finally accept the risk of having facilities in their backyards and are willing to pay the price for decades of neglect.

1. The Blue Ribbon Panel on Ocean Incidents - 1987; THE STATE OF THE OCEAN; May, 1988; Appendix I - Floatables, by R L Swanson; New Jersey Department of Environmental Protection.

METEOROLOGICAL CONDITIONS LEADING TO THE 1987 WASHUP OF FLOATABLE WASTES ON NEW JERSEY BEACHES AND COMPARISON OF THESE CONDITIONS WITH THE HISTORICAL RECORD

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During the summer of 1987, the New York Bight and the larger Mid-Atlantic Bight once again experienced a series of incidences whereby waterborne floatable waste materials and debris were stranded along beaches from New Jersey to Virginia. Of particular concern were the stranded carcasses of dolphin and hospital wastes. Examinations of the local climatological data help to explain the process by which floatable material was transported shoreward. Concern however exists that, short of eliminating the sources, the events of 1987 portend beach conditions of the future.

The climatology of the summer of 1987 is compared with that of 1976 when similar strandings of floatable wastes occurred on the south shore of Long Island. The summer wind record of these two years is also compared with the historical wind record 1949-1987. These analyses indicate the unusual nature of conditions that prevailed in both 1976 and 1987 and how they differed from each other. While major washups of floatable wastes are unusual we now know under what conditions they are likely to occur. Emphasis must be placed on alleviating the problem at the sources.

In the summer of 1987, the New York Bight and the larger Middle Atlantic Bight once again experienced a series of incidences whereby waterborne floatable waste materials and debris were stranded along beaches from New Jersey to Virginia. Of particular concern were the stranded carcasses of dolphin and hospital wastes. These events rekindled the overall attentiveness to the issue of water quality in our marine waters and how we might relieve the stress placed upon them.

During the summer of 1976, the wash-up of floatables was so extensive along the south shore of Long Island that the Governor of New York declared Nassau and Suffolk counties disaster areas. The President assigned the Job Corps, under the supervision of the U.S. Coast Guard, to clean the beaches.

There were a few unusual sources of materials that contributed to the 1976 incident (i.e., a sewage sludge tank explosion in Hempstead Bay and pier fires in the Hudson-Raritan Estuary); it has been established that there were unusual incidents in 1987 as well. Specifically, this past summer there were several cases of illegally disposed municipal and hospital wastes. However, the bulk of noxious materials continue to reach Bight waters and beaches from the same sources in 1987 as in 1976. These include combined sewer outfalls (CSO) from the New York-New Jersey metropolitan area and poor solid waste handling practices at transfer points as well as during transport in the Hudson-Raritan Estuary and at the Fresh Kills Landfill. Other contributors include commercial and recreational boats, and outflow from bays and estuaries.

The larger floatables typically do not occur in quantity in sewage sludge as they are effectively screened. With regard to finding floatable wastes (particularly tampon applicators) associated with sewage sludge dumping, it should be pointed out that previous investigations have led to negative results. That is, essentially none have been recovered when using neuston nets to skim the surface waters behind sludge dumping vessels. In the 1976 investigation, with the use of marketing statistics, estimates of potential inefficiencies in the sewage treatment system, and knowledge of oceanic transport processes, it was estimated that only 7% of the tampon applicators recovered on the beaches were, theoretically attributable to ocean dumping.

The Hudson-Raritan estuary serves as the greatest source of floatable waste to the Bight since the bulk of the individual sources tend to be located around the periphery of the estuary.

Floatables are effectively flushed from the estuary during the time of the spring freshet, typically from March to May in the upper Hudson. The impact of the freshet on the Bight lags this by about one month so that large quantities of floatables can be expected to be flushed into coastal waters at or near the time of the commencement of the summer beach season. Other than at the time of the spring freshet, the floatable load at any one time in the estuarine plume is largely a consequence of the relatively recent rainfall history. A heavy rain following an extended dry period will most likely produce the heaviest volume of floatable material; streets will be cleansed, sewage treatment plants bypassed, and the transfer points and landfills flushed by runoff and perhaps higher storm high waters. It takes a rainfall intensity of only a few hundreths of an inch per hour for an hour or more in the metropolitan area for sewage treatment plants to be bypassed.

Once floatable materials are flushed into the Bight, they are subject to the physical oceanographic and meteorological processes operating on Bight waters. Most frequently they will be carried preferentially with the Hudson-Raritan estuarine plume along the New Jersey coast. This is why the beaches at Sandy Hook are so often cluttered with undesirable materials.

The general flow of surface waters over the continental shelf is from the northeast to the southwest parallel to the trend of the coast. Floatable materials in the surface layers are transported with these currents but also influenced by wind driven transport.

During summer months prevailing winds have a pronounced effect on the distribution and fate of floatables. Typically the prevailing wind is from the south or southwest. These winds tend to transport the floatables to the north and east. Thus floatable materials will tend to be well disbursed - some lost at sea, others creating the general clutter that we have objected to on both New Jersey and Long Island beaches.

In 1976, the prevailing summer wind field intensified and was extremely persistent for a period of two weeks (9-25 June), driving the floatable material northward and eastward and eventually ashore on Long Island. This wind condition was an important aspect contributing to the large-scale oxygen depletion in Bight bottom waters later in the summer. The winds created a reversal in current flow in bottom waters and transported a subsurface bloom of phytoplanktons acros the shelf which converged on the New Jersey coast. Oxygen replenishment was inhibited in bottom waters and the massive bloom created an excessive oxygen demand. The floatable load was heavy because of extremely large river runoff in May.

In 1987, the New Jersey Department of Environmental Protection has indicated that the wash-up of floatable material was prevalent during the periods of 27-29 May, 13-16 August. Also during the periods 3,4 and 9,10 September, heavy concentrations of floatable material was observed <u>off</u> the coast of New Jersey.

The May incident was preceeded by the flushing action of the spring freshet of the Hudson River. Based on river stage data at Green Island, the peak flow is estimated to have reached the Bight in early May. Easterly to southeasterly winds occurred over much of 18-27 May (Figure 1), driving the recently flushed floatable material back toward the New Jersey coast.

Easterly to southeasterly winds dominated the period of 5-14 August (Figure 2). Further, between 3-10 August, there was rainfall in excess of two inches in the metropolitan area which undoubtedly thoroughly flushed the streets, combined sewers, and other major sources of floatables. Thus there were meteorological conditions that led to heavy concentrations of floatables along the New Jersey coast this past summer. Streaks of floatable material were observed on two occasions just off the coast in early September but in neither instance did the material wash ashore in appreciable quantities. On 31 August and 1 September a total rainfall of 0.6 in. was recorded at J. F.Kennedy (JFK) Airport. Over the period 6 - 8 September another 0.8 in. of rain was recorded. Easterly winds blew much of the time between 4 - 8 September (Figure 3). Thus there was the potential to wash materials into the Bight and then ashore during the period of concern. For comparison see the progressive vector diagrams for the months of June and July 1987 (Figures 4 and 5). The winds were by and large to the north and offshore. Floatables were not reported as a problem during June and July.

Review of the 1987 summer climatological information suggests that the normal southerly to southwesterly wind field was less persistent and less

energetic than normal. Throughout the summer the normal wind field was interrupted with winds from the east and northeast. As a consequence of the less energetic winds, the northeasterly to southwesterly flow of surface waters was intensified. The Hudson-Raritan River plume stayed closer to the New Jersey coast than is typical of these months. Currents and their loads of floatables veered shoreward in response to the winds from the east and northeast.

Review of the wind records relative to the historical record (1949 - 87) and the reference period (1949 - 73) indicates that the 1987 winds were on an average considerably different. For example, see Figures 6 and 7 that display the progressive vector diagram of the monthly resultant winds for the period May through September and June through August. The resultant vector for both the five month and three month cases are considerably shorter and slightly west of the 25-year mean resultant vector. Statistically the lengths of the resultant vectors for the two periods are significantly different from the mean of the two series (historical record and reference period). The direction, however, is not. These conditions are indicative of the winds, having blown from easterly and northerly quadrants more than usual.

Meteorologists use a measure called "constancy" as an indicator of the persistence of the wind blowing from a given direction. The higher the value, the more persistent the wind; a steady wind would have a constancy of 100. The 25-year norms for June, July and August at JFK Airport are tabulated in Table I along with the corresponding values for 1976 and 1987. The lower values of the constancy in 1987 suggest that the wind was more variable about the mean direction and that the wind did not just blow from the same southerly to southwesterly direction, but with less intensity. These data indicate two unusual but totally different wind fields. Thus stranded floatable material would be expected to be greater than normal for each of the years but in one case, on Long Island, on south shore beaches and in the other on New Jersey beaches.

Interestingly, the meteorological conditions of 1987 contributed to relatively high dissolved oxygen levels in nearshore bottom waters in the Bight. Thus while aggrevating the floatable situation in New Jersey, the summertime climate also improved the health of bottom waters in 1987. Essentially, however, if floatable material was in the surface waters of the Bight, there was a good possibility that it would be washed ashore. This would also include carcasses of bottle nose dolphins that may have died of natural or other causes.

Table I. a. Wind constancy for the months of June, July and August for 1976 and 1987 compared with the 25-year norm, 1949-73.

b. Wind energy for 1976 and 1987 expressed as a percentage of the norm, 1949-73.

a. Constancy (%)

Month	Norm	1976	1987
June	31.9	55.3	26.2
July	39.1	38.8	28.7
August	28.1	23.3	13.1

b. Energy (%)

June	100	104	84
July	100	104	67
August	100	129	94

A major fact is that floatable wastes are ubiquitous in the New York Bight. The sources of floatable waste in the New York Bight are primarily from combined sewer outfalls, poor solid waste disposal practices, commercial and recreational boats, and outflows from bays and estuaries. Occasionally accidental spills, illegal discharges, etc., will add to the normal heavy floatable load. Source reduction and more intensive beach clean-up endeavors are the only solutions to the problem as meteorological and oceanographic conditions will often tend to intensify the quantity of floatables on the beaches. Ocean disposal of sewage sludge at the 106 nautical mile site is not a significant contributor to the floatable problem.

Certain technological improvements should be explored to reduce the quantities of floatable waste reaching marine waters:

- Improve operation and maintenance of sewage treatment plants,

- Strive to reduce or eliminate combined sewer overflows,(CSO),

- Explore more thoroughly,alternatives for isolating material released to the marine environment by combined sewer overflow,

- Continue to improve the process of removing litter and floatable debris from streets and other paved areas served by combined sewer systems,

- Improve solid waste handling practices aimed toward recycling and the use of wastes as an energy source,

- Improve the process of transferring materials to landfills and reduce the volume of material escaping to estuarine,and marine water from landfills, and

- Intensify removal of floatable materials from area beaches to reduce

Figure 1

PROGRESSIVE VECTOR DIAGRAM

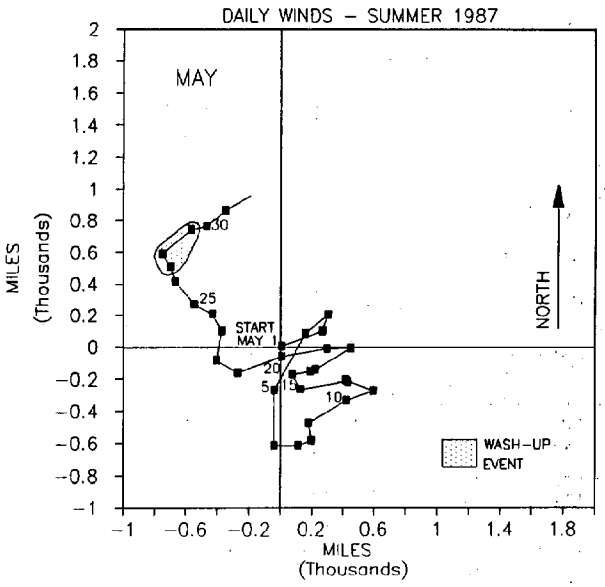


Figure 2

PROGRESSIVE VECTOR DIAGRAM

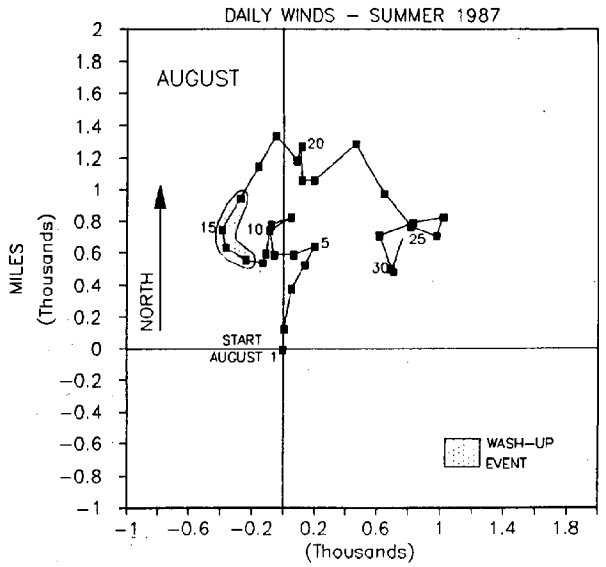


Figure 3

PROGRESSIVE VECTOR DIAGRAM

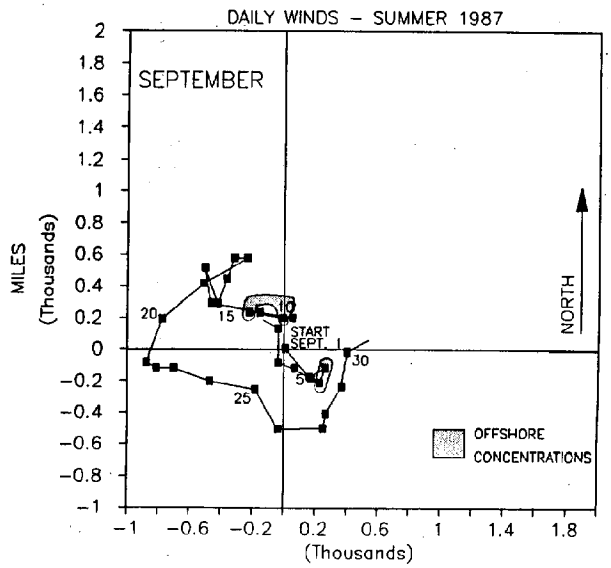


Figure 4

PROGRESSIVE VECTOR DIAGRAM

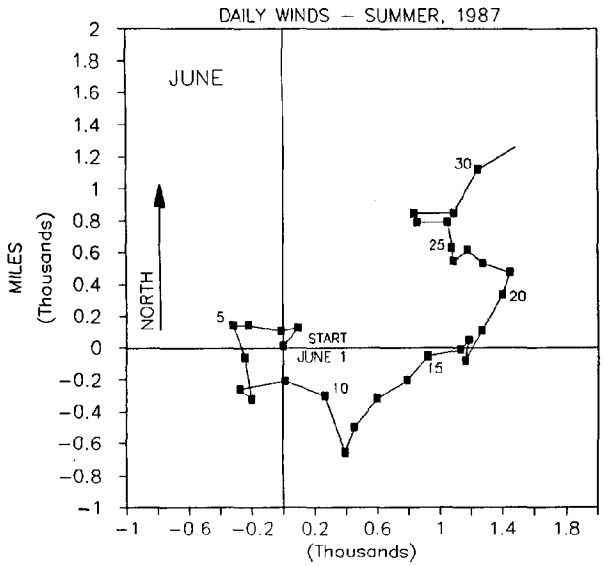


Figure 5

PROGRESSIVE VECTOR DIAGRAM

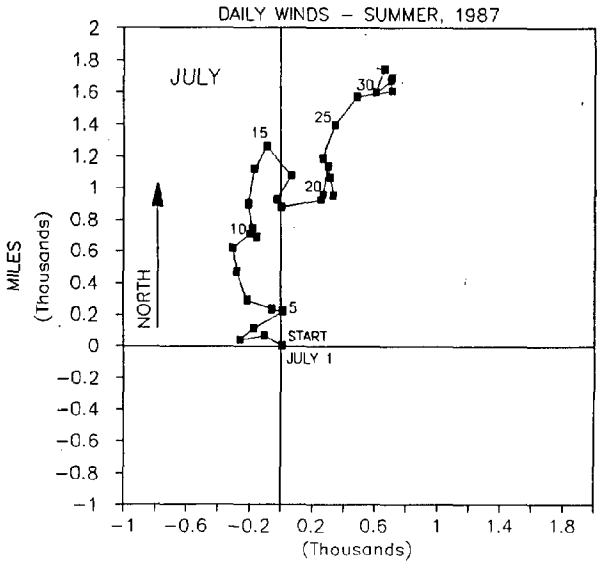


Figure 6

ANNUAL P.V.D. OF MAY – SEPTEMBER
AIR MASSES, 1949 TO 1987

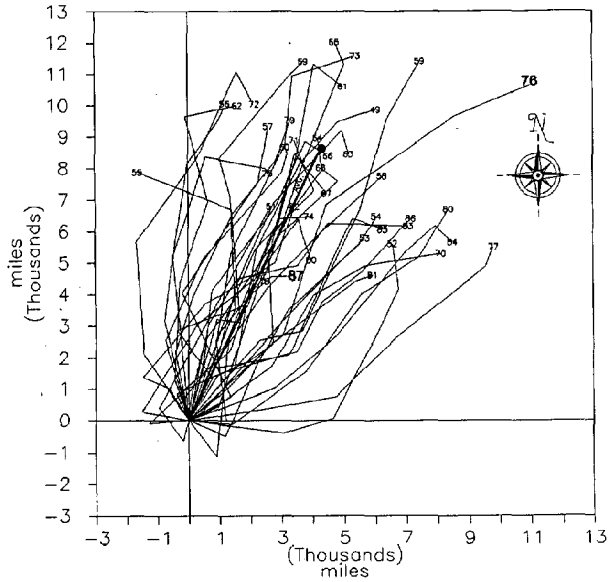
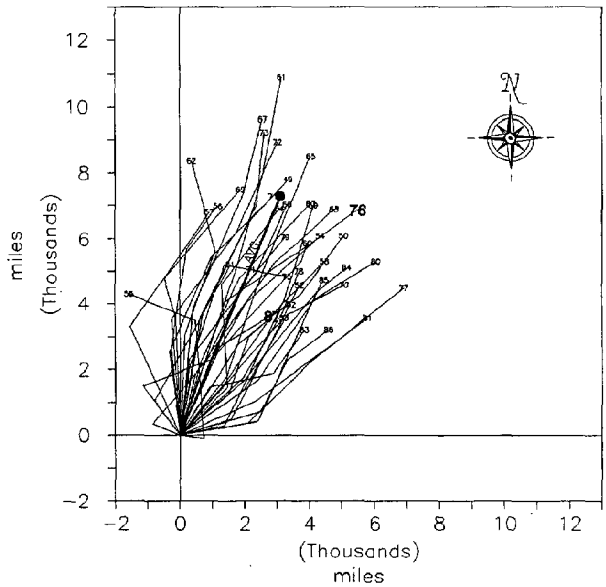


Figure 7

ANNUAL P.V.D. OF JUNE– AUGUST
AIR MASSES, 1949 TO 1987



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UNUSUAL INTENSIFICATION OF CHESAPEAKE BAY OYSTER DISEASES DURING RECENT DROUGHT CONDITIONS

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ABSTRACT

Two protozoan parasites of oysters, Haplosporidium nelsoni (MSX) and Perkinsus marinus, have severely limited the harvest of oysters in lower Chesapeake Bay during the past 30 years. The distribution and abundance of both parasites appears to be regulated by salinity and the three consecutive drought years from 1985-1987 have resulted in a dramatic increase in mortality from these diseases in Chesapeake Bay. Oyster mortality from MSX in monitoring trays at VIMS was 77% and 78% for 1986 and 1987 respectively, the highest values ever recorded in 28 years of continuous monitoring. In addition, Perkinsus was at record high levels and, for the first time in history, both diseases invaded and caused serious mortality in the upper James River seed-oyster area. The increased salinity resulting from low runoff over the watershed allowed both diseases to spread deep into the Maryland portion of the Bay in 1987 and cause serious mortality. Bay-wide oyster stocks are now severely depressed and prospects for rapid recovery are poor.

INTRODUCTION

Two protozoan parasites of oysters, Haplosporidium nelsoni, popularly called MSX, and Perkinsus marinus, popularly, but improperly, called Dermo, cause serious annual oyster mortality along the Atlantic and Gulf coasts of the United States. MSX causes oyster mortality from Massachusetts to Chesapeake Bay (1), and an organism similar to MSX has been reported as far south as Florida (2). Perkinsus causes mortality throughout Chesapeake Bay, south along the Atlantic coast, and in the Gulf of Mexico (3).

MSX first appeared in Delaware Bay in 1957 and spread to the lower Chesapeake Bay in 1959. Perkinsus has probably always been endemic in high salinity portions of the Bay and has caused significant, but tolerable, mortality. However, within a few years of the appearance of MSX the annual Virginia oyster harvest decreased from an average of about 3.5 million bushels to less than 1 million bushels (Figure 1). The industry in Virginia has never recovered. During the 1960s mortality was high on public oyster grounds, but hardest hit were the private planters who had been producing about 85% of the annual harvest. MSX causes about 50% annual mortality in the endemic area (4), and this rate is intolerable for transplanted seed stocks that require two or three years to mature to marketable size. All of the traditional private growing areas in the lower James River and Mobjack Bay have been abandoned since the early 1960's because of the continued presence of MSX.

The distribution and abundance of both diseases appear to be controlled by salinity. In years with normal rainfall, MSX is restricted to the lower Bay and the lower portions of tributaries south of the Rappahannock River (4). During periods of drought, MSX may spread throughout upper Virginia and many Maryland tributaries into populations of highly susceptible oysters, but it recedes as rapidly when salinity returns to normal. MSX requires about 15 ppt salinity to infect oysters and usually does not cause serious moralities unless summer salinity reaches 18 to 20 ppt (4, 5). However, these limitations are coupled with seasonal fluctuations in salinity that allow expulsion of the parasite in spring if salinity drops below 10 ppt for ten days or more (6, 7).

Perkinsus marinus requires only about 12 to 15 ppt salinity to infect oysters and cause mortality (3, 8). Therefore, it has a far wider endemic area than MSX and persists in nearly all Virginia tributaries and also in the lower portions of Maryland. Furthermore, Perkinsus is suppressed but not easily exterminated by low salinities. It can persist several years at low seasonal salinity without causing appreciable mortality. Nearly all oyster growing areas reach 12 to 15 ppt salinity during average summers, which allows some multiplication of Perkinsus.

METHODS

The annual abundance of MSX in the endemic area is determined by placing susceptible oysters from the upper James River seed area into trays in the lower York River. Replicate trays of 500 oysters each are established on May 1st each year. Counts of live and dead oysters are made semi-monthly through December. Dead oysters are removed. Samples for histological diagnosis of MSX

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prevalence are removed in August, September and October. All gapers (recently dead oysters) are processed for histological diagnosis. First season (May - December) mortality is determined from the number of live oysters remaining in each tray after adjusting for those removed for diagnosis. Abundance of Perkinsus is not adequately assessed in tray samples because this parasite spreads slowly into imported oysters.

The annual distribution of MSX and Perkinsus, and the intensity of Perkinsus, are determined by analyzing samples of native oysters from most growing areas in Virginia. Perkinsus is diagnosed by the thioglycollate culture method (9).

EFFECT OF DROUGHT CONDITIONS ON DISEASE DISTRIBUTION AND INTENSITY

There have been three prolonged droughts in Chesapeake Bay during the period 1960 to 1987. During each multi-year drought, 1963-66, 1980-82, and 1985-87 (Table 1), MSX invaded upper Virginia and many Maryland tributaries and caused extensive mortalities. MSX invaded deep into the Maryland portion of the Bay in 1982 after a very dry 1981 (Table 1). Only the years 1983 and 1984 brought some relief from drought. These two years eliminated MSX in most areas above its endemic zone, but they did not stop Perkinsus which has been steadily advancing up the Bay and increasing in intensity during the 1980s. Even though annual streamflow since 1985 has not been particularly low (Table 1), there has been greatly reduced winter and spring streamflow which has allowed salinities to increase far above normal, and the typical spring expulsion of MSX has not occurred in many areas. MSX again invaded deep into the Maryland portion of the Bay in 1987. Both MSX and Perkinsus are presently at record high levels of intensity and have invaded farther into Virginia and Maryland tributaries than ever before. During 1986 and 1987 the first season mortality from MSX in monitoring trays at VIMS was 77% and 78% respectively, the highest values ever recorded in 28 years of continuous monitoring (Table 1). The prevalence of Perkinsus was greater than 90% in important growing areas such as Pocomoke Sound and the lower Rappahannock River and mortality was high. During 1987 there were only two locations in Maryland that did not have one of the two diseases (C. Austin Farley, Oxford Cooperative Laboratory, Oxford, MD, personal communication) and in Virginia, for the first time in history both diseases invaded and caused serious mortality in the upper James River seed area, a region usually protected by low salinity (Table 2).

Table 1. First season (May-December) mortality from MSX in monitoring trays and mean annual total streamflow in Chesapeake Bay (X 1000 CFS). Streamflow data from USGS.

Year	Mortality (%)	Streamflow
1960	30	77.3
1961	33	78.0
1962	35	69.8
1963	42	52.4
1964	44	61.9
1965	56	49.0
1966	56	53.3
1967	62	77.2
1968	44	60.1
1969	48	54.9
1970	42	77.2
1971	41	79.0
1972	7	131.8
1973	20	95.2
1974	59	76.9
1975	51	103.1
1976	56	84.4
1977	51	80.1
1978	42	91.3
1979	49	113.8
1980	56	64.0
1981	48	54.2
1982	38	73.0
1983	30	88.2
1984	13	99.7
1985	42	68.4
1986	77	69.4
1987	78	74.0

Although Perkinsus was overshadowed by the high mortality caused by MSX during the 1960s and 1970s, it is presently the most serious threat to oyster populations in the Bay. The spread of Perkinsus into areas with dense populations of susceptible oysters and favorable salinities has allowed a rapid intensification of infections and unusually rapid transmission from bed to bed rather than the more typical situation of confinement to a single bed with slow transmission from oyster to oyster.

The intensification of Perkinsus and a comparison of the different responses of MSX and Perkinsus to low salinity is illustrated in Table 2. Neither disease was present at Wreck Shoal in June, 1987, but both MSX and Perkinsus became abundant during late summer and fall with a high proportion of heavy and moderate infections. During winter of 1988, prevalence and intensity of Perkinsus

Table 2. Prevalence and intensity of Haplosporidium nelsoni (MSX) and Perkinsus marinus at Wreck Shoal in the James River, Virginia seed area.

	MSX		Perkinsus	
DATE	INF./EXAM.-%	H-M-L*	INF./EXAM.-%	H-M-L
6-15-87	0/25 - 0		0/25 - 0	
8-20-87	12/25 - 48	1-1-10	14/25 - 56	0-0-14
9-23-87	6/25 - 24	1-0-5	25/25 -100	3-6-16
11-4-87	10/25 - 40	2-1-7	23/25 - 92	5-3-15
1-7-88	10/25 - 40	4-1-5	20/25 - 80	1-1-18
2-4-88	13/25 - 52	2-1-10	17/25 - 68	0-1-16
3-2-88	14/25 - 56	2-0-12	17/25 - 68	1-2-14
4-6-88	14/25 - 56	1-0-13	12/25 - 48	0-0-12
4-27-88	13/25 - 52	1-0-12	4/25 - 16	0-0-4
6-6-88	9/25 - 36	3-2-4	14/25 - 56	3-3-8
7-6-88	3/25 - 12	0-0-3	21/25 - 84	2-6-13
7-27-88	3/25 - 12	0-0-3	22/25 - 88	10-3-9

*H=heavy infection, M=moderate, L=light

gradually declined, but MSX persisted through April. May, 1988 was very wet and by early June salinity at Wreck Shoal was near 10 ppt. Although there was some development of MSX in early June as water temperature increased, it appears that the low salinity greatly reduced the prevalence and intensity of MSX (Table 2). However, the prevalence of Perkinsus was not affected by the low salinity; it rapidly intensified as temperature increased in early summer and heavy infections developed much earlier than in 1987.

EFFECT OF DISEASES ON CHESAPEAKE BAY OYSTER HARVEST

The drought conditions and resulting increase in oyster disease intensity and distribution has been catastrophic for oyster populations. Total annual Chesapeake Bay oyster landings declined dramatically in the early 1960s, primarily because of the impact of MSX on Virginia Landings (Figure 1). A second major decrease in landings occurred in the early 1980s as a result of the spread of MSX into Maryland and intensification of the disease in Virginia. Harvest increased slightly as a result of the wet years 1983 and 1984, but harvest in Maryland was depressed again in 1987, as a result of both diseases.

The increase in Virginia landings since 1985 is misleading. Estimated overall mortality for public beds in Virginia during 1986 and 1987 was between 70 and 90% as a result of the combined effects of both MSX and Perkinsus. Because of the scarcity of market oysters on most public beds in 1986, small seed oysters from the James River were harvested as market oysters for the first time in history. Prior to 1986, these small oysters were always transplanted to private beds for additional growth. During the 1986/87 season, 68.4% of the market oysters harvested from public beds came from the James River seed area, and during the 1987/88 season, 91.0% of the oysters came from the James River seed area (VMRC, unpublished data). Thus, the impact of diseases has caused a change in market oyster production in Virginia from the traditional harvest areas to the James River seed area. This change has resulted in a slightly increased harvest, but has effectively denied private planters an economical source of seed oysters, and has concentrated the fishery in a very small area with risk of overfishing. With broodstocks already seriously depleted rapid recovery of the industry is unlikely.

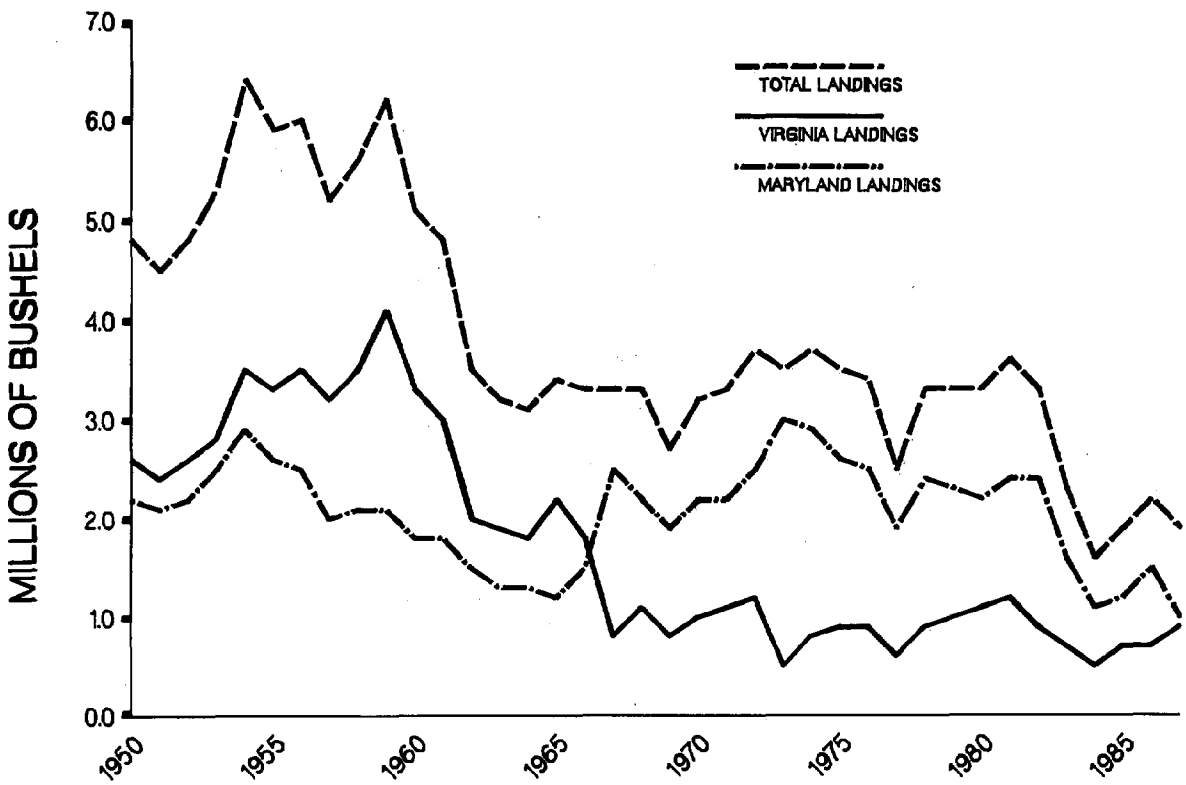

Figure 1. Annual Chesapeake Bay oyster production. Virginia data courtesy of the Virginia Marine Resources Commission; Maryland data courtesy of the Maryland Department of Natural Resources.

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DISTURBANCES IN CORAL REEFS: LESSONS FROM DIADEMA MASS MORTALITY AND CORAL BLEACHING

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ABSTRACT

Population fluctuations are common features of marine ecosystems. In western tropical Atlantic coral reefs, the sudden mass mortality of the sea urchin, Diadema antillarum, in 1983-84, and the widespread bleaching of corals, in 1987, were well publicized events. Unfortunately, the causes are unknown.

Episodic perturbations like these frustrate a scientific community that is hard pressed to explain them to an impatient public. The typical a posteriori analysis employed seems ineffective to us in establishing causality in such cases; instead, robust basic research programs, undertaken by skilled observers and experimentalists, offer more promise. We propose that periodic ecological disturbances in tropical benthic communities should be construed as natural experiments and opportunities to make observations leading to substantial insight into other aspects of ecological function and population ecology. To support this, we compare ecological effects of Acanthaster outbreaks in the Pacific, Diadema mortality in the western tropical Atlantic, and coral bleaching events in both places.

1. INTRODUCTION

Population densities of marine organisms typically vary widely with time. Such variations go mostly unnoticed because the species in question is not a structurally visible component of an ecosystem, because it is economically unimportant, or because adequate census information for it is unavailable. Occasionally, scientists note radical changes in population density. Sometimes the public becomes aware of the scientific observations or alerts scientists to specific events. Only rarely can scientists provide adequate cause-and-effect information to explain such phenomena. Yet public impatience is growing with the inability of scientists to provide adequate and timely answers, and scientists are recognizing the need to address this disaffection.

In this paper, we consider variations in the population densities of several marine organisms that have captured widespread public attention. We speculate about the causes of these events, which we term "idiopathic," borrowing the term medical science applies to diseases arising from an obscure or unknown cause. We use these examples to show that our best clues to causes and effects of idiopathic population fluctuations have come from strong basic research programs, and we speculate where the best opportunities will arise for basic research to make fundamental advances in understanding these population fluctuations. Finally, we argue that future scientific credibility and success will depend in large part on the ability of scientists to educate the public about the practical value of basic research and on the willingness, in turn, of the public to support such research.

2. BACKGROUND

Figure 1 illustrates a simple point that is perhaps more simply made by the old aphorism that it does little good to lock the barn after the horse has escaped. One cannot easily deduce the cause of a population explosion or mass mortality after it occurs: yet the hue and cry is to investigate the direct effects on the subject population, when the clues are sparse as to the nature of the causative agent(s). In any case, if a chain of causative events is suspected, distinguishing from proximate and ultimate causality is often impossible after the fact. However, the great opporunity to assess indirect effects on populations dependent on the subject population is not often appreciated.

Disturbances occur in virtually all ecosystems–rain forests to chaparral, coral reefs to the deep sea. The term "disturbance" as it pertains to ecological systems has been used with ambiguity in the literature (see Pickett and White[1] for review); here we use it sensu Taylor and Littler[2] to include all factors that directly or indirectly cause the removal of organisms and the freeing up of substratum. These factors could include physical influences (storms, fire, ice scouring, predators, active interference by competitors) and physiological stresses (toxins, pathogens, pollutants, extreme temperatures or salinities, etc.) which can affect morbidity, and in severe cases, mortality.

The spatial extent to which disturbances affect a community can vary tremendously. While most disturbances have localized effects, such as individual predation events, a pulse of pollutants from a point source, wide ranging effects seem more likely to relate to meso- or macroscale climate events, and in some cases, pathogens. Here we consider disturbances that act over very extensive areas, but it is important to recognize that these are composed of the sum of effects on local populations.

Below we provide case study examples of region-wide perturbations for coral reefs for which cause-and-effect relationships are poorly defined. We will not restrict ourselves to Atlantic and Caribbean examples, but will consider coral reefs world-wide.

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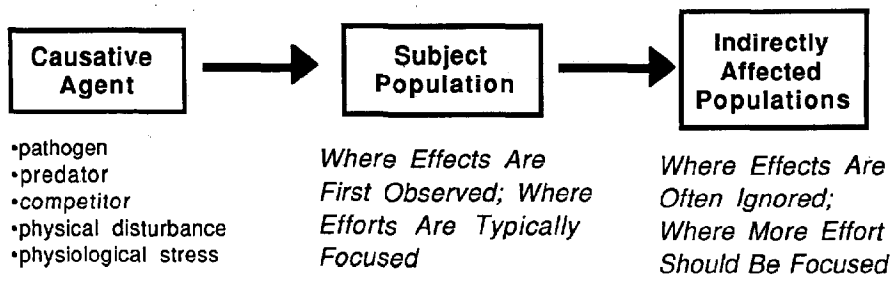

Figure 1. A diagram relating typical agents of population disturbances to their proximate and ultimate effects.

3. CASE STUDIES

Crown-of-Thorns Population Explosions

The major effects in tropical Indo-Pacific reefs related to the well-known, but heretofore inscrutable outbreaks of Acanthaster planci, can be viewed from two very different foci–the causes and the consequences. Viewed from either perspective, there is more hope for understanding these population explosions if the entire system of predators, community associates, and abiotic influences are not viewed simplistically from the perspective of isolated populations, but rather from the perspective of the entire ecosystem.

The effects of these population explosions of Acanthaster are similar to those of the other examples given below, i.e., coral bleaching and sea urchin die-offs in over-fished regions, in that reefs are suddenly left with vast amounts of "bare" substratum open to the processes of colonization and succession.

Understanding the cause of these population explosions results from understanding the population dynamics of Acanthaster, its reproductive life history, and controlling factors (chemical, physical and biological) in larval, juvenile, and adult stages. This is not an easy pursuit, but is one in which attention to ecological complexity is paying off. Early, simplistic hypotheses related to pollution, loss of predators, and adult behavior (see Potts[3] for review) have not been robust enough to account for the occurrence of outbreaks in geographically and ecologically different reef systems where levels of pollution, terrestrial influences, ambient nutrients for primary producers, anthropogenic impacts and "normal" population densities of Acanthaster vary widely. Even Birkeland's[4] more mechanistic view of the importance of terrestrial runoff and plant nutrients does not appear to apply to outbreaks in regions that are constantly oligotrophic and far from terrigenous influence.

Approaches directed at larval phases and the multiple processes affecting recruitment[5,6,7,8,9] offer much potential for understanding why population densities can vary so widely. The abilities of larvae to develop normally with the low phytoplankton densities typical of coral reefs[6], the morphology and behavior of pre-settling larvae, the relationship between the occurrence of outbreaks and currents[7], and the bathymetric patterns of observed recruitment[10] have led Olson to predict (pers. comm.) that outbreaks occur stochastically following the unusual retention of large larval cohorts on reefs (the usual situation being considerable loss of competent larvae by off-reef transport).

The lesson of Acanthaster is clear: clues to outbreaks rest not only in isolated studies of individual populations, but in the development of a more synthetic understanding of the ecosystems in which the species is found. We have gained little in trying to piece the puzzle together after the fact. However, the changes that Acanthaster has wrought on coral reef communities illustrate the key roles of the species most susceptible to it.

Diadema

The dramatic die-off in 1983 of Diadema antillarum in the western tropical Atlantic Ocean (WTA) remains a mystery with regard to its etiology[11], although informed guesses about the whats and whys can be made. The speed and trajectory of the die-off[12] implicates water-born pathogens as potential causes. The initial observation at Galeta, Panama, at the Atlantic mouth of the Panama Canal hints at some transcanal introduction. With our very limited understanding of the role of marine pathogens in controlling floral and faunal populations, and our poor success at isolation, identification, and culture of pathogens, disease as a cause, will be difficult to pursue.

The consequences of the loss of this sea urchin from the entire WTA region, however, placed in context of basic research on herbivore-plant relationships, are not surprising. This predictability rests on our knowledge of the general role of such regularly encountered urchins in shallow-water ecosystems of tropical and temperate seas: (1) the interrelationships with prey, competitors and predators[13]; (2) their reproductive ecology; (3) our understanding of the variation of urchin densities in space; (4) our appreciation of the consequences of perturbations[13] to associated species populations of the community/system, and (5) previous occurrences of abrupt population declines[14,15].

This knowledge derives from basic research in population and community ecology of marine grazer species or systems in which grazers are common; it also clearly points to the need to consider such an "event" in the context of the system when we ask questions about effects and causes. To understand the consequences of the demise of Diadema in the WTA, we must also look at what has caused it to flourish in much of this region. This is because the consequences are very much dependent upon antecedent conditions.

Coastal harvesting of reef-associated fish stocks is in-

tense in many regions of the WTA (e.g., Haiti, Jamaica, the Virgin Islands); it is relatively low-level in other regions (e.g., Belize, Honduras, some of the Bahamas). The harvest is primarily by way of artisanal fisheries with a preponderance of use of gill nets and fish traps which can decimate fish populations. In heavily fished regions, primary competitors (parrotfish, surgeonfish, chubs) and predators (triggerfish, hogfish) of sea urchins are part of the acceptable catch, with the result that urchins are released ecologically from major controlling elements in the natural reef arena. While not shown experimentally, there existed in the WTA prior to the 1983 die-off, a very strong correlation between fishing pressure, reef fish stocks and the abundance of Diadema. This relationship was seen on regional as well as local geographic scales. For example, in the U.S. Virgin Islands, local areas protected from fishing pressure (U.S. National Parks and territorial reserves) exhibited rich reef fish populations and consequently much reduced urchin densities in comparison to nearby areas without fishing controls[17].

On the basis of experimental studies from before the die-off, Hay and Taylor[13] and Hay[16] contended that overfishing on reefs encourages the success of sea urchins, particularly Diadema, via reduced population controls of competition and predation. Once well established, the urchins themselves can depress herbivorous fish (competitor) populations by exploitation of resources and facilitate their own success. From this, Hay and Taylor[13] predicted that in overfished areas, the loss of urchins will have a greater effect than in non- fished areas because:

1. Compensatory shifts in grazing pressure are hampered. Both functional and numerical (recruitment and population increases) responses by the herbivorous fish guild to the loss of urchins are needed in overfished regions, rather than the predominantly functional responses (greater resource consumption per individual) in areas of lower fish harvesting.

2. The population density of urchins will be larger due to the decreased abundance/impact of key urchin controls (predators).

Intra-region comparisons of heavily fished and protected waters around St. Thomas following the 1983 die-off support these general predictions, as do much broader geographic comparisons, i.e., Belize vs. the Virgin Islands[17]. The effect of a >95% reduction in urchin densities in Belize (it remains at better than 90% reduced to date) was essentially disguised by the rich and compensating fish assemblages of the barrier reef system. Community composition, algal primary productivity and the abundance of algal assemblages have remained within the realm of normal variation. The importance of ecological context is unfortunately not frequently recognized and considered[18]. Reports on the results of the die-off to date[18,19] have focused only on what some[13,16] would consider to be anomalous states of reef systems in which fish populations are uncharacteristically low.

The lesson from Diadema is straightforward: natural "experiments" (i.e. mass mortalities) have enabled us to confirm on a broader level what we know from more restrictive experimental manipulations.

Coral Bleaching

Considerable attention was paid in the world press to observations in the fall, 1987, of widespread "bleaching" of corals and other zooxanthellae-bearing cnidarians throughout the Caribbean and Bahamas. The term bleaching refers to the loss of algal endosymbionts (i.e. zooxanthellae) from their host invertebrates, and it has been a well recognized phenomenon physiologically since the observations Yonge[20], who was among the first to observe it experimentally. Because bleaching typically occurs when hosts are exposed to stresses such as oxygen deprivation, lowered salinity, or elevated temperature, it is generally regarded as a response to a physical perturbation, with the latter usually associated with its ecological manifestation–although there is no evidence to preclude a disease-based etiology. Public speculation as to the causes of the event were essentially the same as those proposed for Diadema mortality several years before: pollution, disease, climate change, etc.

In fact, sporadic reports of transitory coral bleaching events in the WTA have been reported that seem to relate well to temperature stress[21,22,23,24]. However, we are not aware of any published scientific reports documenting the previous widespread occurrence of the phenomenon in the WTA, as was reported in the popular press for 1987. While there is no doubt that widespread observations of severe bleaching occurred, several problems have arisen in interpreting the severity of the event: (1) many of the observations were anecdotal, not systematic, owing to the relatively limited presence of trained observers and researchers in the Caribbean; (2) no unifying causative agent could be identified after the fact; and (3) follow-up studies have been limited owing to fiscal limitations on research budgets of nations in the Caribbean basin. Moreover, the sensational nature of press reports has rendered it difficult to place the dimensions of the problem in perspective.

In contrast to the recent bleaching events in the WTA, there have been widespread observations of persistent coral bleachings in the tropical Pacific that have been well documented in the scientific literature. Glynn[25] provided convincing evidence that the widespread incidence of this disturbance in the eastern Pacific was associated with high temperature anomalies relating to the El Nino Southern Oscillation (ENSO) of 1983–one that has been regarded as a 100-year event.

The recovery of bleached hosts and the resultant long-term ramifications of bleaching appear to relate to the length of the stress event more than the size of the temperature anomaly. Corals that bleach as a result of short-term, acute temperature stress (up to about $4^{o}C$ over maximum thermal tolerance level) often appear to recover and repopulate with zooxanthellae[21,22,23,24]. In contrast, long-term, chronic temperature stress (approximately $2^{o}C$ over maximum thermal tolerance level) may cause massive mortality to susceptible species and can lead to substantial ecological alterations[25,26]. Glynn et al.[27] found that lipid depletion in corals accompanied the loss of zooxanthellae and increased morbidity and mortality; they

suggested that a long-term influence on coral recovery to chronic temperature stress relates to the loss of nutritional benefit of the zooxanthellae. Although disease does not appear to be the primary causative agent of bleaching and mortality in the eastern Pacific[28], as a secondary effect, stressed corals appear to be more susceptible to disease complications[29].

When chronic stresses occur, and when bleaching and high mortality among susceptible species causes shifts in community structure, populations dependent on corals as a nutritional source or habitat exhibit effects comparable to those described above for Acanthaster or Diadema. For example, Glynn[26] found that the relative effect of corallivore predation by Acanthaster and Arothron meleagris (a tetrodontid pufferfish) increased after the 1983 bleaching and coral mortality occurred. Not only were surviving populations of bleaching-susceptible species more strongly affected by Acanthaster predation, but also were populations of species that although insusceptible to bleaching were more susceptible to Acanthaster predation and were often protected from corallivore predation by being surrounded by bleaching-susceptible species, but Acanthaster-insusceptible species–the loss of perimeter "defense" appeared to be an important factor in the declines of these species.

Clearly, the lesson from the bleaching of corals, like that of other major reef disturbances has not been in what it has taught us about corals, but instead what it has taught us about indirect ecological effects that their population changes have had on other species.

4. DISCUSSION

Prediction of the effects of idiopathic events on complex communities is not easy, but in many systems we have enough knowledge based on experimental and correlative studies to help us make educated guesses. If we can infer some generalities in the structuring elements of similar communities from geographically separate regions, with different species components, then predictions may be readily achievable. These may derive from basic experimental investigations, comparative observations, or localized perturbations that have affected the same species or related species or associates. Our existing understanding of the habitat requirements, reproductive modes, life histories, trophic interactions, etc., should give us considerable insight into how communities will respond to species losses providing we are able to generalize from this information.

Public impatience with science's lack of answers to anomalous events relates, in part, to poor public understanding of how science is conducted. It is axiomatic that science education and scientific communication to the public must be improved. However, as environmental scientists, we must ask ourselves what else we must do, and how we can become more predictive and better able to ascribe mechanisms to phenomena we observe.

Some interesting comparisons can be made between medical science, which is clearly successful at diagnosing and predicting the course of anomalous events (i.e. disease) and environmental science, which is clearly not. The comparison is somewhat unfair, because medical science has a more constrainted focus and is more mature scientifically, but the comparison is nonetheless instructive. While medical science has developed strong support for both a research component and a healing component that communicate with each other well, in the environmental sciences, the diagnostic and "healing" component (i.e. environmental engineering) is poorly developed and communicates poorly with the research component. There is no equivalent of the M.D.-Ph.D. in the environmental sciences–someone trained equally to diagnose, to treat, and to conduct research. In the environmental sciences, we rely on brute force engineering technology to diagnose and cure our ecological ills. While in medical science it would be preposterous to make numerical modeling the basis for diagnosis and cure, in environmental science it is de rigueur. While medical science devotes massive resources to the study of pathology, in the environmental sciences there is no equivalent interest in what might be termed ecopathology, the study of the course of anomalous ecological events. While in medical science handbooks such as the Merck Manual offer physicians an orderly and codified guide to the etiology, pathology, diagnosis, prognosis, and treatment of human disease, we have not even a first approximation of that for environmental science.

In short, we in environmental science have done a poor job of summarizing, codifying and understanding what ecosystems have and have not in common. Until we do better at this, our ability to diagnose or correct environmental ills will be extremely limited. We will not be able to do this without adequate basic research. Although it may never be practical or fully desirable to pattern "ecological medicine" on the model of human medicine, it is probably worthwhile to draw eclectically from it.

5. CONCLUSIONS

a. Episodic, large-scale fluctuations in populations of Caribbean marine organisms have received considerable public notice, but ultimate cause-and-effect relationships are largely unknown.

b. By focusing on proximate effects, i.e., population fluctuations of a single species, we lose information on ultimate causes. However, opportunities for natural experiments exist in following the relations between affected species and species that it in turn affects; such experiments have yielded useful information in the past and offer promise in the future.

c. Failure of the public and public officials to understand scientific limitations and to act accordingly can result in public loss of confidence in science and scientists. We must improve science education and public awareness of the strengths and limitations of science.

d. Continuing support of basic research provides the best opportunities for understanding ultimate cause-and-effect relationships in idiopathic population declines and outbursts.

e. The role of marine pathogens in the etiology of episodic populations events is largely unstudied.

f. Anecdotal or press-related reports of episodic events cannot be relied upon as adequate documentation; we must rely on the peer-reviewed scientific literature for that purpose.

g. A better understanding of "ecopathology" may result if we do a better job of comparing ecosystems and codifying and summarizing their characteristics.

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RED TIDE, THE FIRST OCCURRENCE IN NORTH CAROLINA WATERS: AN OVERVIEW

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ABSTRACT

On 2 November 1987, the toxic "red tide" dinoflagellate, Ptychodiscus brevis, was identified from nearshore waters of North Carolina. This massive and persistent red tide was a major biogeographic event and extended the range of P. brevis by 800-900 km. Before the end of this bloom some 3.5 months later, there were 48 cases of neurotoxic shellfish poisoning reported in humans and over 1,480 km^2 of shellfish harvesting waters were closed. This affected approximately 50% of the waters normally used for commercial harvest of oysters and 95-98% of those areas used for commercial harvest of clams. The economic loss to the coastal community was conservatively estimated at $25 million. The following is a summary of this event.

1. OCCURRENCE AND TRANSPORT OF THE BLOOM

On the weekend of 31 October-1 November 1987, there were reports from people on or near the beach (Emerald Isle on Bogue Banks, NC 34°38'N 77°06'W) of water discoloration and eye and respiratory distress and skin irritation. These symptoms are frequently recorded during Florida red tides where waters are closed to shellfishing when P. brevis concentrations reach 5,000 cells/l[1]. Normally this species is present in the Gulf of Mexico in low concentrations (<1,000 cells/l) but blooms (>5,000 cells/l) can develop offshore and about 25% of these reach nearshore areas along the west coast of Florida[2]. There have only been three documented cases of P. brevis cells on the Atlantic coast of Florida and each of these occurrences was preceded by a bloom on the west coast. Murphy et al.[3] documented the transport of cells to the Atlantic coast of Florida via the Florida Current-Gulf Stream System. Each of these three "transported" blooms occurred in October and none lasted much more than a week.

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On August 24, 1987, 68 days prior to the first reports of a red tide on the North Carolina beaches, a P. brevis bloom was reported off Naples, FL. Satellite imagery (AVHRR) of sea surface temperatures (SST) and thermal frontal analyses of the position of the Gulf Stream showed a strong shoreward intrusion of the Gulf Stream onto the continental shelf in Raleigh Bay on 19 October, 1987[4]. This warm filament continued to move shoreward and by 22 October was within 7 km of the shore east of Cape Lookout (Fig. 1). This parcel of water remained intact for at least 17 days and inshore waters of both Onslow and Raleigh Bays warmed from less than 21°C to 22-24°C in about 6 days. Dinoflagellate blooms develop in a defined water mass and the sustained integrity of this water mass determines the duration and extent of a bloom[5]. The original parcel of warm water remained intact until mid to late November. Satellite imagery of SSTs on 14 December 1987 indicated that another parcel of Gulf Stream water had entered Raleigh Bay, keeping nearshore water temperatures warm enough to maintain the P. brevis bloom[6].

2. CELL CONCENTRATIONS AND SHELLFISH HARVESTING BAN

Since P. brevis cells are both motile and positively phototactic[7], they can concentrate on the surface during the day and physical factors such as percent cloud cover, winds, currents, and tides affect their distribution. The highest and most persistent concentrations of P. brevis cells were immediately adjacent to the parcel of Gulf Stream water. The highest cell concentrations of this bloom (2,000,000 cells/l) were within 18 km of Cape Lookout on 4 November, 1987. P. brevis cell concentrations were generally >100,000 cells/l from Cape Lookout Bight to 100 km southwest into Onslow Bay from 3 November 1987 to late December 1987[4]. Based on recommendations of the FDA[8] and procedures followed by the Florida Department of Natural Resources[1], shellfish waters were closed to harvesting when P. brevis cells exceeded 5,000 cells/l.

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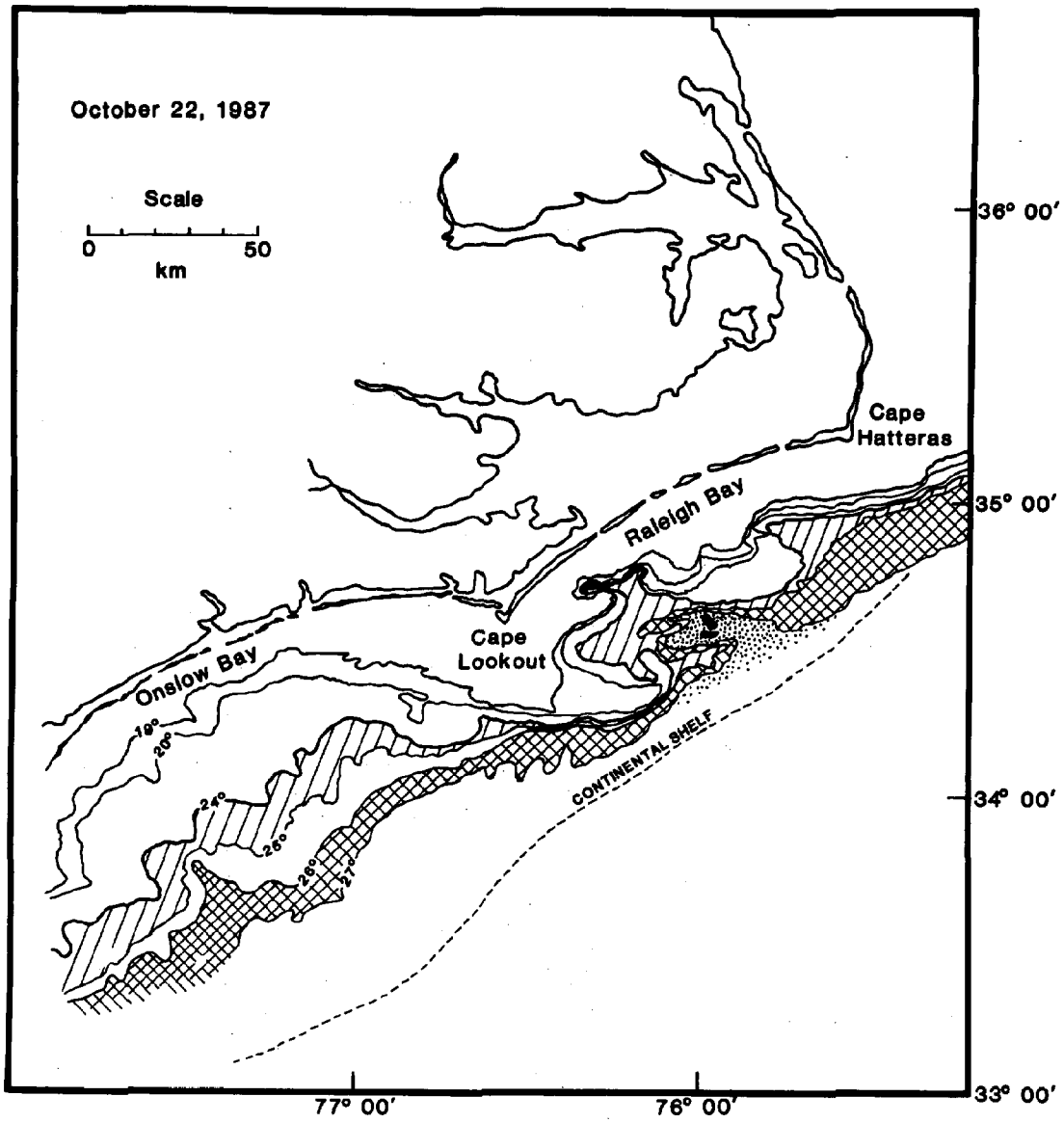

Figure 1. Strong shoreward intrusion of the Gulf Stream onto the continental shelf in Raleigh Bay, 22 October 1987. Center of water parcel from the Gulf Stream is 28° C (solid). Drawings based on satellite imagery of sea surface temperatures from S. Baig, National Hurricane Center, Coral Gables, FL, J. Clark, National Ocean Service, Camp Springs, MD, T. Lemming, National Marine Fisheries Service, NSTL, MS and R. Stumpf, National Environmental Satellite Data and Information Service, Washington, DC.

As cells were moved into different areas along the coast, sampling efforts were extended and additional closures of shellfish beds resulted. The initial closure of 375 km^2 was on 2 November and was followed by 5 more closures to include more than 400 km of coastline (1,480 km^2 of shellfish harvesting area).

3. TOXICITY TESTS AND REOPENING OF SHELLFISH AREAS

P. brevis produces several neurotoxins which can accumulate in filter-feeding shellfish causing mild to severe nausea, vomiting, diarrhea, chills, dizziness, numbness and tingling of face, hands or feed within 3 to 4 hours after consumption of contaminated shellfish. P. brevis toxin can be detected in shellfish meats by a standardized mouse bioassay[8] and all openings of shellfish harvesting areas were based on bioassay test results. The first reopening of a shellfish harvesting area was on 19 February 1988, some 3.5 months after the bloom first occurred. All reopenings prior to 31 March 1988 were for clams (Mercenaria mercenaria) only. Oysters (Crassostrea virginica) apparently depurated the brevitoxins more slowly. On 31 March about 21 km^2 of oyster harvesting area was reopened but the 80 km reach extending southwest of Cape Lookout remained closed until 6 May 1988. This was the area of highest P. brevis cell concentrations as well as the highest toxicity according to the bioassay results[9].

4. NEUROTOXIC SHELLFISH POISONING

The epidemiological investigation of cases of neurotoxic shellfish poisoning (NSP) revealed that 48 persons were confirmed to have become ill from consumption of shellfish that were affected by the P. brevis toxin[10]. The illness was generally mild and of short duration (mean = 17 hours). Thirty-five of 48 cases (73%) occurred before the first ban on shellfish harvesting was instituted on 2 November and the majority of illness occurred between 27 October and 5 November 1987. An illness that occurred in December was from shellfish harvested on 31 October and frozen. Most of the people affected by NSP lived along the North Carolina coast from Cape Lookout to 75 km southwest.

5. EPILOGUE

Whether this red tide bloom represents true dispersal of the species or is simply a "transported bloom" of expatriate organisms is not yet known. Some toxic dinoflagellates produce encysted zygotes that remains dormant in sediment as part of a sexual life cycle[11]. In such cases, cysts may seed nearshore waters for future red tide blooms. A true dormant (zygotic) cyst is not known for P. brevis. We consider it more likely that any future red tide bloom in North Carolina waters will result from the transport of organisms by a sequence of physical oceanographic events similar to those which caused this bloom. Any future efforts to predict these blooms should consider factors affecting the variability of the Florida Current-Gulf Stream System and Continental Shelf transport mechanisms.

6. ACKNOWLEDGMENTS

We would like to thank R.L. Ferguson and P.J. Hanson who collected the samples on 2 November from which the initial observations and identification were made, G.H. Gilbert, D.L. Mason, S.W. Mobley, D.P. Clawson, J.P. Lewis, J. King, L. Brooks, T.D. Willis, L. Settle and T. Stiles for sampling and/or counting assistance and J. Overton and his staff for their technical assistance. K.A. Steidinger, C. Tomas, and B.S. Roberts were particularly helpful during this bloom. Travel funds were provided by the Southeastern Massachusetts University Research Committee for J.T. Turner and his help and support made our work far easier. We had an unusual level of cooperation, understanding and facilitation from our colleagues and we would especially like to acknowledge F.A. Cross, D.E. Hoss, W. Hogarth, and R. Benton for their support.

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PATHOLOGY OF THE DISEASED DOLPHINS

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Introduction

During the Summer and Fall of 1987, approximately 750 Bottlenose Dolphins (Tursiops truncatus) died along the eastern and gulf coasts of the United States. Mortality of such magnitude affecting animals of all ages, both sexes and in different nutritional states has not been previously reported. A response team of scientists focused on the problem in an attempt to study and, if possible, determine the cause of the deaths. This paper presents the results of the pathology portion of the study. Standard methods of examination including necropsy, light microscopy, and electron microscopy were utilized. Our results indicate that death of the dolphins, in most cases, came as a result of an overwhelming bacterial infection. Whether this occurred due to increased virulence of bacteria with which the dolphin has co-existed for many years, or whether some as yet unidentified mechanisms caused a reduction in nonspecific disease resistance and/or immunosuppression of the dolphins was not determined by this study.

Materials and Methods

Dolphin tissues were collected during the postmortem examination at the Dolphin Study Center at Virginia Beach and the Brigantine Stranding Center, Brigantine, New Jersey. The majority of dolphins necropsied were found along the beach after being washed ashore. In many cases, the putrefactive, postmortem changes were so advanced that the carcasses were useless for laboratory studies and had to be discarded.

Tissues collected during necropsy and considered suitable for microscopic examination were placed in 10 percent phosphate-buffered formalin solution. Tissues selected for electron microscopy were cut into 1 mm cubes and placed in 2.5 percent sodium cacodylate-buffered glutaraldehyde solution. Processing and staining of the tissues were by previously published standard methods.[1,2]

All tissues for light microscopic examination were stained by the Harris Method for Hematoxylin and Eosin.[2] Where indicated, selected tissues were stained with Gomori's Methenamine Silver, the Periodic Acid Schiff Reaction method, and Brown and Brenn's tissue Gram stain.[2]

Tissue to be examined by transmission electron microscopy were stained with a five percent aqueous solution of uranyl acetate[7] and the Venable-Cogsill method for Lead Citrate.[5] Tissues to be examined for the presence and location of lipid deposits were stained with one percent osmium tetroxide[7]. Examinations of the tissues were conducted by diagnostic veterinary pathologists and an electron microscopist.

Results

The pathology studies involved the necropsy of dead animals and collection, fixation, processing, staining, and examination of approximately 400 tissues. Fifteen of the tissues were examined by electron microscopy.

Among the more frequently observed gross lesions were the following:

1. Sloughing of large areas of skin to the level of the subcutaneous tissue. Many of the skin lesions, according to Dr. Joseph Geraci, resembled burns from phenol and hydrochloric acid which he had observed in dolphins earlier in his career.

2. Ulcers on the palate, gingiva, lips, tongue, and skin.

3. Large volumes of port wine-colored fluid in the abdominal and thoracic body cavities.

4. Spleens enlarged two to three times normal size.

5. Yellow discoloration and emphysema of the pancreas.

6. Urinary bladder filled with coffee-colored urine.

7. Pulmonary congestion, hemorrhagic infarction, and/or bronchopneumonia.

8. Liver abnormalities ranging from severe fatty change to extensive cirrhosis (fibrosis).

9. Brain hemorrhages.

Examination by light microscopy disclosed a wide variety of pathomorphic tissue alterations attributable to septicemia. The tissue sections

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contained areas of infarction and numerous thrombi in the blood vessels. Myriads of bacteria were present in many of the thrombi and appeared to have invaded the walls of blood vessels and passed through them into the adjacent tissues. Electron microscopy also demonstrated this change. In many cases, inflammatory cells had surrounded and engulfed the bacteria. In several lungs, changes typical of a bacterial pneumonia were observed along with a concurrent mycotic pneumonia. The ulcers and other areas of degeneration in the skin were with few exceptions associated with septic thromboemboli within blood vessels supplying the area. Within the kidneys, changes of acute tubular necrosis were present along with thromboembolism of the blood vessels. A fibrinopurulent necrotizing myositis with severe diffuse necrotizing vasculitis was present in many of the skeletal muscle sections. In the heart sections, bacterial emboli were detected within the blood vessels and in some cases, bacteria had invaded the blood vessel walls. In both lymph nodes and spleens, the most remarkable changes were the paucity of lymphocytes, areas of necrosis, and bacterial emboli within the vasculature. In the other tissues examined, lesions identical or closely resembling the lesions described above were seen. The presence of colonies of bacteria in normal appearing tissues were also observed. In many instances, the bacteria were large Gram positive bacilli. These changes are recognized as postmortem events occurring after the death of the animal being examined.

Discussion

During the die-off of Bottlenose Dolphins (Tursiops truncatus) along the eastern and gulf coasts of the United States in the Summer and Fall of 1987, reporting agencies estimated that at least 750 Bottlenose Dolphins died. Due to environmental conditions which enhanced the autolytic and putrefactive decomposition of the dolphin carcasses, less than five percent of thesespecimens were suitable for comprehensive laboratory examination, i.e., bacteriology, virology, toxicology, parasitology, and pathology studies. The frequent delays in transporting the specimens from Brigantine, New Jersey, and Virginia Beach, Virginia, study centers to Ames, Iowa, was due to less than ideal air carrier scheduling compounded the loss of specimens from decomposition.

To conduct a meaningful examination of tissue by light or electron microscopy, the specimens must be removed from the carcass and placed in fixative as soon as feasible. This enhances fixation of the tissue cells thereby retaining the greatest possible degree of structural detail necessary for an accurate diagnosis. The inability to achieve this accounts for the small number of specimens examined at the laboratory.

The pathomorphic changes present in the epidermis of these dolphins appeared during gross examination to be the result of caustic or corrosive chemicals. However, when examined by light microscopy, a consistent finding was the presence of septic thrombi blocking the underlying vasculature. The lack of oxygen and nutrients resulted in the death of the tissue. Many of the morphologic manifestations of shock, specifically of septic shock, which we observe in domesticated land animals, were present in varying extent and number frequency in these cetaceans. Some of these changes include acute renal tubular necrosis, disseminated intravascular coagulation (widespread clotting within blood vessels), sludging or slowing of the blood circulation, and visceral pooling of bood. The manifestations of septic shock when compared with the observations made during the necropsy of the dolphins appear to be compatible in many respects. Bacteria are the most likely etiogenic agent of these lesions in view of there frequent occurrence within histologic lesion and the large number of isolations made from the tissues.

The changes observed microscopically suggest that an overwhelming Gram-negative, bacterial infection with resulting endotoxemia was the primary cause of septic shock and the death of the dolphins.

If the above inferences are correct, what factors are responsible? Two possibilities with the most proponents are 1) that the animals became immunosuppressed or had increased susceptibility to various organisms or, 2) the virulence of the causative bacteria became increased by some, as yet, undetermined mechanism.

While there are several procedures capable of evaluating humoral and cell-mediated immunity as well as macrophage functions, they were not applicable to this situation. This was due to the nature and quality of the specimens and the logistical difficulties previously mentioned. Some observations made during the course of this study support the hypothesis that immunosuppression of the dolphin immune system could have played a role in the death of the animals, e.g., lymphocyte depletion in the spleen and lymph nodes and mycotic pneumonia in several of the animals. Tissue levels of several potentially immunosuppressive agents are being studied by the Pathobiology Laboratory of the National Veterinary Services Laboratories, however, no definitive data was available at the time this presentation was in preparation.

Increased virulence of the bacteria interfacing with dolphins in the affected pods is another possibility currently being studied by two groups of scientists in Maryland.

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STATISTICAL CHARACTERISTICS OF THE 1987 BOTTLENOSE DOLPHIN DIE-OFF IN VIRGINIA.

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ABSTRACT

A sample of 153 bottlenose dolphins (Tursiops truncatus) that died during 1987 was examined. The age and sex composition led us to believe that the factor that increased the mortality was random with respect to those parameters. There were 3 lactating and 3 pregnant as well as non reproductively active females in the sample. The sex ratio was 69 females to 68 males, 16 sex unknown. There were 19 sexually mature females, 20 sexually mature males and 11 dependent calves in the sample. The ratio of dependent calves to lactating females (3.6:1) indicates greater mortality in calves than in mature animals.

INTRODUCTION

In July of 1987 we began to notice increased mortality in the bottlenose dolphin, Tursiops truncatus in Virginia. We had been monitoring cetacean mortality for more than ten years and the historic data (1977-86) provided an average mortality for Virginia in July of 0.9/year. After 10 animals had been reported in July of 1987 we felt that we were dealing with an unusual situation. We reported our findings to the Marine Mammal Commission and the National Marine Fisheries Service and they rapidly convened the Dolphin Response Team under the direction of Dr. Joseph Geraci.

Although mortality had been reported from North Carolina to New Jersey, we felt that it was best to concentrate our efforts in what seemed to be the most active center of mortality, the Norfolk - Virginia Beach area. When the morality tapered off in Virginia at the end of October, there had been 233 reported carcasses, 188 of which were examined by biologists. In normal years (1977-86) the average for those months is 4.9. The causative agent responsible for this mortality has not been defined as of the end of July 1988.

The mortality affected all age classes (Figure 1) and is important as it is the only sample of a bottlenose dolphin population that can be considered random. That led us to treat it as a separate sample instead of merging it with our long-term data base. This sample should valuable in trying to deduce the causes of the mortality.

MATERIALS AND METHODS

The Marine Mammal Program of the Smithsonian Institution examined 153 (Figure 1) specimens of dead bottlenose dolphins (Tursiops truncatus) that were found on the coasts of Virginia during the months of June through October 1987. Skulls, gonads, stomach contents, vertebral epiphyses, and external morphometrics were collected. The summer of 1987 was unusually warm, providing a handicap in dealing with carcasses. The study lost important data from some animals due to decomposition.

One tooth was longitudinally sectioned and ground to about 150 microns. The section was stored in water and examined under a stereo dissecting microscope which was equipped with a set of simple photographic polarizing filters. Age estimates were made by counting the growth layer groups following the procedures outlined in Perrin and Myrick (1980).

Mammary glands were examined visually for presence of milk. Ovaries and a sample of the mammary gland were preserved in 10% formaldehyde. The ovaries were examined for the presence of corpora albicantia and corpora lutea. Presence of either of those bodies indicated sexual maturity.

Samples of testes was sectioned and stained with Berg's stain (Berg 1963). Testes samples were then examined under a compound microscope and were scored as immature (no visible sperm or spermatids), maturing (trace of sperm or spermatids) or mature (abundant sperm or spermatids).

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RESULTS

Reproduction - females

Of 83 females in the sample, 11 proved sexually mature and 13 sexually immature. The longest sexually immature female was 230 cm in total length, the shortest mature female was 236 cm. Using 236 cm as the point at which females become sexually mature, all 19 females in the sample with total lengths exceeding 236 cm were classified as sexually mature. Unfortunately we were unable to examine the gonads on 8 of those. The females reached sexual maturity at between 2.2 and 6.0 growth layer groups. The oldest immature female had 5 growth layer groups.

Of the 11 mature females, 3 were pregnant and 3 were lactating. Two fetuses were near-term (93 and 110 cm total length) and one was mid-term (22 cm total length).

Reproduction - males

Of 55 males in the sample, we were able to confirm 7 sexually mature and 12 sexually immature males, based on presence of abundant sperm in the testes. The maximum testis length of a sexually immature male was 12.3 cm, of maturing males, 12.7 cm. The minimum length of a mature testis was 15 cm; therefore we can say that males reach sexual maturity at a testis length of 12.7 - 15 cm. The longest sexually immature male was 242 cm in total length, the shortest sexually mature male was 248cm. The youngest sexually mature male had 8 growth layer groups in its teeth and the oldest sexually immature male had 9. Using 248 cm as the point at which males become sexually mature, there were 20 mature males in the sample and 39 immature males.

Reproduction - calves

Mead and Potter (in press) considered 150 cm in total length to be the mean length at weaning. There were 11 animals with lengths shorter than 150 cm in this sample. Extrapolating from the growth curve presented by Mead and Potter, there were 22 animals less than a year old (less than 170 cm in total length) and 14 yearlings (between 1 and 2 years old; total lengths between 170 and 200 cm). This was confirmed by the tooth sections for this sample.

Sample Biases

In an unbiased sample there should be a 1:1 ratio of calves to lactating females. The ratio of calves to lactating females (3.6:1) indicates that there is a bias towards representation of calves in the sample by a factor of almost 4. Looking at the ratio of males/females above age 6 (Figure 1), we find 28 males to 18 females, a ratio of 1.6:1, or, to put it another way, there were 45% more males than females in this sample. If we assume that the sex ratio should be 1/1 then some factor led to a decreased abundance of sexually mature females in our sample. Even if we increase the adult female portion of the sample by 45%, we obtain between 4 and 5 lactating females, which still leaves a 2:1 calf/female ratio.

It is logical to expect that the normal natural mortality should be highest in calves and that any factor that leads to an increased mortality rate will have a disproportionate effect on the calf population. Other than that factor there is nothing in the age or sex structure of this sample that leads us to believe it is non-random.

ACKNOWLEDGMENTS

We would like to thank the many people whose help made this study possible. Dr. Joseph Geraci, who headed the Dolphin Response Team, (University of Guelph), Dr. Robert Hofman and John Twiss (Marine Mammal Commission), Dr. Gerald Scott, Fred George and Thomas McIntyre (National Marine Fisheries Service), Gregory Early (New England Aquarium), Susan Barco and Mark Swingle (Virginia Marine Science Museum) and Wayne Creef (Virginia Beach Beautification Department). Mary Bagladi prepared the tooth sections on contract. This was investigation was aided by an Interagency Agreement (No. 47-0000-16-MMC-01) from the Marine Mammal Commission and a grant from the Research Opportunities Fund of the Smithsonian Institution.

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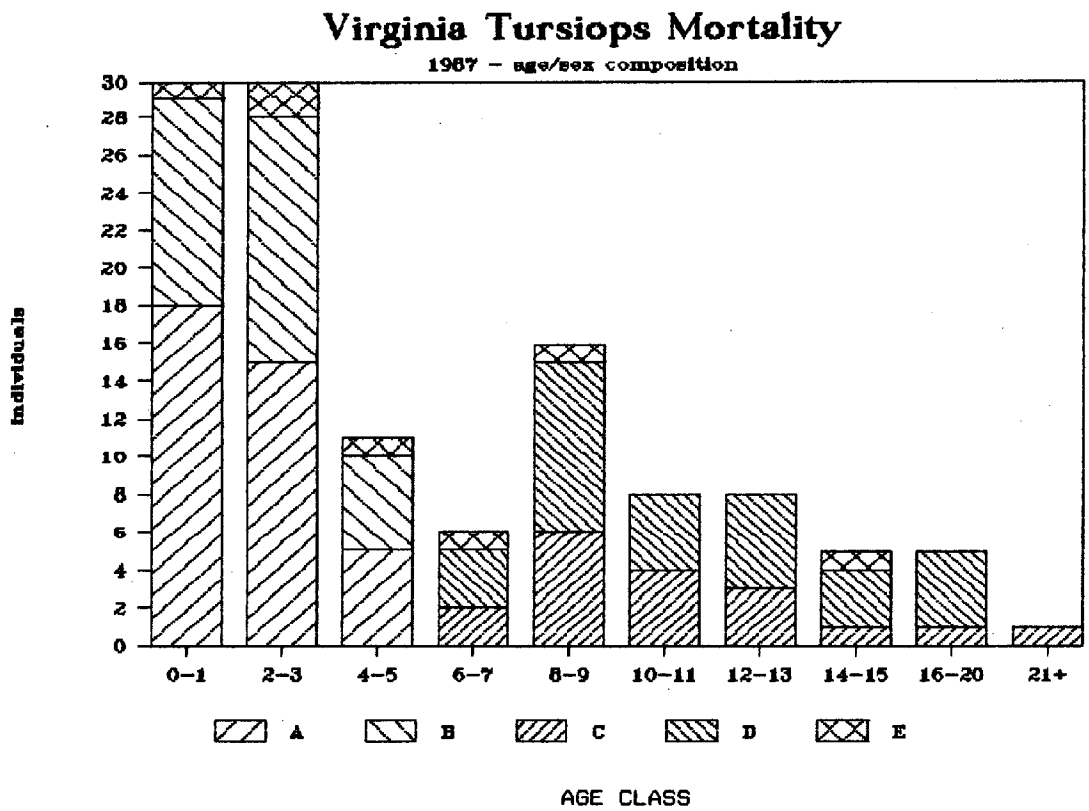

Figure 1. Age/sex distribution of the 1987 Tursiops mortality in Virginia. Age classes are in growth layer groups. A = sexually immature females, B = sexually immature males, C = sexually mature females, D = sexually mature males, E = sex unknown.

RESULTS OF THE DOLPHIN EPIDEMIC INVESTIGATION AS THE DISEASE WAS PRESENTED IN NEW JERSEY SPECIMENS OF BOTTLENOSE DOLPHINS IN 1987

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Dolphins examined from New Jersey waters demonstrated pox inclusion particles in several tissues. Pox-like lesions were found around the lips and snout and in soft tissue of the mouth. Histopathologic studies showed pox inclusion bodies which were confirmed by electron microscopy. The significance of the pox virus findings in the overall disease presentation is discussed.

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THE DOLPHIN DIEOFF: LONG-TERM EFFECTS AND RECOVERY OF THE POPULATION

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ABSTRACT

The 1987-88 mortality of bottlenose dolphins (*Tursiops truncatus*) along the U.S. Atlantic coast was an order of magnitude greater than the prior three year average primarily due to an apparent disease epidemic. Although both coastal and offshore stocks of dolphins are believed to inhabit the waters off the east coast, population surveys and biological samples from stranded and live-captured animals suggests that the observed mortality was principally from a mid-Atlantic coastal, migratory stock of dolphins. Available data suggest a decline of at least 53% in the stock abundance may have occurred. If this degree of reduction has occurred and this stock proves to be reproductively isolated, then the stock is likely below its optimum sustainable population (OSP) level, and thus a depleted stock. Population trajectories from a 53% reduction level were simulated using a range of vital rate and other demographic parameter values. Under the parameter assumptions used for calculations, no combinations resulted in trajectories toward extinction. The resulting distributions of recovery time to the lower limit of OSP were strongly skewed. In the absence of human-induced mortality, the median time to recovery was 32.5 yr (range, 14-90 yr). Under the assumption of a constant human-induced mortality rate equal to estimates of pre-event rates, the time to recovery estimates ranged from 18 to 100+ yr with a median time to recovery of 50.5 yr. In more than 20% of the cases simulated with human-induced mortality, recovery was not achieved within 100 yrs.

1. INTRODUCTION

In the United States, marine mammal populations are managed under the legislative authority of the Marine Mammal Protection Act (MMPA) of 1972 (as amended). The management goal defined in the MMPA is optimum sustainable population (OSP) level, which has been defined to be population levels at or greater than those that produce maximum net productivity (MNP) to the ecosystem carrying capacity. Population stocks outside of OSP (below MNP) are defined as depleted. Removal of animals (incidental bycatch, live-capture, etc.) can be legally authorized from non-depleted stocks.

Although there is considerably more information on bottlenose dolphins than most other cetacean species, for the most part, information necessary for determination of stock status relative to OSP levels is inadequate. Generally, long, consistent indices of population production and abundance are necessary to determine OSP. However, there are cases where catastrophic changes in populations can occur, thereby allowing assessment of the degree of change and status relative to OSP. The recent massive die-off of bottlenose dolphins along the east coast may be such a case.

During the summer and fall of 1987 and the winter of 1988, an apparent disease epidemic resulted in the death and stranding of an unusually large number of Atlantic bottlenose dolphins (*Tursiops truncatus*) along the U.S. east coast from New Jersey to central Florida. In response to this anomaly, a multi-agency team was formed to investigate the causes and effects of the mortality event. This paper is directed at the second component of the investigation: assessment of the effects of the mortality event. The available information on the biology and status of the affected bottlenose dolphin population is presented in six sections: spatial and temporal distribution, stock differentiation, change in population levels, estimates of human-induced mortality, OSP, and estimates of recovery.

2. SPATIAL AND TEMPORAL DISTRIBUTION

Bottlenose dolphins are distributed throughout U.S. Gulf of Mexico and U.S. Atlantic waters. In the U.S. Atlantic, this species is distributed along the coast from Long Island, NY to the Florida Keys (1,2). North of Cape Hatteras, NC, this species demonstrates a disjunct distribution, with con-

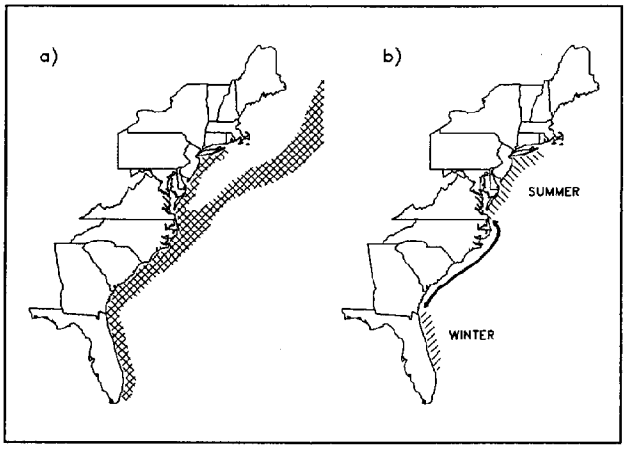

Figure 1. a) *Distributional range of bottlenose dolphins along the U.S. Atlantic coast.* b) *Areas of major concentrations of coastal migratory stock of bottlenose dolphins during summer and winter.*

centrations of animals near-shore (in embayments and within several kilometers of the coast) and offshore, near the continental shelf margin, from 60 to 200 km from the coast. South of Cape Hatteras, the near-shore/offshore distribution pattern is less distinct and there appear to be latitudinal clusters of animal concentration rather than the longitudinally discrete concentration areas found north of Cape Hatteras (Fig. 1a).

Seasonal density distribution patterns have been described for waters north of Cape Hatteras (1) and for U.S. waters south of Cape Hatteras (2). During summer in the U.S. Atlantic, bottlenose dolphins are distributed along the coast, usually as far north as Long Island, NY, and offshore as far north as Nova Scotia, Canada. The main concentrations of bottlenose dolpins during the summer are along the coast from North Carolina north to New Jersey (Fig. 1b.). During autumn, density distribution patterns suggest near-shore animals migrate south along the coast to Florida. During winter, animals in the Atlantic are distributed from south of Cape Hatteras to the northern and central Florida coast, but are concentrated at the southern end of this range (Fig. 1b.). Although bottlenose dolphins occur along the southeastern Florida coast, in winter they are only about $1/10^{th}$ as abundant as along the central and northeastern Florida coasts (2). During spring, the animal con-

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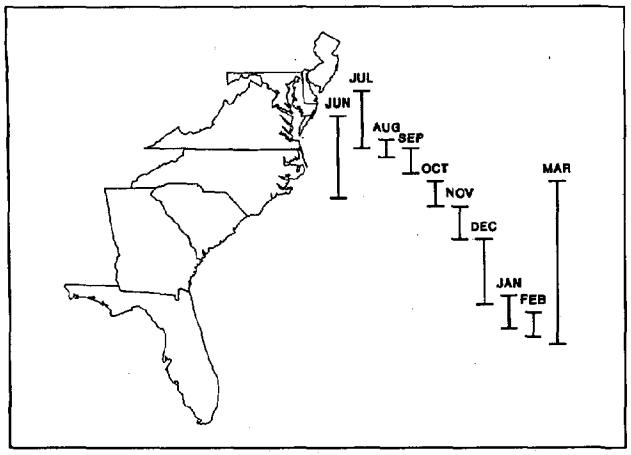

Figure 2. *Interquartile latitude range of bottlenose dolphin strandings along the U.S. Atlantic coast, June 1987 - March 1988.*

centrations shift northward along the coast to complete the hypothesized migratory cycle. It is unclear if the offshore portion of the population follows a similar north-south pattern or what the actual extent offshore distribution might be since sampling has been generally limited to areas within 200 km of the coast.

3. STOCK DIFFERENTIATION

There appear to be both near-shore and offshore forms (stocks) of bottlenose dolphin along the U.S. Atlantic coast and in other ocean areas (3,4). Burn (5) found the pattern of strandings to correlate with the hypothesized coastal migratory pattern based on density distribution patterns along the U.S. east coast (Fig. 2). The stranding data collected during 1987 and 1988 and the observed density distribution patterns along the U.S. Atlantic coast, support the hypothesis of a single coastal migratory stock of animals that ranges seasonally as far north as Long Island, NY and as far south as central Florida. It has been observed that many geographically localized populations of dolphins in the Gulf of Mexico and Atlantic waters show seasonally cyclical patterns in abundance, suggesting emigration from and immigration into embayments (6, 7, 8). It has been well documented that there are both resident and transient animals that utilize localized, near-shore environments over numerous years (9). The working hypothesis for bottlenose dolphin stock structuring in southeastern U.S. waters is that the near-shore bottlenose dolphin population is structured such that there are local, resident stocks in certain embayments and that transient stocks migrate into and out of these embayments on a seasonal basis (3, 9).

4. POPULATION LEVELS AND INDICES OF CHANGE

At present there is no comprehensive estimate of the size of the stocks of bottlenose dolphins in U.S. jurisdictional waters. The abundance of bottlenose dolphins in certain "priority" regions has been estimated. Scott, Hansen and Burn (10) summarized these estimates and proposed that the number of bottlenose dolphins comprising the numerous stocks throughout both the U.S. Gulf of Mexico and U.S. Atlantic waters prior to 1983 may have ranged to at least 23,000 individuals. Extrapolation of this estimate to existing abundance, however, assumes that the stocks have been stable over a period of 15 or more years and that no net migration occurred during the different sampling periods of the studies summarized. The abundance of the stock(s) affected by the apparent disease epidemic was certainly less than the total number of U.S. Gulf of Mexico and U.S. Atlantic bottlenose dolphins.

Historically, about 15,000 animals are thought to have lived in mid-Atlantic near-shore waters based on North Carolina shore-based fishery catch records from the turn of the century (11). In 1979-81, the estimated average mid-Atlantic summer abundance of bottlenose dolphins is believed to have ranged from 4,300 to 12,900 animals (95% confidence region), including both the near-shore and offshore groups (1). The best available information suggests that in recent times, coastal North Carolina and Virginia supported 1,200 or more dolphins during part of the spring and summer (12). This number may have represented a substantial portion of the mid-Atlantic coastal migratory stock prior to the disease epdemic.

Population survey data from several independent sources suggest that there was a greater abundance of dolphins near-shore in 1987 and early 1988 than in recent prior years (13, 14). Offshore, the abundance of dolphins may have been slightly lower in August, 1987, than in the summers of 1980-81 (15). The apparent increase in near-shore abundance might have been caused by immigration from the offshore stock, a real increase in the coastal stock, concentration of animals from wide geographical range, a change in the sightability coefficient for animals surveyed, or some combination of these factors.

It is not clear if both the coastal and offshore stocks were affected by the mortality event. The size and coloration of some of the stranded animals examined suggested that both of the groups were involved (12). In addition, reports received from fishermen and recreational boaters of floating carcasses in the offshore mid-Atlantic region, although not verified, further suggested involvement of the offshore group. Recently, Duffield (16) analyzed 36 blood samples from different stranded and live-caught bottlenose dolphins sampled from Virginia and Florida during the mortality event. All but one of the samples analyzed exhibited the coastal hemoglobin characteristics (17). The single different sample exhibited hybrid coastal/offshore characteristics. This result does not necessarily imply that the offshore stock was unaffected since the likelihood of an animal dying offshore and then being cast ashore is expected to be considerably less than that for an animal dying near the coast. There were no known animals from resident, local dolphin stocks, such as the Indian and Banana River, FL stock, found stranded with symptoms of the disease epidemic. At present, the best information suggests that the *observed* mortality may have primarily affected the coastal, migratory stock of animals that ranges between Florida and New Jersey.

The most direct means of assessing the impact of the mortality on the dolphin population is by comparison of consistent pre- and post-event population indices. Assessment of impact on the basis of the number of dolphins stranded relative to the population at large is dependent on assumptions about the accuracy of abundance estimates and the relationship between the stranded carcass count and the true total mortality (15). The number of animals observed washing ashore is likely a fraction of the total mortality. There is also some chance that the reporting rate of stranded carcasses differed between the years prior to the stranding anomaly due to increased public awareness in 1987-88. In addition, the accuracy of absolute abundance estimates may be questionable since the estimates are usually of surface abundance, unless there has been an effort to correct for animals submerged at the time of the sample.

For the offshore stock in the mid-Atlantic region, a comparison of a pre-event (1980-81) average population index and an index based on a sample taken in August 1987 was used to assess the likely range of the impact of the mortality on the stock (15). The 1987 sample indicated that the impact through August was most likely small (< 10%) relative to the 1980-81 summer abundance level. Because the mortality event was not complete at the time of the August, 1987, sample, and due to the uncertainty about the population trajectory since 1981, this result needs further testing.

For the coastal stock of dolphins, there are no consistent pre- and post-event population survey indices yet available with which to assess potential impact. The pre-event patterns observed in areas such as the Chesapeake Bay mouth (13) and Nassau County, FL (14), may be confounded by the apparent increase in abundance in 1987 and 1988. Thus, the potential impact on the coastal stock was estimated by comparison of the die-off period to prior year average stranding rates. Inherent in this estimation is the assumption that stranding rate is a consistent index of the stock mortality rate.

As of June, 1988, 742 stranded bottlenose dolphins from New Jersey to Florida's east coast were reported to the Smithsonian Institution's marine mammal stranding events program for the 11 month period from June, 1987 through April, 1988 (12). In the prior 3 years, for the same geographical range and months, an average of 73.33 dolphins were reported to the stranding network. Thus, the 1987-88 anomaly represents an order of magnitude increase (10.11 times) in reported strandings relative to the most recent three year historical level. Natural mortality rates on the order 7 to 14% per year are believed to ecompass the most likely range for bottlenose dolphin populations (18). Assuming the stock natural mortality rate (m) to be at the lower end of the reported range (7% per year, 6.42% per 11 months), that the observed mortality wholly affected the near-shore stock, and further assuming that the reported stranding rate is proportional to m and consistent between years, then the observed mortality represents an 11 month m of 64.9%. An annual m would be slightly larger than this value if only the long-term average risk of death was applied to the final 1 month period.

The annual rate of change in the dolphin stock abundance is the difference between the annual mortality rate, annual birth rate, and annual net immigration rate. For the coastal mid-Atlantic stock of dolphins affected by the disease epidemic, Blaylock (19) observed up to 11.5% of the population sampled were calves, implying an annual birth rate (b) on that order. Data collected from stranded animals suggest that calving for this stock occurs in the spring and is not generally protracted over the year. Thus, a potential decline for this stock since early 1987 is estimated as >50% (b - m = -53.4%).

5. ESTIMATES OF HUMAN-INDUCED MORTALITY

The present take of bottlenose dolphins in U.S. waters comes from the live-capture fishery for public display, incidental catch in other fisheries, and by other direct human actions (9). Live-capture removals for public display are not authorized for the coastal migratory stock of dolphins affected by the disease epidemic. The magnitude of annual removals from this stock due to incidental catch and other directed human causes is not well documented.

Marine mammal stranding data provide information useful for estimating an index of human-induced mortality of cetaceans in the U.S. Gulf of Mexico and along the U.S. Atlantic coast. Many of the cetaceans that strand are examined for causes of mortality. Burn and Scott (20) examined the stranding data provided by the Smithsonian Institution (12) for evidence of human-induced mortality in bottlenose dolphins. A total of 386 bottlenosed dolphins stranded from central Florida north along the Atlantic coast were reported from 1982 through May 1987. Of these, the percent of strandings showing some evidence of human-induced mortality (p) was 9.3%. Data from June 1987 to present were not examined in this context because of the ongoing stranding anomaly. For the range of the disease-affected coastal stock of dolphins, Table 1 lists the bottlenose dolphin strandings by state and type of purported human-induced mortality.

Table 1. *Summary of coastal U.S. Atlantic bottlenose dolphin strandings from 1982 to May, 1987, classified by interaction type. Data provided by Smithsonian Institution Marine Mammal Events Program.*

State	All	Fishing Gear	Parts Missing	Gun Shot	Prop Wound	Broken Bones	Other	p[1]	f[1]
MA	3	1	0	0	0	0	0	33.0	3.5-6.9
RI	1	0	0	0	0	0	0	0	0
NY	2	0	0	0	0	0	0	0	0
NJ	4	0	0	0	1	0	0	25.0	2.3-4.7
DE	1	0	0	0	0	0	0	0	0
MD	7	0	0	0	0	0	0	0	0
VA	70	8	5	0	0	1	0	20.0	1.8-3.5
NC	122	3	3	0	0	0	1	5.7	0.4-0.8
SC	9	0	0	0	0	0	0	0.0	0
GA	38	1	4	1	0	0	0	15.8	1.3-2.6
FL[2]	129	4	3	0	0	0	0	5.4	0.4-0.8
Total	386	17	15	1	1	1	1	9.3	0.7-1.4

[1] p, percent of total strandings resulting from human actions; f, expressed as percent, represents the estimated annual human-induced mortality rate using p and the range of natural mortality rates 7-14% per year.

[2] Data for Florida represent central Atlantic and northeastern coastal regions only.

Assuming the classification scheme of Burn and Scott (20) to be accurate and that the stranding data indexes human-induced mortality rate in proportion to the natural mortality rate, then estimates of human-induced mortality rates can be derived from these data. Using the range of natural mortality rates (m = 7 to 14%), the additional mortality rate due to human-related activities (f) can be estimated by these proportions ($f = m((1-p)^{-1} - 1)$). Estimates of f by state and for the coastal migratory stock range are presented in Table 1. These data indicate that added mortality due to human activities may range from 0.7 to 1.4% per year for the coastal migratory stock of dolphins.

6. OSP

The OSP is defined as the range of population size from the level resulting in maximum net productivity to the ecosystem carrying capacity (K). Under the terms of the MMPA, population stocks outside the OSP range are defined as depleted. By analogy with other large mammal species, the population level expected to result in MNP for bottlenose dolphins is greater than 50% of K (21, 22).

Management of bottlenose dolphin stocks has been based not on explicit determination of stock status relative to OSP, but rather on the estimated MNP for the stocks of interest. The basic assumption upon which this management method was developed was that annual MNP for cetacean stocks generally ranged from 2 to 6% of stock abundance. This range has been demonstrated to be biologically achievable, depending on combinations of calf and non-calf mortality rates and upon the age of first calving and calving intervals (23).

Under this management scheme, if 2% represents the true MNP, then a long-term average removal rate of 2%, in addition to natural mortality and with no net migration effect, is expected to result in an equilibrium stock abundance level at the lower end of the OSP range for stocks with initial abundance within the OSP range. For stocks with initial abundance outside of OSP, an average long-term removal equal to MNP is expected to result in an equilibrium stock level below OSP. Stocks outside of OSP can be recovered to OSP while sustaining removals as long as the long-term average removal rate is less than MNP.

7. ESTIMATES OF RECOVERY

The dynamics of the mid-Atlantic coastal migratory stock of bottlenose dolphins were modeled as a difference equation with density dependence as described by the Pella-Tomlinson model standardly applied to whale stocks by the Scientific Committee of the International Whaling Commission (24, 25). The model takes the form:

$$P_{t+1} = (P_t - H_t)S + R_{t+1}$$

where P represents the population size, H, human-induced removals, R, recruitment, and S, survival over time index t (taken as 1 year). Human-induced removals were taken as:

$$H_t = P_{t-1}e^{-m/2}(1-e^{-f})$$

where f is the human-induced mortality rate estimate, conditioned on natural mortality rate, m. The annual survial rate, S, is taken as e^{-m}. The number of recruits, R, is defined as :

$$R_{t+1} = (1-S)P_{t-x}(1+A(1-(P_{t-x}/K)^z)$$

where x is the median age at maturity (Table 2), A the resilience term, K the carrying capacity, and z the compensation term. Given a range of the relative lower limit of OSP (i.e. *MNPL*) and independent ranges of *MNP* and m assumptions (see Table 2 for values used), the corresponding parameter value for A was found as in Holt (26):

$$A = MNP/m(1\text{-}MNPL^z)$$

with the value of z found by solution of:

$$MNPL = (1/(z+2))^{1/(z+1)}$$

The time to recovery was taken as the number of years required for the simulated stock size to reach *MNPL* after an overall reduction of 53% from the assumed equilibrium population level in existence just prior to the disease epidemic. Holt (26) argues that $A > 1/(z+1)$ results in a super compensation effect in the stock-recruitment relationship whereby the absolute number of recruits increases at declining population sizes relative to that number at K. However, constraining $A \leq 1/(z+1)$ implies that the full range of assumed *MNP* cannot be realized given the range of assumed *MNPL*. As

Table 2. *Parameter values used in simulations of the dynamics of the coastal migratory stock of bottlenose dolphins.*

	Symbol	Values	
Natural Mortality Rate	m	0.07, 0.14	
Human-Induced Mortality Rate	f	0.0, 0.007	m=0.07
		0.0, 0.014	m=0.14
Maximum Net Productivity Rate	MNP	0.02, 0.04, 0.06	
Maximum Net Productivity Level	MNPL	0.6, 0.8	
Median Age at Sexual Maturity	x	8, 11, 14	

literature suggests that the *MNP* and *MNPL* ranges are biologically reasonable (21, 22, 23), the unconstrained A values were used.

Population trajectories resulting from the range of parameter values used are shown in Fig. 3 for *MNPL* values of 0.6 and 0.8. The distribution of recovery times over the parameter range is shown in Fig. 4 for the the cases of no human-induced mortality versus constant human-induced mortality rates. The recovery time distributions are heavily skewed. In the cases of no human-induced mortality, the median expected recovery time from a reduction of the specified magnitude was 32.5 yr with a range of 14 - 90 yr. In the cases where there is an assumed constant rate of human-induced mortality equal to estimates of the pre-epidemic rate, the distribution of expected recovery time is shifted to longer periods, with a median value of 50.5 yr and a range of from 18 to > 100 yr. For the cases including human-induced mortality, 22% of the simulations resulted in no recovery within a 100 yr time interval. None of trajectories simulated resulted in extinction.

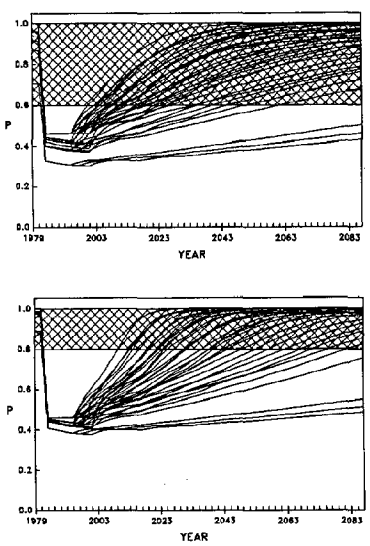

Figure 3. *Simulated population levels relative to carrying capacity (P) over the range of model parameter values used. Upper plate hatching represents OSP range with MNPL 0.6; lower plate MNPL 0.8.*

As the recovery standard used in these calculations was the lower limit of OSP, the recovery time estimates can be considered conservative. Uncertainty in the degree of reduction was not explicitly treated in the simulations run. However, the parameter ranges used result in a large range of reductions from K and thus may reasonably reflect expectations for reductions > 53%. In contrast, if the true reduction was less than the specified level then the recovery time distributions are non-conservative.

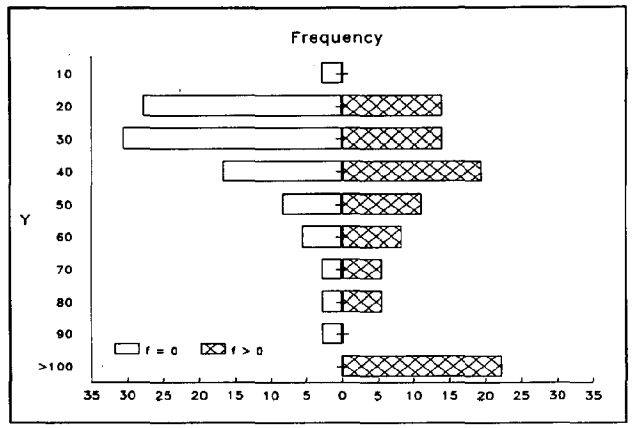

Figure 4. *Frequency distribution of simulated bottlenose dolphin population recovery times in years (Y) for the cases of f = 0 (no human-induced mortality) and f > 0 (constant human-induced mortality rate).*

Consistent and long-term population monitoring of the affected stock will be necessary to reduce the uncertainty associated with the estimates of recovery. Assumptions about the magnitude of depletion, the degree of human-induced mortality, and the degree of involvement of other bottlenose dolphin stocks need testing via direct experimentation and monitoring. As no consistent pre- and post-event indices are yet available, development of such indices through continued and new population sampling surveys and studies of biological samples from stranded animals will first be needed to test the assumptions.

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HISTORIC SHIPWRECKS: RESOURCES WORTH PROTECTING

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ABSTRACT

Historic shipwrecks are classified by archaeologists as "cultural resources" to indicate that shipwrecks are a significant facet of America's resources--as much so as her natural resources. Like coal and oil, cultural resources are non-renewable: once destroyed, they are lost to us forever. How do we determine which are historically significant? Fortunately, there is already in effect a valid and pragmatic evaluation system: criteria for the National Register of Historic Places. The Register applies strict standards for the determination of significance. Only a small fraction of all sunken ships lying in U. S. waters would meet these criteria. Currently, no state or federal law prohibits diving on shipwrecks. Hopefully, divers and archaeologists will join forces to protect these historically significant sites.

INTRODUCTION

During the past few years, controversy raged over proposed federal legislation to protect historic shipwrecks. Such legislation, some said, would result in loss of business for dive shops, instructors, charter boat services and salvage companies and, in addition, create cumbersome and arbitrary federal and state regulations, punitive enforcement and, eventually, loss of all wreck diving privileges. In 1988, the Abandoned Shipwrecks Act became law. Guidelines are being prepared to assist states in conforming to the new federal legislation. Let's put concerns over the law aside for a moment and take a look at the source of the controversy--America's historic shipwrecks.

THE NATURE OF HISTORIC VESSELS

The first European settlements in America were established along the coast where small boats soon sailed the bays and rivers which were the highways of the seventeenth century. America continued to have a strong maritime orientation, and by the nineteenth century our ships fished and traded throughout most of the world's seas. We know very little about the ships that the early explorers and colonists sailed, since the first accurate plans of ships were not produced until the late 1700s. Although plans and models of European warships survive from that period, very little is known about the merchant ships and small craft built in America until the mid-1800s. Even such famous warships as the Civil War USS Monitor are known only by early plans and an occasional faded photograph. America has enjoyed an exciting and important maritime heritage, and our knowledge of this legacy can be enhanced and enriched through the study of historic shipwrecks.

Historic shipwrecks are classified as "cultural resources" by archaeologists and preservationists to indicate that shipwrecks, along with other types of archaeological sites, are a significant part of America's vast resources, as much so as her natural resources. Like coal and oil, cultural resources are non-renewable and, once destroyed, are lost forever. Most ships lying in the waters of the United States never carried important passengers, fought famous battles nor set speed records; however, many of these ships could provide important archaeological data which would shed new light on our past if interpreted through publications, museum exhibits and films. Archaeology is much more than the recovery of artifacts; it is the interpretation of the artifacts, within the context of the entire shipwreck and its historical background, which gives meaning and significance to the site.

PROTECTION OF HISTORIC SHIPWRECKS

With so many shipwrecks out there (estimates range in the thousands), is it really necessary to protect them? The general public, including the sport diving community, has for many years actively supported the conservation of natural resources, recognizing that these resources should be preserved for future generations because of their beauty and intrinsic value. Cultural resources, too, require protection if they are to offer value to those that come after us. Although there

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are indeed many shipwrecks yet to be discovered, only certain ones are capable of providing the archaeological information that we seek. It is those shipwrecks that should be protected for long-term preservation and future study.

Contrary to the information being distributed by some groups, a shipwreck does not have to be located and salvaged in order for it to have historic value. In fact, historic shipwrecks lying undetected in deep silt are like untapped oil reserves: they lie in a stable state of equilibrium with their environment, deteriorating at an impressively slow rate, waiting for the time when adequate funding and personnel are available to excavate them properly and to recover from them their precious glimpse into our past.

Ocean engineers and sport divers seem to be among the most appropriate advocates for the protection of shipwrecks, since those groups are generally more aware than the general population of the importance of the sea and are more sensitive to maritime matters. Few ocean scientists or sport divers loot historic shipwrecks, and so they may not be aware of the amount of destruction taking place.

I have seen many offshore wrecks badly damaged--not by sport divers, but by salvage companies looking for a few dollars' worth of copper or brass. My dive buddies and I have returned from dives saddened by the irreversible destruction of our favorite dive sites. In other cases, historic shipwrecks were damaged by small groups of divers, who often left recovered artifacts to rust away under back porches or in garages. Countless other wrecks were destroyed in previous years through construction and dredging projects where proper archaeological surveys were not conducted in advance. Some serious damage to shipwrecks is inadvertent. Wrecks are often damaged by commercial fishing activities, especially trawling and dredging, by boat and ship anchors, and by the forces of nature. These forces and activities often result in loss of important archaeological sites, which deprives all of us of the opportunity to learn from and enjoy the information which the site might have offered.

PROTECTIVE LEGISLATION

If we accept the fact that there are numerous historic shipwrecks in American waters and that some, if not many, of these are currently threatened with damage or destruction, let us turn to the idea of protective legislation. Should there be laws to protect historic shipwrecks? What applicable laws currently exist?

At the present time nearly all U. S. coastal states have laws protecting historic shipwrecks from improper salvage. Although the federal shipwreck protection law is new, archaeological sites on land have been protected for many years and several federal laws dictate protection of submerged sites in cases where federal funding or federal permits are involved. The main benefits of the new federal legislation should be the clarification and coordination of current laws, separation of admiralty and salvage claims from those involving historic shipwrecks and better protection of those wrecks which have been determined to be significant.

Determination of significance has been the subject of much unnecessary concern. Some fear that all shipwrecks will capriciously be classified as significant and sport and commercial wreck diving will be virtually eliminated. No such action has been contemplated and almost all existing state shipwreck legislation permits some type of public access to shipwrecks, including historic wrecks. In fact, there is already in effect a valid and pragmatic evaluation system: the criteria for the National Register of Historic Places. In order for a shipwreck to be declared eligible for the National Register, it must meet a series of tests for significance. The criteria are specific and are designed to recognize those archaeological resources which are most representative of our past. Already, the National Park Service has issued a special publication which describes the criteria for nominating a historic shipwreck to the National Register. Dozens of U. S. shipwrecks have been placed on the National Register of Historic Places after a careful review at both state and federal levels, while many have been found ineligible for the Register.

NEW OPPORTUNITIES

New laws do not have to adversely affect the recreational activities of most divers. In fact, divers have already discovered that participation in scholarly shipwreck research can be rewarding and exciting. All over the world, groups of sport divers are teaming up with professional archaeologists and ocean surveyors and engineers to locate and investigate shipwrecks.

It is interesting to note that many preservation efforts in England, Europe, Canada and elsewhere are actually organized and carried out primarily by sport divers. In Ontario, for instance, divers concerned about their historic shipwrecks have formed organizations such as "Save Ontario's Shipwrecks" (SOS) to take an active role in the preservation process. In this country, sport divers have already worked alongside archaeologists on shipwreck excavations in Florida, Maryland, Michigan, North Carolina, South Carolina, Virginia, Vermont and elsewhere.

National certifying organizations have begun to develop training programs in underwater archaeological methodology. In

1979, a National Scuba Workshop in Florida produced a resolution asking all national certifying agencies to include in their basic training programs a brief statement on the importance of preserving cultural as well as natural resources. Efforts are underway to create more such programs. Many universities now offer courses in underwater archaeology, either for college credit or for continuing education credits.

Many sport divers are interested in history and archaeology, and quite a few are skilled researchers. As federal and state underwater archaeological programs begin to develop and grow, so will opportunities for sport divers to become involved in sponsored research projects such as archival research, shipwreck surveys and excavation, conservation and museum exhibit preparation. Instead of prohibiting diving, the new federal legislation may well foster a whole new age of cooperation between professional and amateurs interested in our maritime past.

THE ABANDONED SHIPWRECK ACT: A CONTEXT

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ABSTRACT

The Abandoned Shipwreck Act became law in 1988. As author of the act, and as a resource manager, the author discusses the act.

The discussion includes, the purpose of the act, the potential effects of the act, and the current status of state law. To understand the act one must understand the relationship of shipwrecks and historic shipwrecks, in particular, to broad based social, economic and environmental systems. The magic lure of gold and the evolution of state laws in the face of conflicting social values has left a ten year legacy of confusion. The act and the paper should contribute to sorting out the confusion.

INTRODUCTION

"In the early morning hours of July 31st, the wind suddenly shifted to the east-northeast, and the hurricane struck with all its fury. The ships, gripped in the incredible force of the crashing waves and mighty winds of nature's most awesome phenomena, were lifted like matchsticks on mountainous crests to be plummeted in the next instant into deep troughs of the ocean. Tons of seawater crashed over the railings of the galleons and, with the shriek of the wind, drowned out the screams of the seamen washed overboard to their death." (Cobb Coin, Inc. v. The Unidentified Wrecked and Abandoned Sailing Vessel, 525 F. Supp. 186 [S.D. Fla. 1981]). So begins U.S. District Judge James Lawrence King's decision concerning the fate of the artifacts recovered from the shipwrecks of the 1715 Spanish Plate fleet off the coast of Florida. A decision which challenged state laws.

In 1981 and 1982 decisions resulting from the Cobb Coin case in the Southern District of Florida created a jurisdictional conflict between the authority of state governments and the Federal court to control the excavation of state land for the purpose of recovering shipwrecks. In response to this situation I drafted federal legislation resolving the conflict in favor of the state governments.

The purpose of this article is to explain the need for and the purpose of The Abandoned Shipwreck Act. This article will briefly present the state perspective, the most relevant federal court decisions on this issue, and the purpose of the bill.

INTEREST IN SHIPWRECKS

Since the 1950's, rapid advances in the technology of diving and remote sensing equipment have for the first time made shipwrecks accessible to many people. Three groups have a special interest in abandoned shipwrecks: the sport diving community, members of the archaeological and historic preservation communities, and professional treasure salvors.

Although most shipwrecks have been located by fishermen. Recently many wrecks have been located by sport divers. Most shipwreck sites are destroyed by dredging and port development, but recently many wrecks have been damaged by treasure salvors and some by sport divers. A few shipwrecks have been protected by the designation of underwater parks and a few have been excavated by archaeologists.

The state as a multiple-use manager of its resources must consider these three groups. Each group has a different use for the resource. For the sport diver, the wrecks are an important focus for recreational diving; some divers like marked underwater trails explaining the wrecks, some like wrecks undisturbed by modern man, and others like to collect artifacts from wrecks. The diver's desire for unrestricted access to shipwrecks may conflict with the treasure salvor's desire for exclusive use of a

wreck, and the diver's random collecting of artifacts from wrecks may conflict with the archaeologist's concern for ordered collection.

To the archaeologist, shipwrecks are an integral part of the total material cultural resource base. Certain social, economic and technological systems of the past are reflected in the patterned pieces of ship and cargo spread across the ocean floor. The treasure salvor's goal is primarily economic; he wants to minimize the cost of recovering gold, silver or artifacts that have a maximum commercial value.

STATE LAWS

States have generally managed shipwreck resources in the context of the water or coastal management priorities of the state. The first state ("state" will continue to be used to refer to jurisdictions of the United States including states, territories, possessions, and the District of Columbia) to pass legislation which specifically addressed abandoned and historic shipwrecks was Colorado in 1963.

Colorado is typical of many Western states, that is those west of the 98th meridian (about the Mississippi River). Colorado is short of water and follows a principle of prior appropriation of water: first come,first served. The laws regarding water and the lands beneath the water are carefully drawn to protect individual and state rights to use and to allocate a scarce resource. The definition of the state's area of jurisdiction, the state's claim to title to the shipwrecks, and the state's permit process reflect the priority concern for the protection of water resources. This strong concern for water management explains the existence of laws specifically addressing shipwrecks in states where few, if any, shipwrecks have been located.

In contrast to the Western water rights system is the Eastern system of riparian rights. Where water is more plentiful, a system of use, return, and reuse of water by those adjacent to the water source is feasible and has become customary. Laws concerning shipwrecks in the Eastern states tend to have been developed in response to comprehensive historic preservation legislation and to the location of particular shipwreck sites rather than as part of water resource systems. In Florida, for example, legislation developed between 1965 and 1967 in response to the discovery of artifacts from the 1715 Spanish Plate fleet. The other states to develop laws in the 1960's are: Georgia, Maine, North Carolina, and Texas. Since 1970, 25 additional states have passed laws specifically addressing shipwrecks. States without specific legislation for shipwrecks treat them under their general historic preservation legislation.

Although the laws developed in different legal and resource contexts over a 25-year period, the laws in Eastern and Western states are remarkably similar. It is notable that no state prohibits sport diving on historic shipwrecks. Indeed 15 out of the 30 laws provide state compensation to private parties for recovery activities.

Each state defines the area of state jurisdiction to be compatible with the state law implementing the federal law which affirmed title to the land, the Submerged Lands Act (43 USC 1301-1315) and generally includes rivers, lakes and coastal waters out to three miles.

STATE MANAGEMENT

The state's ability to issue or deny permits for activities on state lands is essential to good management. An "after the environmental damage has been done" case-by-case Federal Court approach to each archaeological site would be burdensome to those states attempting to manage intensively used areas such as ports and state parks.

Over the years, states have worked closely with the groups interested in shipwrecks, the archaeologists, sport divers, and salvors. States have recognized that sport divers are discovering and studying historic shipwrecks and are also major contributors to many local economies. At least 80% of the known shipwrecks have been discovered by sport divers, 15% by state projects and fisherman, and 5% by treasure hunters.

Under the Act, states are expected to continue to protect historic shipwrecks and encourage sport diving on wrecks. States such as Michigan, Vermont, South Carolina, and Florida have encouraged sport diving by producing publications, creating underwater parks, placing moorings near wrecks, and sinking ships as dive sites.

Based on current figures, only about 5% of the 12,000 or so known wrecks will be defined as historic. The historic shipwrecks are mostly prehistoric canoes, canal boats, and steamboats with mundane cargoes such as cloth and shovels. Archaeological excavation of these sites is being accomplished by sport divers and college students. Every year more than

25 groups sponsor, through participant funding, over 50 projects to map and recover shipwrecks. However, most of the fishing boats, barges, ferries, and work boats that are lying on the bottom are not of interest to the treasure hunter or the archaeologist, but are a major source of recreational interest to a minority of sport divers.

Since the 1950's, states have managed historic shipwreck archaeological sites as part of their historic preservation programs and, since 1966, have applied minimum national standards to their management efforts. The National Historic Preservation Act standards define what is historic and set forth management procedures that incorporate: 1) public participation on decision-making boards, and 2) public hearing and appeals processes. Historic shipwreck projects are eligible for grants and, in addition, 15 states, provide monetary compensation to private sector profit groups. There have been problems in the past involving state permits and contracts, yet these conflicts have been judiciously resolved by state courts, and citizens have always had an impartial forum for conflict resolution.

States manage many offshore resources including major sectors of the economy such as fishing, oil and gas, and tourism. The disposition of artifacts recovered from shipwrecks has not been a major administrative burden or economic benefit. States may be expected to continue to accession and deaccession their cultural resources for parks and museums for the public benefit.

THE FEDERAL COURT

The public interest of the Federal Admiralty Court, to return goods to commerce, has its roots in English history during a time when commerce and piracy had reached points of significant economic impact and the admiral of a ship was the law of the sea. The admiralty system developed in the courts, rather than through legislation, during a time when there was a need for the ordered recovery of goods.

The Federal Court sitting in admiralty makes a salvage award considering three criteria based on rules established in The Blackwall (77 U.S.(10 Wall) 1, (1869)) opinion:
(1) marine peril; (2) voluntary service, and (3) success in recovering the vessel or cargo. Further, the court will consider the degree of danger present in the rescue, the value of the property recovered, and the time and labor expended by the salvor. In case of abandoned property, the salvor may receive the property or the proceeds from the sale of the property.

Three important features of the court system are time, cost, and a case-by-case approach based on judge-made law. First, time is a critical consideration in an understanding of court responsibilities and procedures. There are a limited number of courts and judges and in each case all parties have full rights according to procedure. Currently, there may be a delay of as much as two years in many courts before a case is heard and then the appeal process may postpone a decision for as many as ten years.

Second, cost is important to individuals filing a claim for an award with the court because the complex procedures usually require the services of a lawyer and if there are counterclaims by other parties, states, or the Federal government, legal fees and court costs may escalate rapidly. Often, too, for highly specialized cases such as for historic shipwrecks, the court may request the services of a special master, a specialist, and this cost is then added to the court costs.

Third, the court takes a case-by-case approach. Each judge in each district makes an independent decision based on precedent after a case is brought to court. In the realm of marine affairs, where there is little statutory law, there is much room for interpretation by the judges. Also critical is the concern that a wreck must be located and efforts made to recover property before there is a claim to file with the court for an award.

Unfortunately, the conflict of use concerning the submerged land often comes during attempts to locate buried shipwrecks, since the excavation of a particular site might conflict with excavation for some other purpose, such as mining, that is not part of the court's tradition.

Only about a dozen cases in the history of the Admiralty Court have dealt with abandoned property. Of these cases only half have concerned shipwrecks with some historic value. As mentioned earlier, states have claimed historic shipwrecks in state waters.

Conflict between the authority of the Federal Court and that of state government was created when the Federal Court for the Southern District of Florida determined that contrary to state claims they had jurisdiction over a

shipwreck in state waters. The decision, quoted at the beginning of this article referred to here as Cobb Coin, placed the state of Florida and potentially other states in a conflict relationship situation with the Federal court over the resource represented by buried shipwrecks. The conflict situation increased in complexity with a later contradictory court opinion in Massachusetts where the Federal court determined that it did not have jurisdiction.

To date, seven conflicting federal court actions have thrown into doubt the legal regulations that govern abandoned shipwrecks within state waters. In the first case, Cobb Coin Co.,Inc. v. The Unidentified Wrecked and Abandoned Sailing Vessel, 549 F. Supp. 540 (S.D. Fla. 1982) the U.S. District Court for the Southern District of Florida held that the Federal admiralty law of salvage applied to abandoned shipwrecks lying within Florida's submerged lands. The court found that the Submerged Lands Act of 1953 transferred title to the lands and natural resources of the lands beneath navigable waters to the states, but that title to abandoned wreck sites was not included in the transfer. The court found that the traditional principles of salvage govern activities associated with these shipwrecks. The court determined that the Florida statute purporting to govern shipwrecks within state waters was, in some ways, inconsistent with and was superseded by salvage principles, and the Cobb Coin Co.,Inc., was entitled to exclusive salvage rights over the wreck and cargo. The court also suggested that Federal admiralty principles, as applied to the salvage of historic shipwrecks, could be fashioned to safeguard the artifacts and invaluable archaeological information associated with the shipwreck, and that the public's interest in the shipwrecks could be accommodated through a proper award of a portion of the artifacts to the State of Florida. As a result, the court currently is the overseer of five state-permitted wreck sites in Florida's waters.

In contrast, the U.S. District Court for the District of Massachusetts found that the State of Massachusetts had a plausible, that is a colorable, claim to an abandoned shipwreck located within state waters. This meant that any action against the vessel was in effect a claim against the state. But the Eleventh Amendment of the United States Constitution barred an action against the state without its consent. When a salvor filed a claim in Federal court seeking title to the vessel, the court dismissed the action for lack of jurisdiction at the request of the State of Massachusetts. Maritime Underwater Surveys, Inc., v. the Unidentified Wrecked and Abandoned Sailing Vessel, her Tackle Etc., 717 F.2d.6(1st Cir. 1983).

The U.S. District Court for the District of Maryland reached a similar decision in Subaqueous Exploration and Archeology, Ltd., and Atlantic Ship Historical Society, Inc.,v. The Unidentified Wrecked and Abandoned Vessel, 577 F. Supp. 686(D.MD.1983), finding the state's claim to the vessel colorable, the action being in effect an action against the state, and the Eleventh Amendment a bar to the action.

In a complex set of actions the Fifth Circuit, certain salvors obtained title to items recovered from a buried wreck within submerged lands of the State of Texas after having obtained from the Texas legislature a waiver of the sovereign immunity of the state. An earlier unreported District Court decision, that was not appealed, found that the State of Texas owned the artifacts recovered from the wrecks and that the Eleventh Amendment barred suit against the state. Platoro, Ltd.,Inc.,v.Unidentified Remains Etc. No. 81-1257,695 F.2d.893 (5th Cir.,January 20, 1983).
In one of the opinions in the litigation, the District Court for the Western District of Texas, specifically declined to hold the salvors to the standards of expertise required of marine archaeologists, as the state had urged.

In an 11th Circuit decision, the U.S. District Court for the Southern District of Georgia upheld the state's claim that the wreck was embedded on state property and that consequently title to the vessel rests with the state. In addition, the court found that under the Eleventh Amendment, and alternatively due to the salvors' failure to assert a valid salvage claim, the claim for award was denied. Frank Chance, Paul Chance, and David Topper v. Certain Artifacts Found and Salvaged From the NASHVILLE a/k/a The RATTLESNAKE, Her Engines, Boilers, Tackle, etc. 606 F.Supp. 801 (S.Ga.); affirmed, 775 F.2nd 302 (11th Cir.1985).

Another 11th Circuit decision indirectly affirmed state authority. Joan M. Klein v. Unidentified Wrecked and Abandoned Sailing Vessel, etc., 758 F.2d. 1511 (11th Cir. 1985). In that case the court determined that a shipwreck embedded in the submerged lands of Biscayne National Park owned fee simple by the U.S. government was as a consequence of being embedded, the property of the U.S.

government. The U.S. government had received the land and the shipwreck from the previous fee simple owner, the State of Florida.

In October 1987, The U.S. District Court for the Eastern District of North Carolina upheld the state's assertion that the Eleventh Amendment bars an action by a salvor when that state asserts title to a shipwreck located in its waters. Alan Richard Riebe v. The Unidentified, Wrecked and Abandoned 18th Century Shipwreck, etc. unpublished, decided October 6, 1987, W. Earl Britt,J.,U.S. District Court.

In sum, the Federal court has, but once, upheld state authority.

THE ABANDONED SHIPWRECK ACT

The bill was introduced in 1983 and passed the House of Representatives in 1984 but was stopped in the Senate by Senator Paula Hawkins of Florida. The bill has been reintroduced in each Congress. In December 1987, the bill, S. 858, passed the Senate and was sent to the House. S. 858 passed the House on April 13, 1988 and was signed into law April 28, 1988 as the Abandoned Shipwreck Act.

The primary purpose of the Act is to recognize each state's authority to control the excavation of state lands for the purpose of recovering embedded and historic shipwrecks. The Act accomplishes this purpose by declaring that the state has title to shipwrecks which are either embedded in submerged lands, or coralline formations, or are eligible for the National Register of Historic Places.

The Act is needed for two reasons. First, there is a clear need for management. Environmental conflicts often occur when treasure hunters are looking for shipwrecks. Dynamiting of coral reefs, dredging of endangered turtle nesting habitat, excavation of shellfish beds, and disruption of recreational swimming and diving are examples of the activities that the states need to control. The Act meets this need by clearly stating that the state has title to the land and all that is embedded in the land. The Act addresses the state's right to permit the excavation of state land, and the state's right to spend money on the creation of underwater parks, on the conservation of recovered artifacts, on public education, and on displays about shipwreck sites.

The second reason the Act is needed is to decrease the costs to the state caused by unnecessary litigation. State authority has been challenged in Federal Court on six occasions. In one case, Cobb Coin, the Court assumed jurisdiction over the excavation of state land for the purpose of recovering shipwrecks, without regard for environmental or recreational concerns. Many cases are still pending. Now, no future litigation on this jurisdictional question will add to the estimated $20 million that the state taxpayers have spent. Moreover, the Act will not cost the Federal government any money and will not expand the Federal bureaucracy.

In reference to proposals for a strong Federal role, for either the executive or the judiciary, in the management of shipwreck resources, it seems redundant and expensive.

As an alternative to the Act, conditioning the state's authority to own shipwrecks would require the development of a costly Federal bureaucracy. If the state's authority is conditioned, in any manner, an administrator such as the State Governor, the Secretary of the Interior or of Commerce must determine that the state law meets the conditions of the Federal law. If the state law did not meet the conditions, then there would be the need to establish a Federal bureaucracy to administer shipwrecks. Such expensive and drastic measures seem unnecessary when 1) the states are managing these resources, and 2) the Secretary of the Interior already controls much of the state's historic preservation activities through the National Register of Historic Places and money from the Historic Preservation Fund for state plans.

Because states already administer shipwreck archaeological sites, there is no need to substantively distort the Federal Court system, which applies to ships and cargoes that are in imminent danger, to administer archaeological sites. The establishment of a complex court filing system will require increased tax support for the Federal Court and increased state taxes to support state participation. Sport divers, in particular, are understandably adverse to paying higher taxes for the purpose of being excluded from dive sites. There are probably only two commercial operators working in the United States who might benefit from this salvor subsidy on mining old wet wrecks. There are more than 3 million sport divers. However, the majority of sport divers will not be affected by this Act. Even the majority of wreck divers will not be affected because they prefer wrecks which are not legally abandoned

and that they can see, not wrecks embedded and covered with earth.

CONCLUSION

In summary, this article has presented the three groups interested in shipwrecks, the sport divers, the archaeologists and the treasure salvors. A brief review of existing state law and some multiple-use management concerns have been presented. Federal Court challenges to the existing system of state law have been identified. Finally, the purpose of the Abandoned Shipwreck Act to affirm the existing system has been stated.

In conclusion, continuation of the assignment of title to abandoned historic shipwrecks to the states is the simplest, clearest management system. With title, the expenditure of state funds for administration of permit systems, the conservation of materials for public benefit and the transfer of title to certain artifacts would be most clear. Any international claims to historic shipwrecks in state waters would be foreclosed.

The sport divers and other interested groups who know their own interests and their own resources should be allowed to continue to evolve appropriate systems to manage their state's shipwrecks. The management system for a prehistoric canoe in North Dakota need not be the same as the system for a Spanish galleon in Florida or a World War II fleet in Truk Lagoon.

REBURIAL OF A 16th CENTURY GALLEON

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For eight years (1978 - 85) the Marine Archaeology Unit of Environment Canada was involved in the excavation of Spanish Basque whaling vessels in Labrador. During excavation, one of the galleons was completely disassembled. Upon completion of excavation and structural recording, the timbers were systematically reburied on the seabed using a method intended to preserve the timbers. Provision has been made to ensure ongoing monitoring of timber degradation. The rationale behind the procedure, the procedure and the results to date are discussed.

HISTORICAL BACKGROUND

Following Cabot's voyage to Newfoundland at the close of the 15th century, Portuguese, English, French and Basque commercial interests ventured into the northern New World. These Europeans were drawn by the rich stocks of protein in the form of codfish and train oil of the bowhead and right whales. Clearly at the forefront of these commercial ventures were the Basques who had a monopoly on the lucrative whale oil trade in Grand Baya (the general area of the Strait of Bell Isle). The whaling traditions of the Basques predate the Middle Ages and their shipbuilding abilities in the 16th century produced vessels capable of continuous transatlantic duty. The fact that the Basques were world leaders both in the realm of whaling technology and shipbuilding combined to give them a virtual monopoly on early New World whaling. In peak years, from approximately 1540 until into the late 16th century, up to 2000 Basques in as many as 30 vessels journeyed to Labrador in pursuit of whales. The vessels spent four to six months per year harvesting whales from a series of whaling stations along the north shore of the Strait of Belle Isle. This heavy marine traffic in new waters and often threatening ice conditions resulted in its share of shipwrecks, several of which have been reported by Selma Barkham (Barkham, 1978: 8-19). The Canadian Parks Service's Marine Archaeology Unit, under the direction of Robert Grenier, has been conducting an excavation on one of these shipwrecks, a 16th-century galleon at Red Bay Labrador, (Fig. 1).

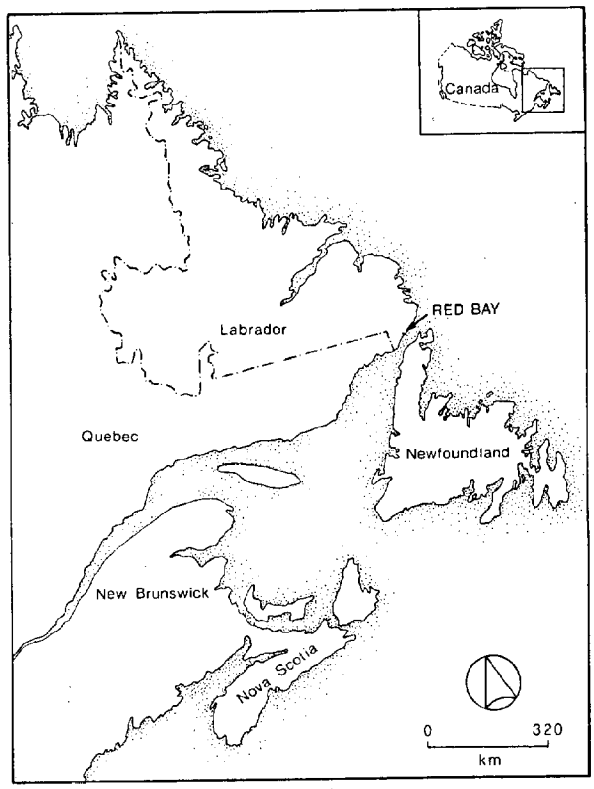

Figure 1

This excavation was concurrent with and complimentary to the excavation of the Red Bay whaling station by James Tuck and the Memorial University of Newfoundland (Tuck & Grenier, 1985).

INTRODUCTION

Over the course of six excavation years, the Canadian Parks Service completed the structural disassembly of the Basque Galleon thought to be the San Juan (Waddell, 1986). By 1985 the wreck had been completely disassembled. Over 3000 timbers had been raised to the surface, recorded and placed in temporary, underwater reburial pits. The major task of the 1985 field season was to permanently rebury the entire complement of ship's

timbers. This paper will provide a general outline of that undertaking. Systematic reburial of such a large number of timbers had never previously been attempted. The Conservation Division of the Canadian Parks Service was asked to develop guidelines for the work. After literature searches, several consultation meetings and some experimentation, a reburial plan was formulated (Murdock and Stewart, 1985). The essence of the plan was to cost-effectively create a sealed and anaerobic environment in which to store the timbers. The reburial would attempt to duplicate the pre-excavation environment of the wreck timbers in terms of light, temperature and gas exposure.

REBURIAL

An estimate of the timber volume was done in order to determine the space requirements of the reburial area. It was calculated that an area 14 m by 16 m by 1 m high would be required. This permitted the stacking of timbers in three distinct layers with 20 cm of sand above each layer. The profile of the reburial area was kept as low as possible in order to minimize any iceberg contact, which is unavoidable in the area. The seabed depression created by excavation of the San Juan was the obvious area to locate the pit, thereby reducing overall profile and avoiding disturbance of the surrounding artifact-bearing unexcavated seabed.

To contain timbers and sand, a sandbag dyke was built using approximately 1200 plastic salt bags, containing some 36 metric tonnes of sand (Fig. 2). The dyke walls, built in stages, were supported by timbers and sand on the inside and by rock fill on the outside. Emphasis was on the use of readily available materials (rock, sand, salt bags) to create a stable tapered wall. In addition, it was felt that a tapered rock wall was essential in minimizing disturbance by scouring icebergs that could severely damage any vertical sandbag wall.

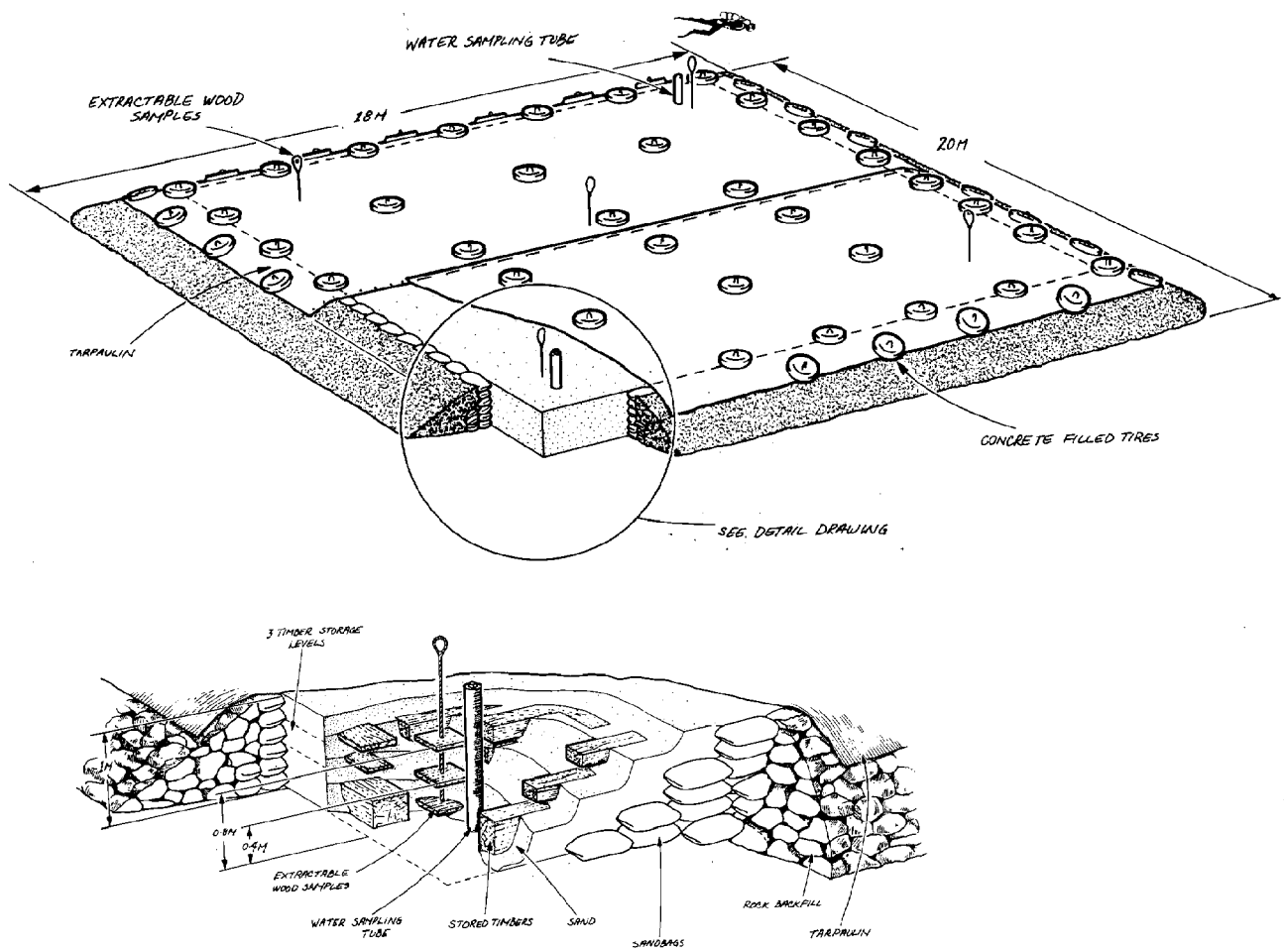

Figure 2

The area of the wreck slopes slightly downward from southwest to northeast. The deeper portion of the pit, the northern side, was used for larger timbers that passed through more than a single reburial layer. This included the 14-metre keel, keelson and several other great and compass timbers. Generally the timbers were buried in three distinct layers. The first layer was laid within the dyke on sterile, previously excavated seabed. Timbers were fitted or "nested" to maximize the total wood volume in each layer (Fig. 3). Upon completion of a layer, the area was mapped to show the location of each timber. Following the verification of the layer map, the sand-covering operation began. Sand was lowered into position over the site in a specially designed dump bucket, carrying approximately two metric tonnes of sand (Fig. 4). This was manoeuvered into position and released into the reburial pit. Gaps between timbers were filled and then 20 cm of sand was used to cover the entire level. The following two timber layers were built up similarly, producing an overall height of approximately one metre. Ninety-six metric tonnes of sand were put over the first timber layer, followed by 93 metric tonnes for the second layer and 126 metric tonnes for the final layer, totalling 315 metric tonnes.

Figure 3. Timbers fitted into northern half of reburial layer 3. (Photo by P. Waddell)

The reburial pit required a covering to prevent erosion of the sand and to minimize gas transfer. The covering used was a 36-mil hypalon tarp, which is a synthetic elastomer rubber with a reinforcing weave. To simplify handling, the cover was made in two pieces, which were laced together underwater (Figs. 2 and 5). The 16-m-by18-m dimensions permitted coverage outside the walls of the reburial pit by one metre on each side. To hold the cover down, 60 concrete-filled tires, totalling nine metric tonnes, were dispersed over its surface.

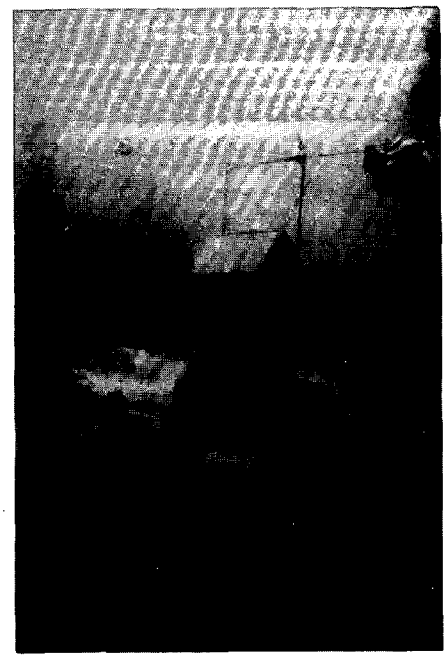

Figure 4. Sand being dumped onto reburial pit (Photo by D. Pagé)

Figure 5. Trial joining of reburial tarp on surface. (Photo by R. Chan)

Reburial of the timbers at Red Bay was the largest undertaking of its kind aimed at maintaining shipwreck timbers in an optimum state. To help determine the effectiveness of the methodology, a testing procedure has been established incorporating wood samples placed at three different depth levels through the reburial site. The samples were strung on ropes that can be pulled from the pit without disturbing the other timbers (Fig. 2). Over time these timbers can be recovered for comparison with frozen control wood samples from which they were cut. Some timbers were reburied outside the reburial pit and these could also be used in assessing the effectiveness of the reburial methodology. Current plans call for the initial recovery of wood samples after five years (1990) and at several more intervals over the next 50 years. The effectiveness of sealing will also be gauged by taking water samples from within the pit itself. Plastic tubing was modified and reburied with the timbers. These vertical tubes (Fig. 2) provide access to water at the bottom of the pit. Syringes can be fitted to sampling tubes incorporated into the protruding vertical tubes. This permits the drawing of water samples without opening and thereby contaminating the pit. There was an opportunity to take an initial water sample from the pit after one year (1986). Analysis of the sample was done and compared to the sea water immediately above the reburial area. Results were as follows:

Test Name	Ambient Sea Water Sample	Reburial Pit Water Sample	Measured Units
Sulfide	0.05	0.04	mg/L S
Dissolved oxygen	9.82	0.20	mg/L O
Alkalinity	100.00	101.00	mg/L CaCO3
PH	7.83	7.09	units
Nitrate	0.002	0.008	mg/L N
Nitrite	0.002	0.008	mg/L N
Ammonia	0.01	1.1	mg/L N
Orthophosphate	0.013	0.076	mg/L PO4
Total phosphorus	0.034	0.308	mg/L PO4
Silicate	0.10	0.75	mg/L Si
Iron	0.09	9.9	mg/L Fe
Kjeldahl nitrogen	0.13	1.6	mg/L N

These results are very promising in terms of achieving an anaerobic state within the sand at the buried timber level. This is essential to reduce wood degradation. The first wood samples will be pulled for comparative analysis with the frozen control samples in 1990. This test and continuing comparisons will, over the years, determine the long-range effectiveness of this preservation technique. The results will provide essential information for those charged or concerned with long-range preservation of cultural resources from the sea.

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SUPPORTING UNDERWATER ARCHAEOLOGY WITH OCEAN TECHNOLOGY

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ABSTRACT

The Yorktown Shipwreck Archaeological Project has employed ocean technology for the location, assessment and excavation of shipwrecks from the Battle of Yorktown, 1781. A total of nine shipwrecks was located, using remote-sensing surveys. The best-preserved of the shipwrecks was excavated using a unique method: a steel enclosure, or cofferdam, was constructed around the shipwreck, and filtration systems were used to clarify the enclosed water, thus alleviating strong currents and near-zero visibility which hampered previous research. During the excavation, recording was accomplished using a three-dimensional measurement system. Final hull measurements were recorded with a device which utilizes high-frequency sonic signals to provide precise measurements. A computer-aided design and drafting (CADD) system provided analysis and report-quality drawings.

INTRODUCTION

In the fall of 1975, a small group of archaeological volunteers, with assistance from state archaeologists, began a study in the York River which eventually became a full-scale research project for the Commonwealth of Virginia. Those archaeologists located and reported on the remains of a large wooden ship believed to have been lost during the Battle of Yorktown, 1781. At least 26 British vessels were sunk during that famous battle, which proved to be the last major battle of the American Revolution. Unfortunately, however, strong currents, near-zero visibility and persistent stinging jellyfish hampered diving activities, thus limiting the effectiveness of the archaeological team.

During the years that followed, numerous applications of ocean technology were utilized in a coordinated effort to locate, evaluate and excavate ships from the sunken fleet at Yorktown.

LOCATING AND EVALUATING THE SHIPWRECKS

Beginning in 1976, the Virginia Historic Landmarks Commission (now the Virginia Division of Historic Landmarks, Department of Conservation and Historic Resources) coordinated a series of technological and archaeological studies. In 1976 and 1977, with support from the Magnetics Branch of the David W. Taylor Naval Ship Research and Development Center, Annapolis, Maryland, and the Virginia Institute of Marine Science, Gloucester Point, Virginia, two magnetometers were utilized for locating additional shipwrecks at Yorktown. Shallow areas were surveyed with a Schonstedt high-balance gradiometer, while deep-water areas (as deep as 90 feet, or 27 meters) were searched with an AN/ASQ 81 magnetometer. Almost 300 magnetic anomalies were recorded and plotted on a large-scale map.

In 1978, the Landmarks Commission received a one-year survey grant from the National Endowment for the Humanities, thus formally establishing the Yorktown Shipwreck Archaeological Project. The first project activity was to survey the same areas near Yorktown with a Klein Associates Hydroscan 530 sonar, which has both side-scanning and bottom-penetrating capabilities. Sixteen primary and 35 secondary sites were identified, many of which correlated closely with previous magnetometer data.

All remote-sensing data were correlated and primary zones were established for diver investigations. The follow-on surveys by underwater archaeologists resulted in the verification of nine British shipwrecks from the Battle of Yorktown: six were parallel to the Yorktown shoreline, two lay in shallow water on the opposite shore, near Gloucester Point, and the ninth was in the deep water of the main channel. In 1980, with the assistance of an archaeological team from Texas A&M University, one of the Gloucester Point sites was positively identified as the remains of the largest British warship, HMS CHARON.

THE COFFERDAM EXCAVATION

One of the shipwrecks, referred to by its archaeological site designation, 44YO88, was found to be in an excellent state of preservation. The state archaeological team felt that complete excavation of the ship would yield new information on 18th century

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ship construction and warfare; however, they felt that it would be very difficult to conduct the excavation in the adverse environment of the York River.

The same problem had plagued earlier archaeological diving. In 1976, the state contracted with archaeologist Dr. George F. Bass, Texas A&M University, to conduct a survey of one of the Yorktown shipwrecks. In an attempt to offset the poor diving conditions, Bass and his team constructed a floating cofferdam designed to isolate a portion of the wreck and filter the enclosed water. The system, which had to be constructed hurriedly and on a small budget, was not successful, but the concept appealed to the state team when they began long-range planning in 1979.

A new proposal was prepared, this one calling for the construction of a rigid steel cofferdam to surround 44YO88 and for the installation of a filtration system to clarify the enclosed water. The project was constructed in 1982 with funds from the U. S. Department of the Interior, the National Endowment for the Humanities, the Commonwealth of Virginia, the National Geographic Society and numerous other corporate and private sources. Such a cofferdam had been proposed before but never built; cofferdams had been used on several occasions for shipwreck excavations in Europe, but all had been constructed in shallow water, with the enclosed water being removed for a dry-land-style excavation. The Yorktown cofferdam was the first to create a "swimming-pool" environment in a silty, algae-rich river.

The Yorktown cofferdam is constructed of interlocking sheet steel pilings to form an enclosure 97 feet (27.4 m) long by 45 feet (13.6 m) wide. It should be noted that since the ship would have been built using the English system of measurement, that same system was used throughout the Yorktown project. With a water depth at the site of approximately 20 feet (6.1 m.), the cofferdam encloses approximately one-half million gallons (1,892,500 l.) of water, which is being filtered by commercial swimming pool filters donated by the Purex Corporation. Two separate filtration systems are employed, each using an electric pump to circulate water through a bank of sand filters.

Initially, the system did not work as expected. River water was freely exchanged with cofferdam water through seams in the walls and through the porous silt and clay in the river bottom. Introduction of river water brought new silt and algae to be removed and limited the effectiveness of the filters. Then, in 1985, the Ecolochem Corporation of Norfolk, Virginia, offered long-term assistance with the problem Ecolochem, the largest mobile filtration company in the world, conducted a series of tests and monitored the filters around the clock. From late 1985 to the close of the project in 1988, average visibility was better than ten feet, compared to near-zero in the open river; visibility occasionally reached as much as 30 feet (9.1 m.), permitting excellent photographic recording of the site.

As a result of the cofferdam's success, the project was reported in the June, 1988 issue of National Geographic magazine, and also featured in the BBC-TV documentary "Discoveries Underwater."

Each year since 1982, research has been conducted at the site in cooperation with the Program in Maritime History and Underwater Research at East Carolina University, Greenville, North Carolina. This cooperative research has helped refine excavation and recording methodologies and has provided an excellent training opportunity for students pursuing an advanced degree with a specialty in underwater archaeology. Within the protective confines of the cofferdam, students do not have to contend with the hostile environment posed by most coastal or riverine sites; instead, they can concentrate on archaeological methodology. The cofferdam is an ideal training situation.

Silt was removed from the site by airlifts, often referred to as "underwater vacuum cleaners." These devices use compressed air to create a suction in a rigid hose or pipe. The suction is used to remove silt and clay from the wreck site. As artifacts were exposed, they were recorded using a variety of techniques. The main recording system utilizes a three-dimensional measurement and calculation scheme devised by Charles Mazel. Three surveyor's tapes are pulled from known reference points to an object being located; these direct tape readings are then converted to rectilinear coordinates using a simple computer program.

This same measurement job can now be done electronically using the Sonic High-Accuracy Ranging and Positioning System (SHARPS). This device, developed by Applied Sonics Corp. and distributed by Marine Telepresence Inc., Poquasset, Massachusetts, utilizes sonic signals and associated computer hardware and software to locate objects quickly and with a very high degree of accuracy. The system was given its first field test at the Yorktown cofferdam in 1985, then used in 1987 to record in detail the hull shape of 44YO88.

Following data collection, SHARPS data were transferred by phone link to a Prime mini-computer at the Virginia Beach facilities of Advanced Marine Enterprises, where a computer-aided design and drafting (CADD) system helped generate detailed drawings of the hull and other key features. This combination of electronic data-gathering and computer processing provides a rapid and efficient flow of data from field to final drawings.

THE SHIPWRECK, 44YO88

The technology discussed above has produced a wealth of data on Yorktown shipwreck 44YO88. The vessel was a merchant ship which had been leased by the British Navy

for use as a supply ship during the Revolutionary War. From its boxy shape and heavy construction, the ship is believed to have been built in England as a collier, or coal-carrier. It was a brig, a two-masted ship with square sails, rated at approximately 170 tons. A hole found in the ship's starboard side verifies that it was one of a group of ships purposely scuttled to produce a barricade against an amphibious landing on the Yorktown beach.

The ship's structure contains several unusual features, especially in the construction of bow and stern, which include horizontal timbers in place of cant frames.

Objects found within the hull indicate that the captain had a well-appointed cabin, with fashionable furniture, panelling with raised molding, and a unique china cabinet. Dozens of intact barrels carry markings indicating a variety of contents including beef, pork, grains and other supplies.

CONCLUSIONS

Ocean technology made numerous significant contributions to the Yorktown Shipwreck Archaeological Project. From the remote-sensing surveys which helped locate the shipwrecks, to the cofferdam technology and, later, the recording techniques utilized at the site, ocean technology was involved in every phase of the research. It is hoped that in the future there will be even more interchange of ideas, methods and skills between underwater archaeologists and marine engineers, which will enhance even further the efficiency and accuracy of underwater excavation. In turn, underwater archaeologists will produce further evidence of America's rich maritime heritage.

ARTISTS ON OCEANOGRAPHIC EXPEDITIONS, A NEGLECTED PARTNERSHIP

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ABSTRACT

The partnership between artist and marine scientist has too long been neglected and needs to be brought to the attention of both artists and oceanographers. The work of two artists nearly one hundered years apart is presented with examples of their art at sea.

Benjamin Shephard on H.M.S. Challenger during its 1872-1876 global expedition painted a series of charming sketches of the Challenger between her departure and her arrival in Australia. A century later, the U.S. marine artist, Jack Coggins, aboard the NOAA Ship Discoverer painted oils, watercolors, and sketches of work aboard.

INTRODUCTION

Oceanographic ships and the work of marine scientists at sea could provide exciting subjects for the marine artist, yet few have risen to accept the challenge. With a conference theme of "Partnership of Marine Interests", the artist/marine scientist partnership, one long neglected, seemed a natural to bring to the attention of both artists and oceanographers. A nineteenth century sailor who filled a sketchbook with paintings of his research ship and a twentieth century professional artist as a member of the scientific party aboard an oceanographic ship exemplify this unique partnership.

SHEPHARD ABOARD H.M.S. CHALLENGER

J. Welles Henderson is the "guru", the "godfather", of the Philadelphia Maritime Museum. A number of years ago on a visit to Boston, he was pursuing his favorite pastime- snooping second-hand and antique bookstores for illustrated log books of 19th century ships to add to his museum's collection. It was there that he found a sketchbook of really delightful sketches of a british ship on what appeared to be a long voyage. He bought the sketchbook. On his return to Philadelphia, he studied the sketchbook more carefully and felt that the vessel might have been engaged in some sort of marine scientific, oceanographic endeavors. He called me at the NOAA lab in Miami and asked if I had ever heard of a british ship named H.M.S. Challenger. Indeed I had, and I questioned him at length about his discovery. It proved to be an exciting find - an original book full of sketches of the Challenger at sea and at various ports of call. Each full-page sketch was titled and dated. The artist was one B. Shephard. The 34 paintings show the ship off Gibraltar, off many of the islands in the Atlantic Ocean and the southern Indian Ocean, at Halifax, St. Croix, Capetown, and six paintings of the ship among the iceburgs near the Antarctic Circle.

Shephard's depiction of the ship in every painting is accurate and very detailed. Other than for the paintings themselves, Shephard had a delightful disregard for accuracy. For example, the vessel towed by the Challenger into St. Thomas in the Virgin Islands on March 23, 1873, was named Varuna. Shephard has a good painting of the ship in tow, but his title lists her as the Baruner, missed the actual date by four days, and even misspelled the name of the island to which the abandoned vessel was being towed. Another titled "H.M.S. Challenger in a gale in the Gulf of Florida, May 21th, 1873" shows the ship under reduced sail heeled way over amidst monstrous seas under black clouds. In truth the official log of the expedition [1] mentions no storm in May of '73. The ship was enroute from Halifax to Bermuda, and there is no Gulf of Florida between these two ports, or anywhere else, for that matter. But these are the comments of an incurable nitpicker. Shephard's water colors are magnificantly done and well preserved. They provide to today's oceanographers and maritime and scientific historians a new dimension to our knowledge and understanding of what is still regarded as the greatest marine science expedition of all time.

Shephard's original sketchbook now resides in the Philadelphia Maritime Museum. The sketches have been reproduced in the original sketchbook format, and an accompanying text for each painting has borrowed extensively and shamelessly from two contemporary personal journals kept by expedition members [2] and [3]. Copies of the Challenger Sketchbook [4] are available from the Philadelphia Maritime Museum, 321 Chestnut Street, Philadelphia, PA. 19106.

COGGINS ABOARD NOAA SHIP DISCOVERER

In 1968, at the invitation of the Expedition Chief Scientist aboard the NOAA Ship Discoverer, the well-known American maritime artist, Jack Coggins, joined the expedition at Barbados. The ship was carrying out studies of the interactions between the sea and the atmosphere as precursors to the multi-ship BOMEX Expedition. Operations included

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CTD lowerings, meteorological, and tethered balloon observations, and the anchoring of instrumented vertical towers that obtain meteorological data at several heights above the sea and oceanographic data at several depths as well as wave data at the sea surface. Professor Michael Garstang and his students at Florida State University had designed and built these towers and were proud that the ballasting system maintained the towers in the true vertical -an essential characteristic for their measurements.

Coggins did a large oil painting of one of these towers with a Boston whaler in the foreground and the Discoverer in the background. Like Shephard a hundred years earlier, Coggins also injected an element of artistic license. When he painted the instrumented tower as floating absolutely in the vertical, it looked to him like a bridge abutment rising from the sea floor. To impart the feeling of its being a floating tower, he painted it as leaning about 20 degrees in a choppy sea. The painting is magnificent, but Professor Garstang was furious when this painting was reproduced as a NOAA Christmas card and widely distributed throughout the oceanographic community.

The other three large oils depict a nighttime CTD lowering, interior view of night operations on the ship's bridge, and one of the ship underway. Water colors show a meteorological balloon release, the instrumented inflated kite (Kytoon), putting Nansen bottles on the wire and a series of sepia sketches of work aboard. These paintings are skillfully done with great attention to accuracy and detail, the hallmark of all of Coggins' work.

These paintings hung for a number of years on the walls of NOAA's Atlantic Oceanographic and Meteorological Laboratory in Miami and are now in the possession of the person who commissioned and paid for them.

Some 25 color slides of the artistry of Shephard and Coggins constitute the major portion of the paper presented at Oceans '88. They are, however, too numerous and too expensive to reproduce in color for this proceedings volume.

CONCLUSION

With the availability of good cameras and good photogaphers, artists are no longer required to document our work at sea. But in the tradition of the Roux (pere et fis) in Marseille, Fritz Hugh Lane in Gloucester, Coggins, Barber, and Goertmiller today, ships and their work at sea still provide a challenge to the capable artist. Today's oceanographic expeditions should provide a berth for an artist. It is a long neglected but very appealing partnership of marine interests.

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A VERIFIED MODEL FOR OIL SPILL MOVEMENT, BEAUFORT SEA, ALASKA

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ABSTRACT

The discovery of oil and gas along the North Alaskan coast led to development and exploration on shore; offshore drilling on the continental shelf has already begun. The Coast Guard has responsibility for insuring effective oil spill response in these waters which may be ice-infested during all or part of the year. To increase the Coast Guard's expertise, methods were developed to detect and monitor oil spills in the Arctic. A key element was development of a comprehensive model to predict the short-term movement of oil spills. To verify the model, a drift experiment was conducted at Prudhoe Bay. Tracks of several drifters were compared to the model's output, indicating that it had the ability to successfully simulate direction of movement and speed of advance of an oil spill.

1. INTRODUCTION

The U.S. Coast Guard's Arctic Spill Response project was designed to insure that the On-Scene Coordinator (OSC) had the background information and technical expertise to monitor the progress of an Arctic oil spill and its cleanup operation. Initially, it may be crucial for the OSC to determine pertinent facts about a particular discharge of oil particularly the probable direction and speed of advance of the oil. This would provide the OSC with information to make judgements concerning the areas where the environment will be affected, and the resources and priorities for protecting them. Should a spill occur today, the best method for forecasting during the early stage of the spill would be similar to the basic vector addition technique used by the National Response Center for many past spills. This technique is excellent for immediate forecasts of the oil slick's directional movement and outer boundaries. The vector technique has been incorporated into a simple computer model designed for Arctic areas. The model using the vector addition technique will be the fundamental source for oil transport information until the National Oceanographic and Atmospheric Administration (NOAA) Scientific Support Coordinator (SSC) can be activated to prepare detailed oil spill movement data.

The oil spill model that has been developed is easily accessible and, most important, easy to implement. It is designed so that on being notified of a spill the OSC can turn the computer on, enter a small amount of easily obtained data and then let the computer run while the OSC is preparing to depart for the scene of the spill. When ready to depart, the OSC will return to the computer and gather the printed output. Thus, for the OSC, a forecasting system has been developed which will:

a. Predict the movement of the oil spill with sufficient accuracy to permit the OSC to make proper decisions about the deployment of his resources.

b. Consider all factors affecting the movement of the oil slick including: spreading, size and time of original discharge, size and time of any additional discharges, winds, surface currents, and site-specific geography.

c. Require as inputs only that information which is readily available to the OSC such as: time and size of spill, location of spill and local weather conditions.

d. Be capable of providing updated projections as additional information becomes available or conditions change.

e. Be capable of real-time operation to give timely results.

f. Present its output in a format that can be easily used and understood.

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2. COMPUTER MODEL

In this model the movement of a waterborne conservative property such as an oil slick is assumed to be described by a diffusion-advection equation. The equation describes the Eulerian concept of concentration changes with time at fixed locations as the oil is advected and diffused over a region. The diffusion equation was tested in zero current fields. Coefficients were determined for this equation which allowed for a circular spread rate comparable to those rates determined from actual spills (Murray, et al., 1970) and theory (Fay, et al., 1970).

A real-time spill trajectory model consists of two parts. The first and most important part is the data base which provides the surface currents. The second part is the trajectory model is an algorithm which uses the data base to move the oil.

A shortcoming of many models occurs not in the development stage of the algorithms but in the validation of those models to real-world events that they are trying to predict. Because this model was developed for response to oil spills, it was considered essential that the short-term predictive model be tested to determine its ability to provide the basic parameters of oil slick directional movement and outer boundaries. Therefore, a detailed discussion of the mechanics of the model will not be presented; instead the focus will be on the experiments conducted to test the model.

3. BEAUFORT SEA OCEANOGRAPHY

The movement of oil will be affected by winds, tides, surface currents, river runoff and waves. For the North Slope of Alaska the primary mechanisms for movement are the winds and surface currents. Surface winds play an important role in the transport of oil on the water. The wind drift of an oil slick can be described by a wind factor: i.e., oil slick drift rate is a percentage of wind speed.

Actual observations of oil slick movement at sea indicate that the drift rates are between 3.0 and 4.5 percent of the wind speed. The difference between the value of wind drift current and oil slick drift is called leeway. In the model presented the wind drift factor has been set at 3.5% of the wind speed. The direction of movement of the oil spill is downwind.

The area of the Beaufort Sea shelf for which the model was developed is that portion landward of the 40 meter isobath. Current measurements in this area are sparse due to the difficulty of setting and maintaining current meter moorings in the presence of sea ice. However, drifter data, from Matthews (1981), and current meter measurements made by Aagaard (1981) provide some information about the surface water movement. Generally these studies indicate that the water movement on the shelf tends to be in the longshelf direction (generally east and west). However, there is an occasional cross-shelf flow (north and south) of a highly variable nature. It has been generally agreed that the predominant mechanism for water movement on the inner shelf and within the barrier islands is the wind. This hypothesis is supported by several different researchers including Lissauer and Matthews (1982), Matthews (1981), Mungall and Whitaker (1979) and Barnes and Reimnitz (1977). Lissauer and Matthews (1982) studied the movement of surface drifters placed under the shorefast ice just prior to summer break-up of ice and in leads in the pack ice on the inner shelf. Results of the drifter returns from two years of releases show 74% were found to the west of their release points indicating a predominant westerly flow. This westerly flow is in agreement with the dominance of easterly winds in the area of the drifter releases documented by Hufford, et al., (1976). Barnes and Reimnitz (1977) has reported good correlations between near surface currents and local winds off of Prudhoe Bay, Alaska.

A key ingredient to the successful implementation of the model was the development of the current data base for input to the model. In 1979 the Coast Guard R&D Center conducted an experiment to observe the dynamics of ice movement during break-up of the ice in the Prudhoe Bay area (Lissauer and Tebeau, 1980).

During surveys conducted with ice concentrations of less than 50%, floe speed varied between 6.0% and 11.7% of the wind speed for one survey and 5.5% and 12.4% for the second survey. These values are significant because they greatly exceeded expected values even considering the leeway caused by the "superstructure" of the ice. This initial indication that the current data base might require additional input led to other studies.

Lissauer, et al., 1984, examined the circulation on the Beaufort Sea Shelf in "Atlas of the Beaufort Sea." As noted

before it was determined that this circulation is dominated by a longshore transport caused by large-scale meteorological conditions.

Persistent winds from the northeast or strong northwest winds cause patterns of mean current conditions. In order to determine the transport of oil it was found that 3.5% of the local wind speed had to be added to the mean currents. Thus for a local northeast wind of ten knots in the vicinity of Prudhoe Bay, oil would be transported by the mean currents and an additional 3.5% factor for the local wind. Thus oil transport could be approximately 6.5% if the mean currents and the local wind transport were in the same direction. The validation experiment proved that using the mean current patterns plus a wind factor provides accurate oil spill movement patterns.

4. VALIDATION EXPERIMENT

In order to test the validity of the model a field trip to Prudhoe Bay, Alaska, was conducted during the period 1-14 August 1985. Experiments were conducted to study the coastal circulation inside the barrier islands, in order to test the short-term model. A microwave tracking system system (MTS) was set up at Prudhoe Bay. The MTS system can track transponders at line-of-sight distances. The R&D Center has developed surface drifters with transponders imbedded in them. The drifters consist of a waterproof box floated by polystyrene foam sandwiched between two pieces of plexiglass. An MTS transponder and batteries are contained in the waterproof box and are connected by flexible wave guides to the antenna on a 4-foot pole. The drifters float with the upper surface awash, thus the leeway of the drifter is expected to be small to negligible. The structure of the drifter is such that it marks the movement of the upper 2 to 3 feet of water, which is deeper than the layer that will affect an oil spill. The MTS drifters were tested for their ability to describe surface movement by deploying one or more drift cards next to them. The drift cards were brightly painted 4 feet by 4 feet sheets of 1/2-inch plywood whose positions were marked periodically by a monitor boat.

Although the absolute motion of the MTS drifters and the drift cards was very similar, some relative motion was observed. In light winds, calm conditions, the drift cards had a greater motion downwind than the drifter. In 14-20 knot winds, there was no appreciable difference in their motion. This may be due to light winds only moving the top few inches of the water; while in rough sea, turbulence smoothes out the vertical gradient of current for the upper few feet. Therefore, the effect of the surface current on an oil spill may be somewhat different than the effect on the drifters in light winds. However, because of errors caused by estimations of winds and their variability, this difference will not cause a significant problem for the fundamental use of the model.

All position information for the drifters was processed and recorded by a desktop computer. Approximately 40 hours of drift was required to adequately verify the model. A total of 54.28 hours of drift was obtained.

In addition to the drift data, wind speed and direction were measured on Cross Island (approximately ten miles offshore) and on the Arcat vessel which was used as the command center for releasing the drifters. Also, current measurements were taken from the deck of the Arcat.

5. SURFACE DRIFT

Comparisons were made between the wind speed and current speed, as well as the wind speed versus the drifter speeds. As noted before, we expected the currents and the drifter movement to be in excess of the 3.5% value used to estimate the effect of the wind on an oil spill. Our hypothesis that currents along the North Slope were not solely a function of the local winds appears to be correct. Figures 1 and 2 show both current speed and drifter speeds exceed the 3.5% leeway drift speed in all but three cases. Based on this information, the model was developed with a background current data set, upon which a wind drift data set is imposed.

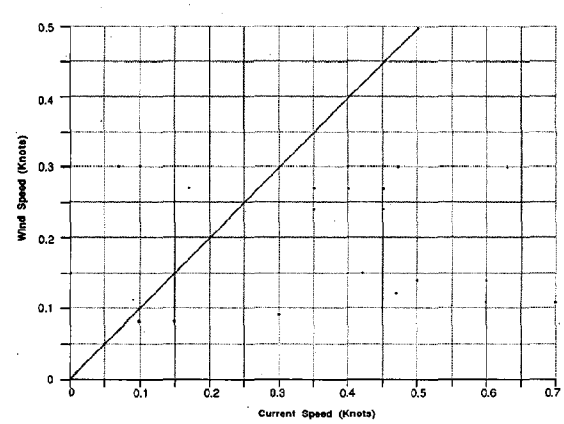

Figure 1. Comparison of Current Speeds with 3.5% Values of the Wind Speed

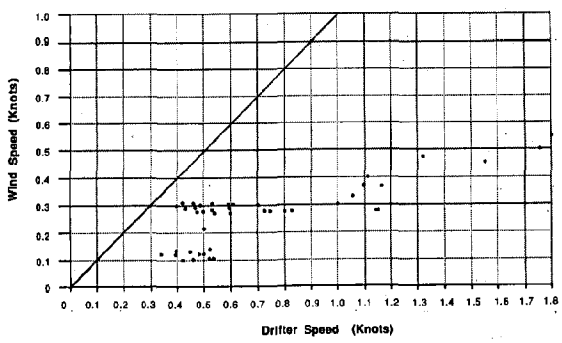

Figure 2. Comparison of Drifter Speeds with 3.5% Values of the Wind Speed

A total of just under 53 hours of drift data was obtained. Table 1 below gives the date and time period of the drifts that were recorded, as well as the average wind speed and direction for the drift period.

6. MODEL VERIFICATION

In order to verify the predictive capability of the model, the drift tracks were overlaid on model outputs. Although there were some discrepancies between the model output and the drift tracks, the overall results verify that the model will provide useful information to the OSC for the first 24 hours of drift of an oil spill in the Beaufort Sea. Figure 3 shows the model output and drift track for 4 August. The model displays letters (H, M, L) which correspond to oil concentrations of High, Medium or Low. The path of the drifter is shown by an arrow with the starting point of the drift marked by a circle. The shoreline and barrier islands are represented by the dotted figures.

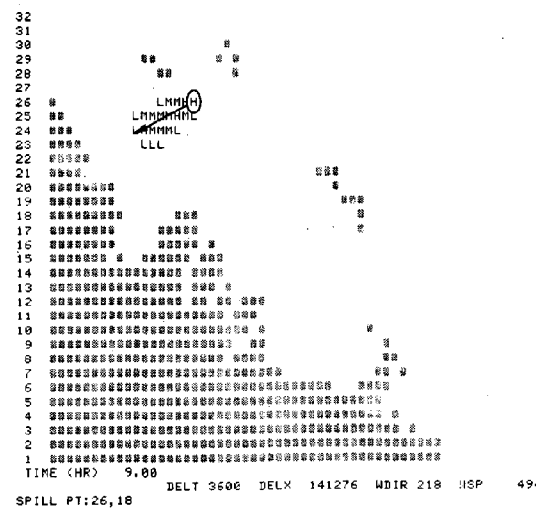

Figure 3. Verification of Model Using Drifter Tracks

The first drift period on 4 August 1985 lasted for just under seven hours. The comparison of the drift track to the model output is in good agreement. The core of the oil spill simulation for the model output appears to be slightly to the south of the drift track, and the drift track exceeded the model output distance by approximately one grid square (1413 meters). However, for the objective of the model to provide the general direction of movement and approximate rate of advance of the oil, the results exceeded our expectations of the forecasting ability of the model. The other drift track/model output comparisons also fortified the predictive capability of the model. The remaining model outputs for the various drifts were in excellent agreement with the drift tracks. These drift data indicate the ability of the model to successfully simulate the direction of movement and speed of advance of an oil spill in the Arctic. It will provide the OSC with an adequate prediction technique for the short-term period of 24 hours. In addition it can be used to verify predictions of oil movement which are provided to the OSC by other sources.

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Hindcast of the Amoco Cadiz Oil Spill

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ABSTRACT

A coastal zone oil spill model developed for the U.S. Department of Interior, Minerals Management Service, was used to hindcast the fate of oil from the Amocò Cadiz tanker accident. Hindcasts were performed on two spatial scales, one small, to provide higher resolution of the coastline details within a few tens of kilometers of the wreck, the second extending several hundreds of kilometers along the coast. The mass balance and physical distribution of oil agreed reasonably well with area-wide observations for both large and small tests. Agreement at the larger scale deteriorated somewhat with respect to detailed spatial distributions. The small scale hindcast appeared to retain too much oil early in the simulation, although mass balances after 30 days agreed well with observations.

1. INTRODUCTION

Oil spill trajectory and fates models typically follow a surface slick until it contacts a coastline, at which time the simulation ceases. The coastal zone oil spill (COZOIL) model described here is designed to simulate oil spill fates both before and after a coastal contact. The model has been designed to include explicit representations of as many of the known active processes as possible. Multiple discrete batches of oil, or spillets, are used to represent the surface slick. Spillets are circular while offshore but become elliptical upon contact with the shoreline. The amount of onshore-offshore foreshortening is governed by a balance between wind stress and gravity spreading forces, and results in alongshore spreading of the spillet. Evaporated hydrocarbons are given no spatial representation, but are simply accumulated from all sources during the simulation. Entrained oil offshore is represented by discrete particles which are advected by the local currents. Inside the surf zone, entrained oil takes on a continuous representation, discretized by alongshore grid cell. Transport in the surf zone is governed by a classical radiation stress formulation. Incorporation of water into surface oil (emulsification) is simulated offshore. De-emulsification (de-watering) is allowed to occur for oil which is on the foreshore or backshore.

Oil coming ashore may be deposited on the foreshore or the backshore, or carried into coastal lagoons, ponds, or fjords. Oil on the foreshore penetrates into the underlying sediments at a rate dependent on sediment grain size and oil viscosity. Oil may also be carried into the beach groundwater system by wave overwash. Reflotation of surface oil occurs during rising tides. These mass transfer pathways are shown schematically in Figure 1.

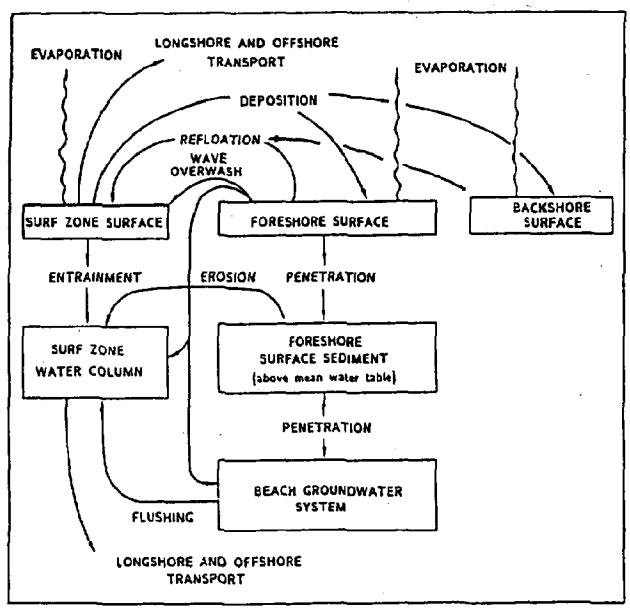

Figure 1. Schematic of processes included in the COZOIL model.

The most severe test of any model is a hindcast of a real event having a strong observational data base. The Amoco Cadiz spill offers the most complete data set of any coastal oil spill to date and, therefore, was selected to test COZOIL. Principal summary references on the spill are Hess (1978), CNEXO (1981), and NOAA/CNEXO (1982). Primary references concerning development of the COZOIL model are Gundlach and Reed (1986), Kana (1986), and Reed et al (1986, 1988).

The sequence of events to be hindcast began at 06:00 on 17 March 1978 when the supertanker began to break apart 2.4 km off the Brittany (France) coastline after grounding during storm conditions (Hess, 1978). A location map of the site is provided in Figure 2. The ship's cargo consisted of about 220,000 mtons of light Middle Eastern crude oil and a small amount of bunker oil, all of which was lost over the next two weeks (Hess, 1978). The oil rapidly emulsified in the high waves around the vessel, incorporating up to 90% water (Hann et al, 1978). After initial oil transport to the south, strong winds spread the oil towards the east for the first ten days. A shift in wind direction to the northeast then carried oil offshore, with a reversal toward the southwest after six days (Hess, 1978). Oil was ultimately spread over more than 300 km of coastline and a large area of offshore waters (Fig. 2).

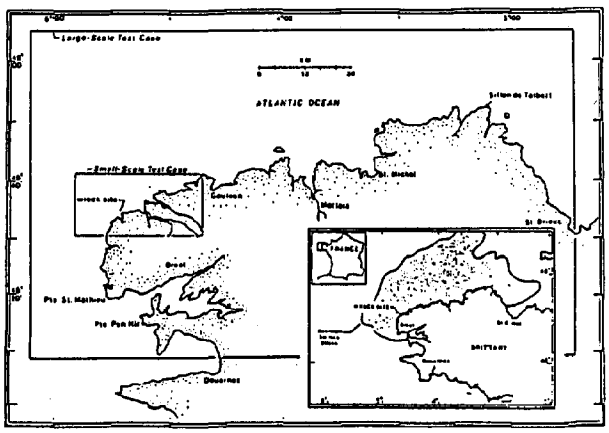

Figure 2. Study area map for the Amoco Cadiz hindcast showing coastal areas impacted by oil and borders of the small-scale and large-scale test cases.

2. MODEL INPUT DATA

The inputs to COZOIL used for the Amoco Cadiz test cases are presented in Table 1. Other inputs, such as simulation duration and time intervals between subsequent output to the monitor or data files are also required, but do not materially affect the computations.

The COZOIL model contains a library with seven crude oils and petroleum products. Of these, Murban Abu Dhabi appears to closely approximate the oil carried by the Amoco Cadiz (Anonymous, 1973; NOAA/CNEXO, 1982).

Hindcasts of the fate of the spilled oil were performed on small and large scales (Fig. 2) to reflect localized oiling within the convoluted coastline adjacent to the grounding site and to cover distribution over the entire spill-affected area. The Brittany shoreline being represented in the COZOIL model is complex and diverse, containing a closely spaced mixture of

Table 1. COZOIL input parameters for deterministic simulation and values used for the Amoco Cadiz hindcasts.

Input Parameters	Value	Comments
Oil type	Murban crude	Primarily light Arabian crudes (Hess, 1978)
Spill size	220,000 mtons	1,613,000 bbl (Hess, 1978)
Number of spillets	144	conforms to Hann et al (1978)
Interval between sequential releases	1 every 2 hrs	conforms to Hann et al (1978)
Coastal reach parameters	Reed et al, 1988	some field measurements
Air temperature	7.5°C	Brest airport
Wind time series		Brest airport
Tidal period	12.4 hour	SHOM (1973, 1978)
Range	6.5 m	SHOM (1973, 1978)
Tidal current amplitude	1.46 m/sec	SHOM (1973, 1978)
Time after mean low tide for simulation start	6 hr	SHOM (1978)

bedrock-dominated shores, mixed sand and gravel beaches, sand beaches backed by dunes or riprap, and estuaries with large mud flats. Because of the large tidal range, sand flats extending up to several kilometers from shore are exposed at low tide.

Shoreline classification is based on Berne (1982), modified to conform with shoreline types defined by the COZOIL model. Shoreline slopes are based on the measurement of topographic profiles across sand, coarse sand with fine gravel, and gravel beaches in Brittany at the time of the spill. Values for adjacent beaches were estimated using these measurements as a basis and from repeated observations of the shoreline by the second author. The foreshore slope, as defined by model requirements, is the slope of a straight line between the berm or high-water mark and the low-tide line. The backshore is the area above the berm or high-water mark. The position of this dividing line can vary substantially in Brittany depending on the tidal phase. A value of 20 m is used as representative of the narrow backshores common in Brittany.

The resulting coastlines for the two hindcasts are shown in Figure 3. In the small-scale case, lengths of individual shoreline segments or reaches vary from about 1.7 to 5 km. At this scale, the model is capable of resolving individual estuaries and embayments along the coast. For example, the Abers Benoit and Vrach (Fig. 3 top) are clearly represented. For the large-scale test case (Fig. 3 lower), the reach lengths range from 20 to 46 km, a much coarser representation in which 11 reaches cover over 600 km of actual coastline.

3. SUMMARY OF OIL DISTRIBUTION DATA

The distribution and quantity of oil along the shoreline during the Amoco Cadiz spill was based on surveys conducted by a combined French-American field team. Measurements during the spill included oil thickness, surface coverage, burial, and alongshore distribution at twenty stations along the coast, augmented by

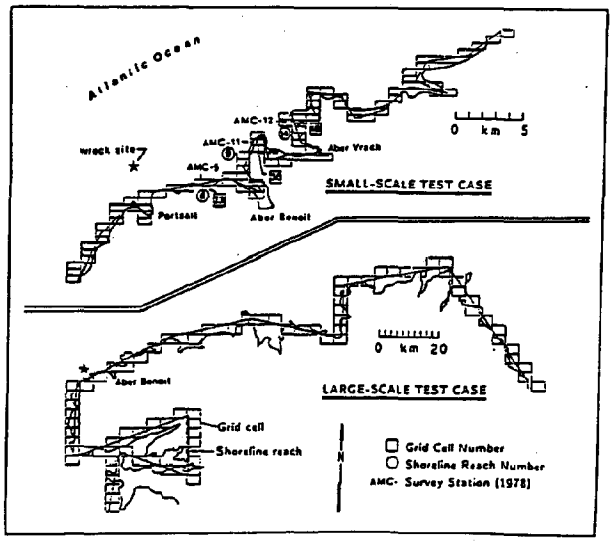

Figure 3. Modeled coastline for both test cases. Grid cells and shoreline reaches are indicated for each. The locations of field stations AMC-5, 11, and 12, are indicated in the top diagram.

approximately 150 additional ground observation stations and an extensive set of oblique and vertical aerial photographs. Results, published in Gundlach and Hayes (1978), D'Ozouville et al (1981), and Finkelstein and Gundlach (1981), indicate that approximately 62,000 mtons of oil were onshore during the period of 17 March to 2 April, and that from 20-28 April slightly less than 10,000 mtons was onshore.

For these simulations, original data were analyzed and recalculated to determine more exact dates with respect to onshore oiling, to differentiate between surface and buried oil, and to calculate 95% confidence intervals for each time period. Stations within the small-scale shoreline section were most often surveyed and provide oil quantities for three time periods, 8.5, 15 and 36 days after the beginning of the spill. For the large scale test, shoreline oil was calculated for 9 and 38.5 days after the initial release of oil. In all cases, the extent of shoreline oiling (in km) was taken from Finkelstein and Gundlach (1981) and D'Ozouville et al (1978). Only oiling of the mainland was considered as offshore islands and rocks are not represented in these model test cases.

4. RESULTS

The first simulation discussed is the small-scale test case, extending about 30 km from the spill site. The second is an order of magnitude more extensive spatially, representing over 600 km of actual coastline.

Small-Scale Test Case

For this test case, shoreline reaches vary from 1.7 to 5 km in length adjacent to the wreck site. The offshore model boundary is located 15 km or less from the shoreline (Fig. 2).

Offshore and onshore distribution

The distribution of oil on the water surface and on the shoreline for the small-scale test case is presented for four time periods in Figure 4.

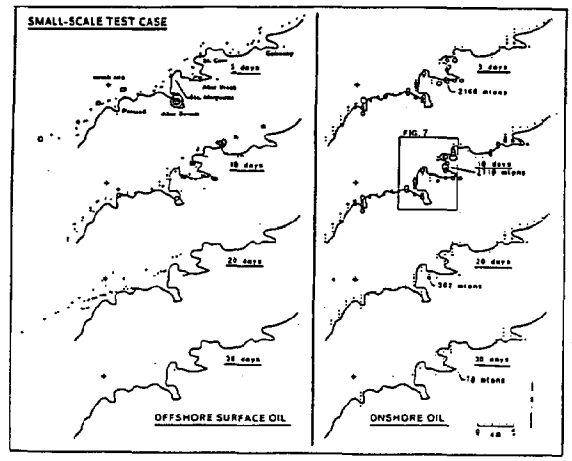

Figure 4. Distribution of offshore surface oil and onshore oil (foreshore surface and backshore) for the small-scale test case. Offshore, circles indicate computed areal coverage of thick oil. Onshore, circles are proportional to the oil mass associated with each grid cell. The maximum value of the circle for each time plot is given.

At 5 days, oil has already been distributed over the entire study area (onshore and offshore), conforming well to that reported by study of aerial photographs (CNEXO et al, 1978). This rapid distribution is the result of strong tides and winds, plus longshore transport inside the surf zone. At day 5, the model shows the highest surface oil concentration in Aber Benoit, an area that was heavily impacted by the spill and contained traces of oil at least until 1987. By day 10, oil quantity within Aber Benoit has decreased while oil in the nearshore area remains fairly evenly distributed alongshore but with less occurring along the eastern edge. Between days 10 and 20, most of the oil on the water surface has been transported out the northern model boundary due to strong offshore winds. A subsequent wind to the southwest, beginning about day 18, carries most of the remaining surface oil out the western model boundary. The overall sequence of oil distribution conforms very well to observations except that the actual spill contained no artificial boundaries so that re-oiling of the shoreline and offshore waters to the southwest occurred after transport offshore.

The onshore distribution of oil (Fig. 4) is represented by circles proportional to the total mass of oil found on the foreshore surface of the beach and the backshore of each grid cell. On day five, shoreline oil is concentrated in Portsall harbor adjacent to the wreck site, in Abers Benoit and Vrach, and on the two north-trending headlands (Presqu'ile Ste. Marguerite and St. Cava) which form a barrier to the easterly drifting oil. This conforms very well with observations made at the time of the spill (Gundlach and Hayes, 1978).

At day 10, the model indicates substantial oiling of the embayment at Guisseny as did occur; however, the model may over estimate oiling at this location because of the lack of shoreline detail. In this case, a large spit protecting the embayment is not adequately represented (Fig. 3 top). At days 20 and 30, oil is found along most of the coast in continually decreasing quantities.

Dynamic mass balances

The dynamic mass balance of oil for 40 days of simulation time is shown in Figure 5 for the small-scale study area. The bottom diagram shows the overall mass balance of oil divided into five major spill components: ashore, water surface, atmosphere, water column, and outside the simulation area. The curve labeled "Ashore" corresponds to the curve labeled "Total Ashore" of the middle diagram, which is composed of four subdivisions: foreshore, backshore, ground water, and surf zone. The top diagram of Figure 5 represents the total oil on the beach, composed of surface and backshore oil but excluding oil in the ground water. This represents the quantity of oil that would be measured on the beaches at the time of the spill. Estimated amounts of oil along this section of shoreline during the spill, compiled for 8.5, 15 and 36 days after the spill, are superimposed on this plot.

Figure 5 illustrates that the proximity of the release point to shore, combined with onshore winds result in a steadily increasing amount of oil deposited onshore during the first 10 days. The removal and deposition of oil in conjunction with the rising and falling of the tide is clearly reflected in the interchange of oil between the ashore and water surface components. From days 10 to 15, the abrupt increase in oil mass leaving the study area, shown by the curve labeled "outside", is due to strong offshore winds. Note the simultaneous decrease in oil on the water surface (Fig. 5 bottom).

In comparing the observed versus simulated total quantity of oil ashore (Fig. 5 top), simulation values exceed observed values on both days 8.5 and 15, but compare well with those from day 36. Observations in the field were always made within low- to mid-tide levels, which conform to the higher values of total oil on the beach surface. The high oil quantities simulated on the shoreline could be due in part to removal rates which are too slow in the model and/or the absence of storm surge events in the hindcast. Two such events were recorded during the first two weeks following the start of the spill (Hess, 1978) and resulted in the rapid removal and transport of oil from several segments of the shoreline. The model, however, clearly shows dynamic variability both from low to high tide and from one tidal cycle to the next, which is entirely consistent with the field observations (Gundlach and Hayes, 1978).

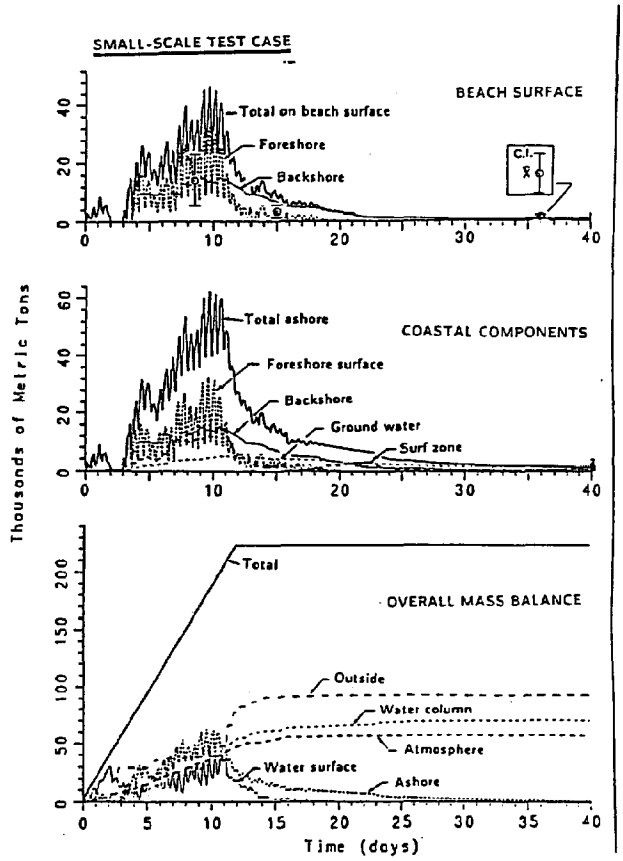

Figure 5. Dynamic mass balances (overall, coastal components, and beach surface) for oil associated with the small-scale test case. Observed values of oil quantity on the shoreline and 95% confidence intervals are indicated in the top diagram.

Large-Scale Test Case

This case encompasses the entire northwestern Brittany region and contains only 11 coastal segments ranging in length from 20 to 46 km in contrast to the previous case having a maximum length of 5 km (see Fig. 3). At this scale only coastline trends and very large embayments, as at Brest, can be differentiated.

Offshore and onshore distribution

Results of the large-scale simulation of the

distribution of the oil is indicated in Figure 6. The distribution of offshore surface oil after 5 days compares extremely well with that observed after 4.5 days using vertical aerial photographs taken by the French government (CNEXO, et al, 1978) during the spill (Fig. 6, top left). The onshore distribution at this time also conforms very well that reported. Note the oiling at St. Michel, the site of a large kill of intertidal organisms (Hess, 1978). The consistent distribution for both the onshore and offshore cases continues through 10 days. Note particularly the oil along the shoreline from St. Michel to Ile Grande. Ile Grande was the site of extremely heavy concentrations within a marsh environment (Hess, 1978).

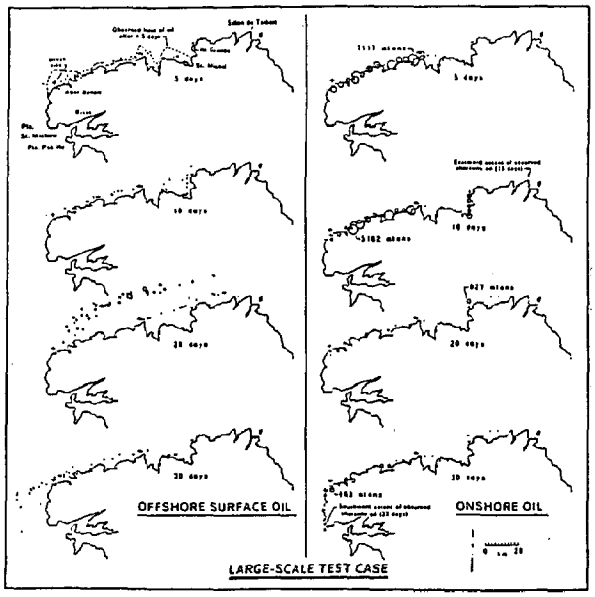

Figure 6. Distribution of offshore surface oil and onshore oil (foreshore surface and backshore) for the large-scale test case. Offshore, circles indicate computed areal coverage of thick oil. Onshore, circles are proportional to the oil mass associated with each grid cell. The *maximum* value of the circle for each time plot is given.

Between days 10 and 20, much of the onshore and nearshore oil is transported offshore because of the wind shift, and at day 20 the oil is returning from its northern excursion and poised to come onshore again. At day 30, this oil is transported to the southwest, oiling the shoreline south of the wreck site. This sequence of offshore transport with very late oiling of the shoreline to the south of the wreck site was well documented at the time of the spill (Gundlach and Hayes, 1978). The southernmost extent of shoreline oiling is essentially correct, ending at Pointe de St. Mathieu, although the model does have one impact near Pointe de Pen Hir which is not documented. The model, however, inadequately depicts the eastward transport of oil to Sillon de Talbert (Fig. 6), perhaps due to under estimation of tidal currents for this portion of the study area.

Dynamic mass balances

The various mass balances for the large-scale hindcast are shown in Figure 7. The effect of the extended boundary is immediately apparent when comparing this overall mass balance to that from the small-scale analysis (Fig. 5). The total lost out the model boundaries reduces from 30% after 15 days in the small-scale study to about 15% after 30 days in the large-scale test. Oil is transported north during the southerly wind event from days 10 to 15, but remains within the model boundaries. When the wind shifts back towards the southwest between days 16 and 21, some of the surface oil which was transported offshore comes ashore between days 22 and 29. Note the increase in the oil ashore at this time, particularly in plots of the coastal components and beach surface.

The total oil ashore is approximately the same (62,000-64,000 mtons) for the large- and small-

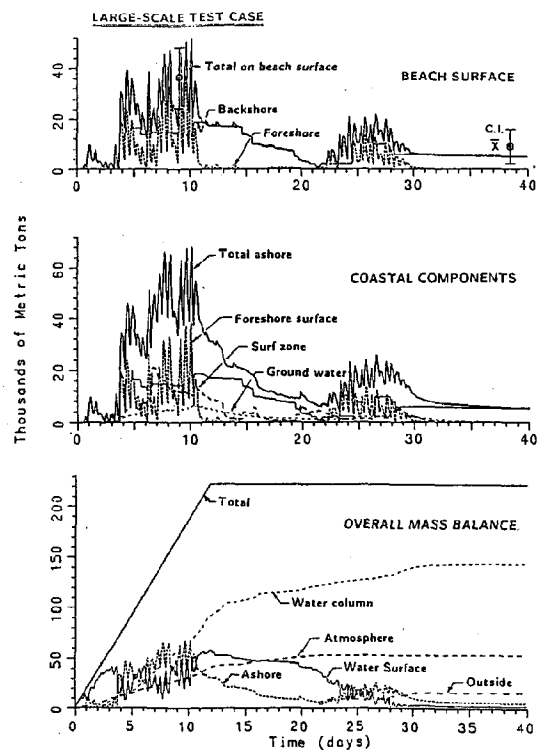

Figure 7. Dynamic mass balances (overall, coastal components, and beach surface) for oil associated with the large-scale test case. A second heavy oiling of the shoreline, reflected in the observations but not in the small-scale test results, is visible between days 23 and 28. Observed values of oil quantity on the shoreline and 95% confidence intervals are indicated in the top diagram.

scale test cases for the first 20 days. This is because the wind is almost continuously onshore for the first 10 days, then offshore for 5 days, and onshore again. The amount of oil on the beach surface, however, now agrees reasonably well with the field values after 9 days and 38.5 days.

5. CONCLUSIONS

Two tests cases of the COZOIL model against the Amoco Cadiz data set have been performed. In general, the model effectively reproduced the offshore and onshore distribution of the Amoco Cadiz oilspill. Mass balance distributions were also simulated realistically, considered from a variety of viewpoints. The lifting of oil off the intertidal beach surface and its redeposition on a falling tide under appropriate wind conditions show clearly in the mass balance time series plots.

The small-scale test case, with relatively detailed resolution of the coastline adjacent to the site appropriately reproduced onshore and offshore surface oil distributions, but generally placed too much oil onshore, perhaps due to a too slow removal rate and the lack of correct hydrodynamics (i.e. including storm surge). The limited boundaries also inhibited the model from effectively reproducing the subsequent redeposition of oil after being transported offshore by winds. On a very fine scale of 0.5 km, the model reproduced the general variance noted in the Amoco Cadiz spill incident, and came close to observed values at three particular stations. Variations in oil quantities onshore within specific grid cells can be lessened by grouping together oil within the grid cells composing the same shoreline reach.

The large-scale test case, using only 11 shoreline segments over the entire area, portrayed the overall distribution of offshore and onshore oil quite well, but fell about 30 km short in the eastern migration of the oil, perhaps due again to inaccurate hydrodynamics. The mass balance of onshore oil quite realistically depicts the actual spill case and compares well with observations.

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THE 1987 NEWFOUNDLAND OIL SPILL EXPERIMENT
An Overview

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ABSTRACT

A joint Canadian-United States exercise involving the intentional spilling of 18,000 gallons of specially treated crude oil was conducted off Newfoundland in September 1987 to evaluate the containment and recovery capabilities of three state-of-the-art booms and skimmers. As part of the exercise, data were collected on a specially instrumented oil spill boom in an attempt to verify a proposed performance test procedure for open-ocean oil spill booms. A visco-elastic chemical additive was used after the equipment evaluation was completed to enhance recovery operations. Additional observations were made on the persistence of spilled oil slicks in advanced sea states. The containment and recovery effort was one of the most successful on record and was conducted in winds and sea states commonly thought to be beyond existing capabilities.

INTRODUCTION

An intentional oil spill of 18,000 U.S. gallons was conducted on September 24, 1987, offshore of St. John's Newfoundland to evaluate the containment and recovery capability of three booms and skimmers. The spill also provided an opportunity to verify a nonpolluting performance evaluation procedure for offshore oil containment booms. The spill was conducted approximately 25 nautical miles east of St. John's. Ocean dumping permit requirements included south southwest currents and westerly winds to minimize chance of shoreline contact; water depths of at least 100 meters; the site had to be at least 25 nautical miles from shore; and the area had to be within 2 to 3 hours steaming from St. John's. The center of the area selected was 47 degrees, 40 minutes North and 52 degrees, 03 minutes West.

A crude similar to the typical high wax Grand Banks crude was unavailable. Brent crude from the North Sea was treated by adding 1 percent slack wax by volume to yield an oil of similar physical properties to the Grand Banks crudes. The modified oil was to have a density of 839.8 kg/m^3 and a viscosity of 20 m Pas at 12 degrees C (Ross, 1987a).

Meteorological conditions were recorded on the Canadian Coast Guard (CCG) Cutter "Grenfell" at 15 minute intervals. These included corrected wind velocities and air and water temperatures.

A wave rider was deployed at the test site but failed to function during the exercise. Consequently, sea conditions were estimated, with reasonable agreement, by various trained observers.

The test plan called for the deployment of three booms as follows: A 250 meter length of the specially instrumented Oil and Hazardous Material Simulated Environmental Test Tank (OHMSETT) boom would be deployed in normal catenary. Approximately 18,000 gallons of treated Brent Crude would be spilled by the command/recovery ship "Terra Nova Sea" into the catenary. The oil would be held in the boom for approximately 1 hour while freeboard and draft data and visual observations of oil retention were recorded. During this period, 200 meters of the Canadian Coast Guard's RO-BOOM would be deployed behind the OHMSETT boom. The tow speed would be increased to significant loss speed (0.5-1.0 knot). One end of the boom would then be released and the oil discharged into the RO-BOOM. Oil would be held in the RO-BOOM for approximately 1 hour while the oil retention capabilities were observed. The St. John's Coast Guard Vikoma Ocean Pack boom (400 meters) would be deployed behind the RO-BOOM during the observation period. The last procedure involving lost tow speeds would be repeated with the RO-BOOM, and the oil would be released into the Vikoma.

Oil would be retained in the Vikoma for approximately 1 hour. The "Terra Nova Sea" would then commence skimmer evaluations. Two skimmers, the Framo ACW400 and an innovative Coast Guard Heavy Oil Skimmer (HOS), would be evaluated for 20 minutes each, and the remaining contained oil would be recovered by the skimmer with the better performance (Ross, 1987b).

The intent of the OHMSETT boom deployment would be to verify the hypothesis that a boom's ability to contain oil is correlated with its ability to sea keep or comply with wave-induced surface motion. If this hypothesis could be verified and quantified, future performance evaluations of offshore containment booms could be restricted to measuring seakeeping capabilities in a range of sea states. No further spills of the 20,000 gallon size of light and heavy oils would be required, in a range sea states, to evaluate each type of

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boom. Ocean dumping permits are difficult to obtain and intentional oil spill exercises of this magnitude approach the million dollar funding level. Intentional spills also constitute a risk of potential damage to the immediate environment. Clearly a cost-effective and nonpolluting evaluation procedure for offshore equipment is necessary to develop a predictive capability for the performance of offshore response equipment. Wind conditions desired were sea state 2 to 4, and winds from 10 to 20 knots.

Practice Run - September 21, 1987

The ships and smaller vessels sailed at 6:00 a.m. and proceeded to a location 5.5 miles off Torbay Point. The CCG "Grenfell" then deployed the OHMSETT boom and passed one end to the CCG "Cutter 212" which took the boom in tow. The CCG "Cutter 206" then attempted to pick up the trailing end of the boom, a job which took 45 minutes. As soon as the 206 had the end of the boom secured, the two cutters attempted to tow the boom, in a "U" configuration, into a position astern of the "Terra Nova Sea." This resulted in the OHMSETT boom immediately beginning to twist on itself, and 1 hour hour was lost in straightening the boom. Eventually the boom was positioned relative to the "Terra Nova Sea" and simulated discharge of the oil was carried out. Data collection, without oil, for almost 1 hour followed.

While the OHMSETT boom was being deployed and positioned, the RO-BOOM was deployed from the CCG "Sir Humphrey Gilbert" and passed to CCG "Cutter 214." This procedure took almost 2 hours, and the RO-BOOM was rapidly positioned with respect to the OHMSETT boom because both the "Cutter 214" and a Boston Whaler were able to tow the boom at speeds of 5 knots.

With the RO-BOOM in position, the CCG "Cutters 212 and 206" commenced to maneuver, presumably to form a "J." The CCG "Cutter 206" then snagged the OHMSETT cable in her screws and cut it, disabling herself. This resulted in delay in the exercise while the cable was freed, and because CCG "Cutter 214" and the Boston Whaler were now approaching closely, the "Cutter 212" took the boom and "Cutter 206" in tow and cleared the area so as not to impede the exercise.

During the period in which the RO-BOOM was being deployed, the CCG "Grenfell" deployed the Vikoma boom. Once the simulated oil release was over, the "Terra Nova Sea" took the other end of the boom and the vessels formed a catenary. After holding position relative to the RO-BOOM for a period, the ships formed a "J" with the boom and practiced deploying the skimmers.

All ships returned to harbour by 5:00 p.m.

Period Between the Dry Run and the Trial

Several meetings of the senior people involved in the exercise occurred between September 21 and September 23, 1987. It was decided to remove CCG "Cutter 206" from the exercise. The Boston Whaler was able to tow and hold the boom in sea state 1, but it was recognized that this would be difficult, with oil, in the desired weather. The Newfoundland Fisheries department had provided a vessel, the "Bernier," and it was decided to use her and a second chartered offshore supply vessel (OSV) to tow the RO-BOOM.

Concern was registered that the weather might, surprisingly, be too calm on September 24, the day which looked best for the actual trial. It was, therefore, decided to interchange the OHMSETT and RO-BOOMs to take advantage of the higher winds and waves expected later in the day.

The long time required to deploy the RO-BOOM from the "Sir Humphrey Gilbert" led to the decision to deploy that boom from the second OSV, the "Triumph Sea." Repairs were carried out on the OHMSETT boom instrumented cabling, and the boom with instrumentation was functional by 5:00 p.m. on September 23.

Since the "Terra Nova Sea" had oil recovery tanks on board, it was decided to dispense with the dumb barge and to release the oil directly from that OSV.

Trial with Oil on September 24, 1987

The "Triumph Sea" and the "Bernier" sailed at 3:00 a.m. All other vessels sailed at 4:00 a.m., and everyone was on station by 6:45 a.m. The "Triumph Sea" commenced deployment of the RO-BOOM enroute, and by 7:30 a.m. the boom was ready to receive oil. Once the OHMSETT boom was deployed, at 8:15 a.m., the oil was pumped into the RO-BOOM with supervision from the helicopter and a small boat.

All oil was in the boom by 9:00 a.m.

It was decided to give the news media a chance to view the test from the air and this was done from 9:00 a.m. to 10:00 a.m. During this period, the CCG "Cutters 212 and 214" attempted to pull the OHMSETT boom into proper position astern of the RO-BOOM and keep it there. Every attempt to move the boom, in a catenary, in the 15 knot winds blowing at the time resulted in the boom twisting. As a result the OHMSETT boom fell progressively further astern of the RO-BOOM.

At 10:30 a.m. the oil in the end of the pocket of the RO-BOOM was 30 cm thick, the wind was 15 knots, and some splash-over and significant drainage under the boom were occurring. The vessels, therefore, formed a "J" and released one end of the boom to allow the oil to flow into the OHMSETT boom. The OHMSETT boom was approximately 1 km

astern, and the vessels were having trouble towing the boom in a catenary without the boom twisting. It was, therefore, decided to direct the cutters with the OHMSETT boom, to the oil, by helicopter, keeping the boom in a straight tow. After 20 minutes, the cutters were adjacent to the thick oil, and, after a further 20 minutes, approximately 80 percent of the thick oil was in the OHMSETT boom. The remaining 20 percent was contained in the Vikoma boom. Data collection on the OHMSETT boom started as soon as the oil was captured and continued for 56 minutes. The CCG cutters then stopped across the path of the vessels towing the Vikoma boom and released one end of the boom. The oil spilled into the Vikoma boom catenary, and one CCG cutter trailed the OHMSETT boom at the throat of the catenary allowing the waves to wash the oil into the Vikoma boom.

The CCG "Grenfell" and "Terra Nova Sea" towed the oil filled Vikoma boom for approximately 1 hour. During this time, the wind had freshened to 15 knots to 20 knots. The boom was moving at over 1.1 knots relative to the sea, and some oil was being lost (approximately 3 mm thick). The CCG "Grenfell" then attempted to move ahead to form the "J" for the skimmers. Not being very maneuverable, she quickly reached 3.4 knots and the oil was lost.

With the oil now lost, the weather abated slightly. The RO-BOOM was still streaming astern of the "Triumph Sea" so it was decided that she and the "Bernier" would form the boom into a catenary and attempt to recover the oil downwind. The helicopter had been lost to the exercise for approximately 1 hour at this time. As soon as it returned, it was refueled and deployed to assist. In the interim a small boat was used to guide the tow vessels into the heaviest portions of the slick. When the helicopter was over the thick oil, it was apparent that the vessels with the RO-BOOM were adjacent to some of the oil and unable to see it. They were, therefore, directed from the air and small boat, and managed to collect 80 to 90 percent of the thick oil which was on the surface at the time.

Oil was successfully contained and recovery was attempted using the three skimmers on board the recovery-command vessel. The first skimmer, the Heavy Oil Skimmer (HOS), was deployed and no measurable recovery was observed. The oil used was modified by adding petroleum wax so that it would resemble a typical Grand Banks crude oil. This type of oil is uncharacteristic of most crudes in that it possesses low adhesive properties. Therefore, oleophilic skimmers, which depend upon the adhesive nature of the recovered oil, do not perform well with high parafin-based oils. This was again proven with the oleophilic HOS skimmer. The skimmer was recovered after several trained observers were satisfied that the HOS skimmer had had sufficient evaluation time in the contained slick. Problems with the ability of the support arms, used to suspend both the HOS and Framo skimmers, to adjust to the roll of the vessel and short period wave action resulted in both skimmers being frequently submerged so that oil and water were washed into the sump of the skimmer.

The second skimmer the Framo ACW-400 was deployed. The overall rate of oil recovery of the Framo was 60 gallons per minute with unknown amounts of the recovery resulting from frequent partial submergence.

At this point, it was decided by the On-scene Commander that the skimmer evaluation was complete. Additional measures were needed to ensure recovery of the remaining contained oil because the weather was deteriorating and night was approaching. Accordingly, approximately 7 pounds of the visco-elastic agent "Elastol" were spread from an 8-ounce styrofoam coffee cup into the estimated 7,400 gallons of oil and oil water emulsion in the containment boom. "Elastol" was added because previous research funded by the Minerals Management Service and Environment Canada had shown that the elastic and adhesive properties of the oil could be increased by addition of the agent, thus making the oil more readily capturable with these types of skimmers. The Framo ACW-400 was retrieved from the slick as the "Elastol" was added and because of the operational constraints on the recovery operation, due to the weather and lateness of the day, the skimmer was not redeployed.

The weir-type skimmer, Pharos Marine GT-185, was deployed into the treated slick and recovered near capacity rates of 85 gallons per minute of oil and oil emulsion with no free water. This recovery rate was higher than anticipated and may have been even higher if the oil had been untreated. Treatment significantly increased the viscosity of the oil. The skimmer was removed from the slick, cleaned, and stored on board.

The HOS skimmer was redeployed and failed to function because of a piece of steel in the return pump. The skimmer was recovered, the steel piece removed, and the skimmer was redeployed.

The HOS skimmer yielded a recovery rate of 50 gallons per minute with a portion of the oleophilic fabric on one of its two drums damaged. Debris was collected at this time in the ventury system used to measure recovery fluid flow rates. The debris may have contributed to the subsequent failure of the HOS skimmer return hose. No flow-rate measurements were taken before the failure. Visual observations on the amount of oil adhering to the oleophilic fabric of the HOS skimmer indicated that recovery rates were significantly increased by the addition of "Elastol."

Operations were suspended because of the advancing sea states and increasing darkness.

An overflight of the area, by helicopter, was carried out during the skimming operation. This revealed a sheen approximately 2.5 by 0.5 nautical miles with 3 patches of brown oil. It is estimated that no more than 260 gallons of oil remained in the thick patches. A further flight 18 hours later

showed that only small brown patches and sheen remained, and this was rapidly dispersing.

Lessons Learned or Relearned

- Thorough proficiency with the recovery equipment to be used is essential.

  Routine practice is required.

- Large volumes of oil are necessary to realistically evaluate performance of offshore response equipment.

- The use of helicopters to direct the placement of tow vessels and the use of small vessels to monitor and advise on boom conditions are essential to maximize the efficiency of conventional recovery operations.

- Accurate measurements of the meteorological and sea conditions are necessary for accurate analysis of the evaluations.

- The requirements for slow-speed towing and maneuvering of large containment booms necessitate the use of vessels with variable pitched propellers, thrusters, and good seamen in control.

- It was not possible to form a recovery configuration with two vessels while towing upwind. The third vessel was necessary for recovery in normal catenary.

- Upwind collection proved impossible when winds approached 15 knots. This is consistent with many past observations for containment operations conducted upwind.

- The upper meteorological and sea state limits for downwind containment and recovery were not reached during this test.

- Steps should be taken to avoid loss of contained oil by shipboard discharges such as cooling water impinging upon the slick.

- Tankage should be available for recovery of several times as much fluid as discharged to account for the oil and water emulsions and free water recovered.

- Analysis of the correlation of the ability of a boom to seakeep with its ability to contain oil is continuing.

- Recovery of high wax oils similar to Newfoundland crudes in 10 degrees C water is significantly enhanced by the use of "Elastol."

DISCLAIMER

Mention of specific products in this paper does not constitute or infer endorsement or acceptance by the Minerals Management Service, the Conservation and Protection, or the authors.

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SHIPBOARD NAVIGATIONAL RADAR AS AN OIL SPILL TRACKING TOOL
A PRELIMINARY ASSESSMENT

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Minerals Management Service

ABSTRACT

The utility of shipboard navigational radar as an oil spill tracking tool was evaluated in a wide range of sea states during an intentional oil spill exercise off Nova Scotia, in September 1987. Specially tuned ship's navigational radar onboard the Canadian Coast Guard Cutter "Mary Hitchens" was able to detect slicks of five barrels of spilled crude oil during periods of fog, rain, and darkness. Slicks were detectable in winds ranging from less than 10 knots to over 30 knots. There appeared to be a correlation between slick thickness and the capability for radar detection.

INTRODUCTION

The capabilities of two x-band shipboard navigational radar units to detect oil slicks were evaluated during a joint Environment Canada-Minerals Management Service cruise offshore of Nova Scotia, Canada, in September 1987. Two series of spills were conducted; each consisted of five releases of 5-imperial-barrels of Alberta Sweet Blend Mix (ASBM) crude and ASBM to which Bunker C had been added. The behavior of these slicks was monitored until the slicks had visually dissipated. Radar was used to track these slicks, and the radar images were compared with visual observations when conditions permitted. Winds ranged from less than 10 to over 30 knots during the radar evaluation. Weather ranged from fog to rain to clear conditions.

The application of airborne x-band and synthetic aperture radar for slick detection is a proven technique with a number of worldwide operational units routinely available. Previous evaluation of shipborne radar (Axelsson, 1974) indicated that detection ranges for oil slicks were limited to approximately 1 kilometer even though the radar unit evaluated had a maximum nominal range of 75 nautical miles. Discussions of factors influencing radar imagery conventionally describe a critical viewing angle of at least 20 degrees for sufficient reflection to yield a discernable pattern of sea surface conditions (Simonett, 1983). One evaluation of optimal antenna viewing angles (C-Core, 1981) indicated that 30 to 45 degrees from the vertical angle would be required. This lends credence to the findings of Axelsson and appears to explain the previously reported limited oil spill detection range of shipborne radar. However, evaluations during this cruise indicate that clear depictions of slicks are possible at ranges of 12 nautical miles or more.

One explanation of how the radar receives returns from the ocean surface is through back scattering. Microwave back scattering from the ocean surface may be due to Bragg scattering by the short (approximately 5 cm) waves for x-band radar causing a resonance in the microwave return to the antenna. This constructive interference is apparently necessary for discernable depiction of differences in sea surface texture except when breaking waves are present (Milgram, 1988). Bragg scattering is also a function of antenna viewing angle.

This evaluation of shipboard radar was predicated on the damping of short period waves by the slick and the ability of radar to detect and represent differences in the short period wave field.

Field Experiment

The joint Environment Canada-Minerals Management Service cruise to evaluate two oil spill chemical additives was conducted from the Canadian Coast Guard Cutter "Mary Hitchens" on September 9-10, 1987, offshore of Nova Scotia, Canada. Two shipboard radar units were used coincidentally to track and monitor each of the ten 5-imperial-barrel oil spills during this exercise. It should be noted that an unidentified freighter transited the restricted exercise area and discharged an oil slick approximately 50 meters wide from horizon to horizon. The results of the evaluation of the chemical additives are reported elsewhere in these proceedings.

The two radars evaluated were the Sperry MK-340 and the Decca 914 with a Bright Track repeater. The Sperry MK-340 is an x-band radar with a horizontal beam width of 1.9 degrees and nominal ranges of 0.25, 0.5, 0.75, 1.5, 3, 6, 12, 14, 24, 48, and 120 nautical miles. The radar is a 50 kilowatt unit with its antenna approximately 50 feet above the ocean surface. The Decca 914 is also an x-band radar with nominal ranges of 0.25, 0.5, 0.75, 1.5, 3, 6, 12, 24, 48, and 60 nautical miles. The horizontal beam width is 1.9 degrees. The radar is a 25 kilowatt unit with an antenna height of approximately 40 feet above the ocean surface.

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Results

Initial attempts to track the first five of the 5-barrel slicks over a range up to 12 nautical miles were unsuccessful with both units operating in standard navigational mode. Both radar units had sophisticated interference filters to reduce sea return and interference from rain. Approximately two hours were initially required to adjust the gain and sea and rain clutter filters to optimize the representation of the sea return. Once a relatively homogenous sea return was available on the radar, the author analyzed areas of diminished sea return representing short wave damping due to the oil slick. The radar could subsequently be returned to navigational or slick detection mode by activating and deactivating the automatic filter program. The Decca did not offer the resolution of the Sperry and was less sophisticated so that initial adjustment for optimal sea surface return was more easily accomplished.

No photographic capabilities existed for the Sperry radar screen. The Decca Bright Track Unit, however, allowed a wide range of screen brightness control, and the following photographs were taken with this unit.

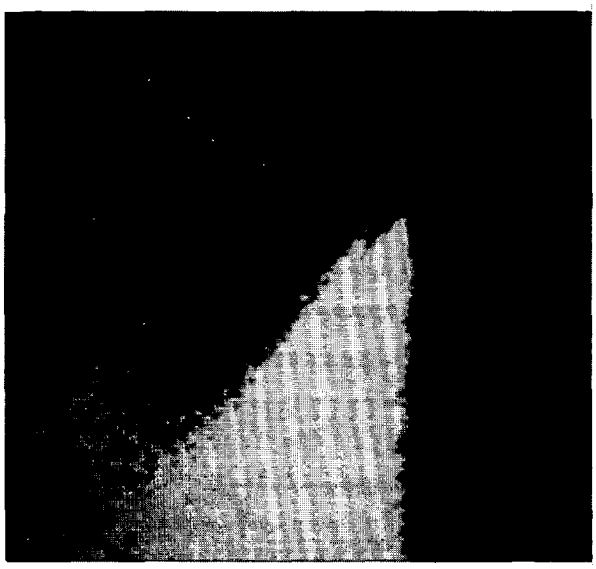

Figure 1 clearly shows the "mast shadow" artifact caused by the mounting of the radar unit just forward and starboard of the ship's mast. This pie-shaped hole in the sea return was apparent at all times.

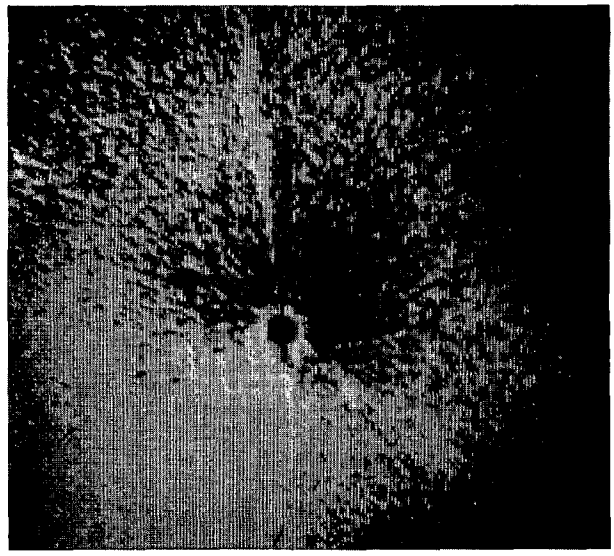

Figure 2. A five barrel slick (Slick No. 3) is visible at 11 o'clock (350 degrees relative). Range-3 nautical miles, winds 15-20 knots. The slick had deteriorated with patches of thick oil and mousse surrounded by sheen. The freighter's slick is visible at 9 o'clock (270 degrees relative).

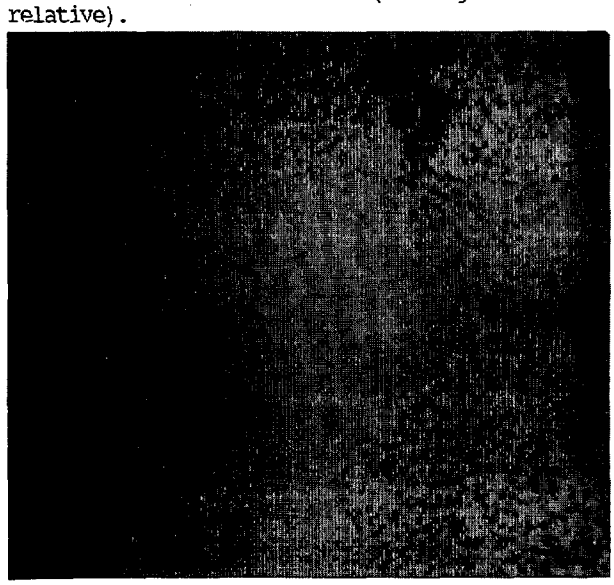

Figure 3. A slick is clearly visible from 6 to 7 o'clock (180-200 degrees relative) even though partially obscured by the mast shadow. Slick very light, mostly sheen, winds less than 10 knots. Range 3 miles.

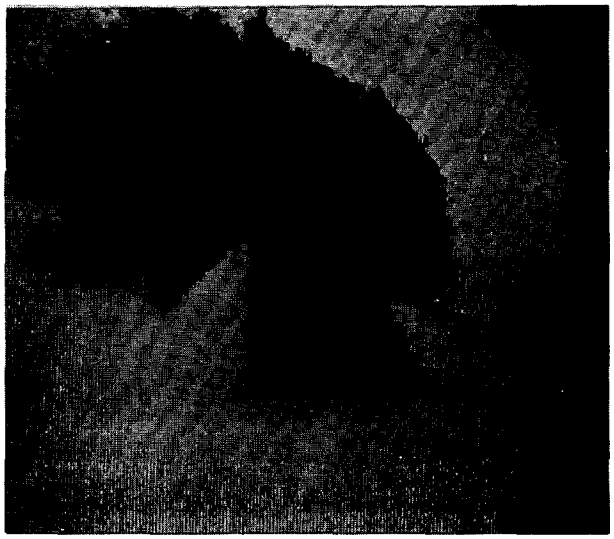

Figure 4 shows the mast artifact from 6 to 7 o'clock (180-200 degrees relative). The slick from the freighter is visible at 4 o'clock and 9 o'clock (110 and 270 degrees relative) and was a continuous slick. A heavily dissipated sheen is visible at 12 o'clock (360 degrees relative). Range is 12 nautical miles; winds 25-30 knots.

The Decca Unit did not have the resolution of the Sperry; therefore, the photographs do not offer the detail observed during the evaluations of the Sperry.

The presence of large swells coupled with breaking wind driven waves obscured the slicks when winds exceeded 30 knots. It is unclear whether relatively advanced and confused sea states, or the rapid dissipation of the slick under these conditions, was responsible for the loss of detection. Perhaps both contributed to the apparent inability of either radar to find slicks in confused breaking seas at these high wind velocities. Fog and rain had no effect on the detection capabilities of either radar.

There was an apparent correlation between the observed thicker portion of the slicks and the radar image. As the slick dispersed into sheen thickness, the radar image became more indistinct. This technique apparently discerns thicker (more recoverable) slicks from less recoverable portions and could be used to guide recovery operations, reducing unproductive efforts in slicks too thin for effective recovery.

Conclusions

Shipborne x-band radar can readily detect oil spills in a range of sea conditions if properly tuned.

Slicks were clearly detectable in winds up to 30 knots as long as major swells (8 to 10 feet) were not also present.

Slicks were detectable in 5-10 knot winds, which were the minimum velocities observed during the exercise.

Requirements for tuning the radar to optimize sea return vary with the sophistication of the unit. The higher the sophistication the more difficult the initial tuning.

Radar is a readily available tool to most responders, and its use can expand slick tracking and can eliminate many of the detection problems associated with fog, rain, darkness, and relatively high sea states.

Further evaluation with a range of oils and sea states is required to quantify the limits of this technique.

ACKNOWLEDGEMENTS

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DISCLAIMER

The mention of specific products in this report does not constitute or imply an endorsement by the Minerals Management Service or the author.

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SPATIAL OBJECTIVE ANALYSIS OF SMALL NUMBERS OF LAGRANGIAN DRIFTERS

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ABSTRACT

To analyze the irregularly spaced tracks of freely drifting surface buoys, objective analysis techniques were applied to produce optimal estimations of forecast surface current fields on a regularly spaced grid. With the interpolation of raw data to the grid points, further analysis can be done with other computer programs. A computer program using this technique has previously been successfully applied to large oceanographic data sets of many drifter tracks. The objective analysis program has been converted for use on Hewlett-Packard microcomputers and applied succesfully to much more limited data sets of from one to six drifters.

1. INTRODUCTION

The Oceanography Branch has, as part of the Improvement of Probability of Detection in Search and Rescue Project, an ongoing investigation into the drift and leeway of survivors and survivor crafts (1). Others, (2-4) have evaluated the Coast Guard's operational search planning computer models. They have shown that model drift predictions for survivors and survivors' crafts, based on either historical current files or surface current values derived from large-scale winds from U.S. Navy Fleet Numerical Oceanography Center (FNOC), rarely predicted the actual drift as simulated by freely drifting buoys. At present, a single radio-direction finder type datum marker buoy (RDF-DMB) is used to measure surface currents during a search. The initial position of the buoy is established when the RDF-DMB is dropped from an aircraft. However, to obtain a velocity datum, a second position, at a later time, must be determined for the RDF-DMB. This requires the aircraft to break off the search for the survivors and search for the RDF-DMB, causing the loss of valuable time and fuel. The important velocity measurements necessary for an accurate prediction of the drift of the survivors are therefore limited to one or two points. The development of VHF Loran-C buoys (5), has demonstrated that coded buoys reporting their Loran-C positions every 30 minutes will deliver far more positions, more accurately and therefore more surface current data to the search planner. This provides the search planner a clearer picture of the surface currents. The increased data rate requires a more involved analysis than do the data from the RDF-DMB's. This paper summarizes a first look at the use of objective analysis for analyzing data from freely drifting buoys and other sources of irregularly spaced surface current data. A complete account of this work is found in (6).

The use of statistical models for the optimal estimation of oceanic fields given limited measurements is known as objective analysis (7). The basic equations of objective analysis are described in (8). The technique used here is the same as that used by the statistical component of the Harvard Ocean Descriptive Predictive System (9).

In this study, objective analysis was used to nowcast/forecast the surface currents using limited drift measurements. Several types of freely drifting buoys that transmit their positions to a shore-based receiver have been used by the Oceanography Branch. A local positioning system using the Microwave Tracking System (MTS) was used with surface drifters in leeway studies. Both polar-orbiting NOAA/TIROS series satellite and Loran-C positioning were used with surface drogued buoys during drift studies on the continental shelf. All of these studies (4,5,10) typically contained data sets in the form of a time series of buoy positions for one to six drifters. A time series of a freely drifting buoy's positions is called a drift track. The purpose ofthis study was to apply the technique of objective analysis to one of our data sets. A

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computer program using this technique has been successfully applied to large oceanographic data sets of drifter tracks (9). These large data sets, however, included many more drifter tracks than are typically used in our studies. Therefore, the objective analysis program was converted for use on Hewlett-Packard micro-computers and applied to a data set from an MTS leeway study.

2. THE CORRELATION FUNCTION

The covariance matrices required in the solution of the objective analysis are defined by correlation functions. The correlation function is the planar (x,y) and temporal (t) distribution of the weighting factors for estimating an unknown value from the surrounding observations. Essentially, closer observations are weighted more in determining an unknown value than more distance values. At sufficiently large distances and time lags the observations will have no appreciable influence on the interpolated value. Thus, a limit over which the observations are not included in the interpolation is assumed. This greatly simplifies the computation. The correlation function can be determined directly from a data set that is sufficiently large. However, when the data set is small, the mathematical form of the correlation function is artificially imposed. The correlation function used in this present study is:

$$C(R) = e^{-R} \quad \text{where} \quad R = \sqrt{\left[\left(\frac{\Delta^x}{x\,fold}\right)^2 + \left(\frac{\Delta^y}{y\,fold}\right)^2 + \left(\frac{\Delta^t}{t\,fold}\right)^2\right]} \quad (1)$$

where delta_x, delta_y, and delta_t are the components of the difference from the data point to the interpolated point; and where xfold, yfold, and tfold are the e-folding scales of the correlation function.

Equation (1) for x and y is plotted in Figure 1, for values of xfold, and yfold equal 1. At x,y = 1,0 and x,y = 0,1 the correlation (z) value is 0.368, this is called the e-folding scale. The e-folding scale is shown in Figure 1 as the circle at z = 0.368. As the correlation function approaches zero asymptotically the outer portion is cut off to increase computational efficiency. The appropriate values for the e-folding scales are the physical scales of the motions. This is the scale in time and space of the coherence of the dominant motions. The e-folding scale is symmetrical about its axis, but does not have to be equal about all axes. An example would be the alongshore velocity on the continental shelf; the coherence is very long (~200km) in the alongshore (y) direction and short in the cross shelf (x) direction (~20km) and about two days in (t) time. These values could be used as a first guess of the e-folding scales for x, y and t. The appropriate values are based on the physical scales of the value used.

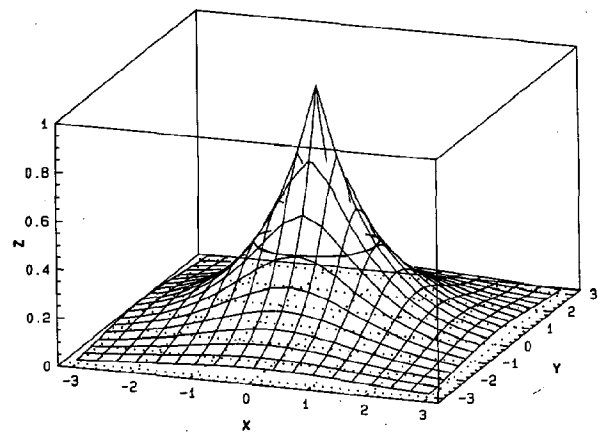

Figure 1. The defined correlation function (equation 1) where xfold and yfold = 1. The z axis is the value of the correlation function. The circle at z = 0.368 is the e-folding scale.

3. TEST RUNS

Objective analysis has been successfully applied to large data sets of freely drifting oceanographic buoys. However, what occurs to the results when the data available to the objective analysis program is systematically reduced to the limit of a single available point? Does the technique fail catastrophically, or do the results simply degrade with fewer data available for input? And if the results just degrade, how do they degrade? To answer these questions, a series of test runs of the scalar objective analysis (SOA) program were done. The data set used to test the SOA was from the Fort Pierce, Florida, March-April 1985 Leeway Experiment. During the afternoon of 1 April, six surface drifters were deployed and were tracked with the Microwave Tracking System, (MTS). Lieutenant Louis Nash, USCG, provided the edited u and v velocity data in the x-y state coordinate plane, Figure 2. Thus we had a data set which was large by our standards for investigating the SOA program. To further simplify the problem we only used velocities at a single point in time - 14:30.

During the test runs of the objective

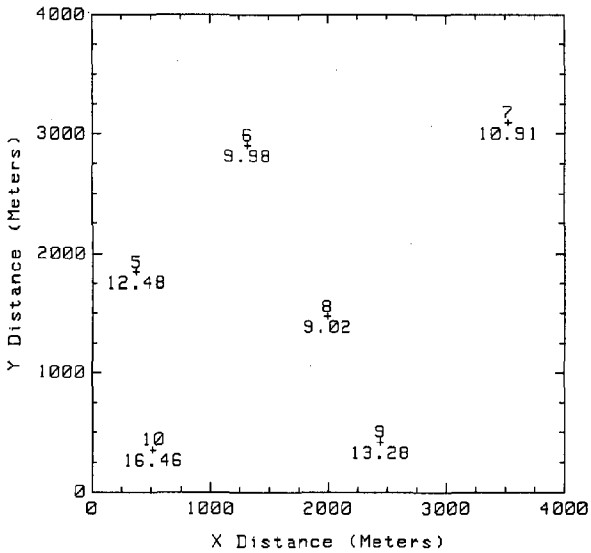

Figure 2. Position and u-component speeds at 14:30, 1 April 1985. The symbols "+" indicate the drifter location. The numerals above the "+" denote the drifter ID; while the numbers below "+" denote the values of the u-component (cm/sec). The reference point (0,0) is located at x 234500 m and y 349000 m in the East zone of the Florida State Plane coordinate system.

analysis program we first tried to calculate the correlation function on all six drifters. However, six drifters proved to be insufficient for the calculation of a sensible correlation function. Therefore we used the analytic form of an exponential decay function as given by equation (1), the correlation function.

Equation (1) was used as the basis for generating current field values on a grid of 15 by 15 regular spaced points from the observed surface current data. That grid has points between current data points and to a limited extent outside the region. Figure 2 shows the eastward component of velocity (u) at 14:30 from the six drifters. In Figure 3 the current field generated by the SOA scheme for the six drifters is shown. The currents near the drifters are reproduced faithfully enough, including the region of currents less than 10 cm/s in the upper central region and the currents greater than 16 cm/s in the southwest corner.

The question was then asked, "What is the minimum number of drifters needed by

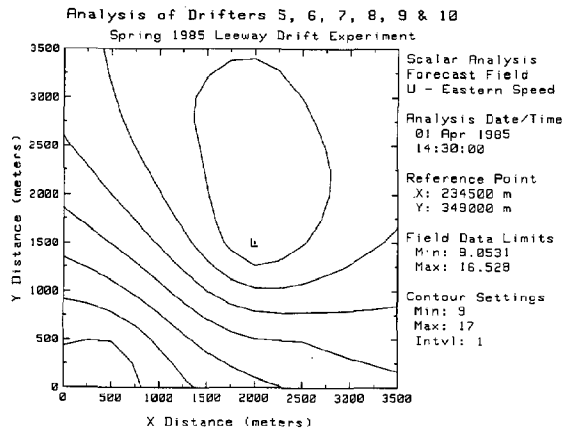

Figure 3. Objective Analysis Forecast of the u-component of velocity for Case 6.

the SOA program to produce a sensible current field?" To start, all six drifters were used to fully determine the current field (Figure 3). This provided the best estimate of the u-current field against which the other fields were compared. When drifters were removed one at a time from the data set the estimated fields changed. The fields generated by the reduced number of drifters were then compared to the results with the "best estimate" field determined by all six drifters. Two different schemes for removing drifters were investigated. Case "A" was to remove the least useful drifters one at a time leaving the "best" to be used to estimate the U-field. Case "B" was to remove the most useful drifters one at a time leaving the "worst" to provide the estimate of the U-field. Both schemes are shown in Table I.

TABLE I
DRIFTER CASES

The Best (A) and the Worst (B) cases used for comparisons of subsets of drifters with the full set of six drifters.

CASE-A (BEST)	DRIFTERS (USED)	CASE-B (WORST)	DRIFTERS (USED)
6	5,6,7,8,9,10	6	5,6,7,8,9,10
5A	5,7,8,9,10	5B	5,6,7,9,10
4A	7,8,9,10	4B	5,6,7,9
3A	7,8,10	3B	6,8,9
2A	8,10	2B	6,9
1A	8		

The differences were calculated at each 15 by 15 grid point between the forecasted field derived from all six drifters and each 15 by 15 grid point of the cases above. The differences from all the 225 points produced the measured error fields. The square root of the sum of the squared differences is an index of the cumulative measured error (CUME). The equation for cumulative measured error index for case 5A is shown below:

Cumulative Measured Error Index (CUME)

$$\text{CUME} = \sqrt{\Sigma (6_{ij} - 5A_{ij})^2} \qquad (2)$$

where the subscripts "ij" are the elements of the 15 by 15 array. Therefore, we have fields of the forecasted U-velocity, an index of the cumulative error for each case of the two schemes. The indexes of cumulative measure error are present in Table II.

The cumulative measured error index for the two schemes are presented in Table II.

TABLE II
CUMULATIVE MEASURED ERROR INDEX
FOR SCHEME A AND SCHEME B

	Number of drifters used for Analysis					
	6	5	4	3	2	1
Scheme A	0.	3.	6.	13.	15.	49.
Schemd B	0.	15.	19.	27.	24.	--

This suggests that "2A" did as good a job at predicting the U-field as did "5B".

Scheme "1A" with just drifter #8 is the special case of the objective analysis taken to its limit. The forecast field is uniform at the value of the drifter (9.028 cm/s).

4. RESULTS OF TEST RUNS

The main portion of the objective analysis technique did not fail catastrophically as input data was removed. Instead, the quality of resulting velocity fields decreased relative to the original field, reading from left to right - Table II. However, the more important point is that the placement of the buoys or drifters relative to the flow field features will greatly influence how well the total flow field is estimated, reading from top to bottom - Table II. An example of an application would be the placing of two buoys on either side of an oceanic front. This scheme would estimate the currents better than several buoys all on the same side of the front. A few well-placed buoys will provide better information than many poorly placed buoys. Therefore, the search planner should use remote-sensing information (e.g., Side Looking Airborne Radar (SLAR) derived sea surface roughness or NOAA6 satellite Advanced Very High Resolution Radiometer (AVHRR) derived sea surface temperature imagery) to assist in the optimal placement of buoys.

The determination of the correlation function from the statistics did fail for the data set used here. The number of buoys required to determine the correlations functions is greater than six. Therefore an analytical formula (Equation 1) was used instead. In this study neither the v-velocity (north - south) field nor the time dependent field were considered. Since there should be a relationship between the u and v fields and between the spatial and temporal fields, correlations in time could be used to infer correlations in space. Thus, the buoys' track histories could be used to determine the time correlation which then would provide a better estimate of the velocity field. Further work is being conducted on improving estimates of the current field from limited amounts of drifter data.

5. CONCLUSIONS

The search planner requires real-time surface current information to determine the most probable location of the survivors and survivor craft. The displacement with time of the search datum can be estimated from the track histories of freely drifting surface buoys. All types of freely drifting buoys will generate data sets that consist of a time series of irregular-spaced positions. As a set of buoys freely drift in the ocean, (1) positions at any one time are not on a regular grid, (2) the displacement from the previous positions of that buoy to the next position is uneven, and (3) the relative displacement among all the buoys is changing with time. Additionally, some types of buoy (e.g., TIROS satellite track buoy) positions are reported intermittently. This results is a "messy" data set.

To take advantage of computer analysis of the buoy tracks, the data set must first be cleaned up. The essence of

objective analysis is that, given an irregular-spaced data set in time and space, a data set is interpolated and extrapolated to a regular (even and square) grid. From this many standard computer programs are available that can be brought to bear on the analysis of the buoy tracks. This analysis can then provide the most information in a timely manner for the search planner.

In summation, an objective analysis program was modified and tested to demonstrate its capabilities on small data sets. The results of the test show that objective analysis can effectively work on as little as two buoy drift tracks. The search planner is going to be required to utilize a variety of data sources to effectively locate the most probable positions of survivors. The use of objective analysis is a first step in preparing these data sets for use by the search planner. The application of these data sets to other computer programs will provide the search planner with the most probable positions of the survivors.

ACKNOWLEDGMENTS

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A MINICOMPUTER APPLICATION TO GRAPHICALLY DISPLAY TIDAL CURRENT DRIFT

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ABSTRACT

An application on a minicomputer has been developed to account for the drift of an object due to tidal currents for up to three tidal cycles. An algorithm using the National Ocean Survey's Tidal Current Tables and Tidal Current Charts of Long Island Sound and Block Island Sound as data sources accounts for the changes in current velocity over the duration of the tidal cycles. This algorithm allows for entry of the last known position and time of an object and yields both a graphic and tabular display of subsequent times and positions of the object. The resulting drift position can then be used on the same minicomputer to derive bearing and range of the drift position from other geographic positions or can be used to update the most probable position in Search and Rescue (SAR) case planning.

1. INTRODUCTION

The key to successful SAR in any circumstance is timely and accurate location of the search object's most probable position or "datum". Search patterns are usually centered around datum. Datum moves over time due to environmental factors acting on the search object. Datum drift is composed of total water current acting on the search object and the object's leeway (movement of the object with respect to the water due to wind action on the freeboard or "sail area" of the object).

In an estuarine environment the total water current is mainly composed of tidal current, wind driven current, and occasionally, location particular river outflow current.

In accounting for tidal current drift over time, a SAR case planner would normally be required to make numerous calculations to achieve a vector sum based on the last known position of an object, and the time elapsed until a search response unit arrives on scene. Use of manual methods is very tedious and time consuming, increasing opportunity for error and inaccuracy.

Having a desktop computer perform the many calculations required to solve for tidal current drift relieves the SAR controller of a sizeable burden, particularly at a time in the SAR case planning phase when efforts could be better spent on initial resource mobilization and utilization.

This report describes the development and test of a technique used for applying tidal current drift to the last known position of a drifting object.

2. BACKGROUND

In 1986, an effort began at the Coast Guard Research and Development Center to design a system for solving maritime drift using the Geographical Analysis and Archiving Display System (GAADS). GAADS was developed in-house as a refinement of a ship-based Aerostat radar tracking and display system. The object in development of a maritime drift solution system using GAADS was to provide a search planner with rapid calculations and graphically show the results on a digital chart display, in a user friendly manner, on a desktop mini-computer.

The area chosen as a procedural test-bed was Long Island Sound and Block Island Sound. This provided an area with tidal currents of a high velocity (hence a major factor in determining datum drift), and in close geographic proximity to the R & D Center for testing.

The algorithm used is based wholly upon data presented in the annual Tidal Current Tables, Atlantic Coast of North America (Tidal Current Tables)[1] and Tidal Current Charts, Long Island Sound and Block Island Sound, Seventh Edition 1979 (Tidal Current Charts)[2]. Hence, this is an adaptation of existing, standard information rather than development of a tidal current forecasting method.

3. SYSTEM DESCRIPTION

The Tidal Current Charts (TCC's) give a full discussion of their proper use. In brief, there are thirteen charts depicting the direction and magnitude of the tidal currents at 144 tidal current stations (TCS's). The direction is represented by an arrow. Magnitude is shown by figures with the speed in knots at average spring tide velocities (figure 1). The data shows average speed and direction at the exact location of the tidal current station.

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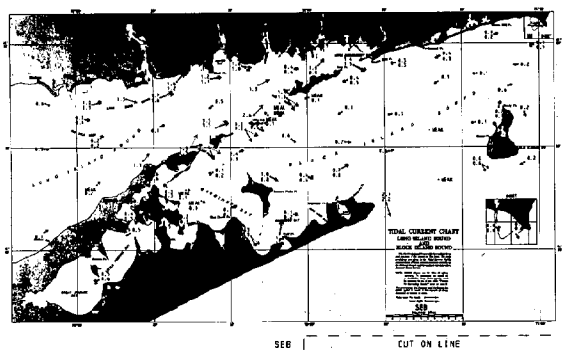

Figure 1. Excerpt from Tidal Current Charts

There are six charts for the duration of the flood tide, and seven for the duration of the ebb tide. The charts are computed on an "equal interval" basis for each flood and ebb phase. For reference to a specific chart, the user must divide the duration of flood or ebb from the Tidal Current Tables by six or seven, respectively.

There is also a table of "Factors for correcting speeds" which must be applied to the charted velocity values to account for the daily differences between the maximum predicted current of a tidal cycle at "The Race" (from the Tidal Current Tables) and the averages on which the charts are based.

Proper use of this technique gives a straightforward prediction for the tidal current at a known position and time. For continuous drift while time and position keeps changing, adaptation of this technique was necessary.

A TCS array was configured using 83 of the 144 stations shown on the TCC's. TCS's in Gardiners Bay and the Peconic Bays were not included, nor were those inside relatively closed embayments and rivers. Examples of some of these include the Housatonic, Connecticut, and Thames Rivers, and New Haven Harbor. The array was made up by listing TCS location by longitude and latitude, thirteen direction and velocity pairs corresponding to the thirteen equal interval charts in the TCC's, the TCS number from the charts, and the TCS number from the Tidal Current Tables. The direction values used in the array are those from the Tidal Current Charts. Comparison of the direction vectors on the charts with the average direction values from the Tidal Current Tables shows agreement in all but a few instances. In those instances where the differences were greater than five degrees, the values from the Tidal Current Charts were used.

If the velocity values found in the Tidal Current Charts for the TCS's are compared to time, a regular distribution replicating the sinusoidal nature of tidal function is found. Figure 2 shows this for a representative TCS. In figure 2, the horizontal axis represents units of equal time interval with respect to Slack, Flood Begins (SFB) and Slack, Ebb Begins (SEB) at The Race. This depiction is not a representation of actual time. The vertical axis indicates magnitude of the current velocity.

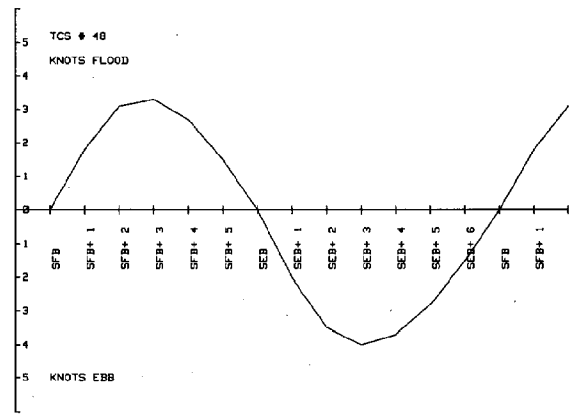

Figure 2. Comparison of Tidal Current Station velocities with respect to equal intervals of the tidal cycle

The resultant "curve" shown in figure 2 is not "smooth" in that it does not depict the actual addition of constituent sinusoidal elements. The approximation of velocities between times of equal interval suffices for the purposes of this work. Though the velocity of the tidal current is always changing with respect to time, an adaptation of this concept was necessary for microprocessor application.

Rather than account for an object's drift over a small increment of time, (in effect interpolating velocities of current between the forecast velocities at equal intervals of the tidal cycle from the TCC's), the increment of time was set as the duration of an equal interval of the tidal cycle. Using the time of equal interval found as per the instructions in the TCC's, the duration of each equal interval was centered at the time of each equal interval. This produced an incremental or "stepped" representation of velocity with respect to time as shown in figure 3.

Since the "curves" represent tidal current velocity with respect to equal intervals of tidal cycle, the area between the curve and horizontal zero axis represents a "distance" value for the duration of the tidal cycle. Comparison of the area below the curves shows approximate agreement between the "smooth" curve and the "stepped" curve. In fact, 6 representative curves were examined, and by use of a polar planimeter, the areas under the curves agreed in most instances within 2 %. This degree of accuracy was viewed acceptable, considering that for a value of 3 knots, accuracy is within .06 knots.

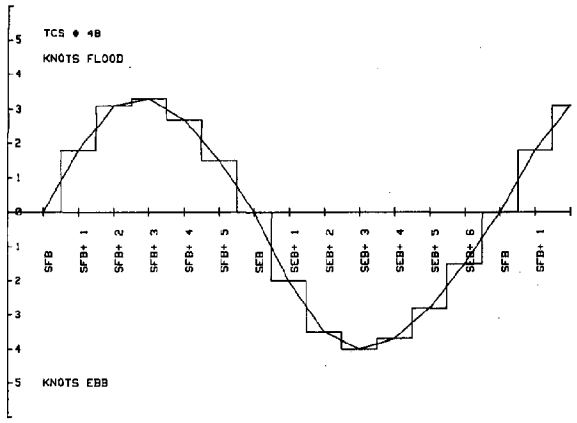

Figure 3. Incremental representation of Tidal Current velocities over the tidal cycle

An additional consideration was the point during the equal interval at which the value of the incremental velocity should be centered. Comparison between beginning the step at the instant of equal interval and at half the equal interval preceding the moment of equal interval (the curve shown in figure 3) was done. Beginning the step at the preceding half interval showed closest correlation with respect to time.

The method described accounts for the change in tidal current velocity over the duration of the tidal cycle.

The algorithm uses predicted tidal current values at the tidal current station nearest the last known position of the search object, predicts drift for an equal interval of the tidal cycle, then selects the nearest tidal current station closest to the predicted drift position, and uses that predicted value for the subsequent drift. This occurs for every equal interval of the tidal current cycle, and for additional tidal current cycles if desired. A "dead reckoning" feature of the GAADS software allows for interpolation of datum between the times of equal interval.

Two factors yield uncertainty in this process. One is that the magnitude and direction of the predicted value at a particular time is used for the entire equal interval of the tidal cycle (from approximately 53 to 65 minutes). In fact, for most equal intervals of the tidal cycle the current is continually increasing or decreasing. The other factor is that as the "closest" (in linear distance) tidal current station is used for drifting the search object, tidal current shear, divergence or convergence may not be adequately addressed. Also no "averaging" of the values between tidal current stations is done. This may or may not have major effects on prediction. From one aspect, this may be of benefit, particularly where tidal current stations are separated by a hydrographic/geographic feature such as a shoal or island. From the other, effects of current flow as represented by techniques such as a streamline analysis of currents, with gradient resolution, is not taken into account.

Comparison of actual drift versus predicted drift gives an indication of validity of the methods used.

4. TEST AND EVALUATION

As this work was conducted on a minimally funded basis, full scale, real world drift testing of the algorithms and techniques used was not conducted. Instead, "tests of opportunity" were conducted. These tests of opportunity involved free drifting objects, where their deployment was necessary for other aspects of SAR research. Two drift tests were conducted during evaluation of small, remotely monitored LORAN-C drifting buoys. Three drift tests were conducted during drogue effectiveness comparisons. These tests were conducted in the areas shown in figures 4 (a) and 4 (b). Both the LORAN-C drifting buoy tests and the drogue effectiveness tests relied on a 5' x 5' x 5' cross-type drogue, buoyed at the water surface to ensure that only surface currents were measured, without any object leeway.

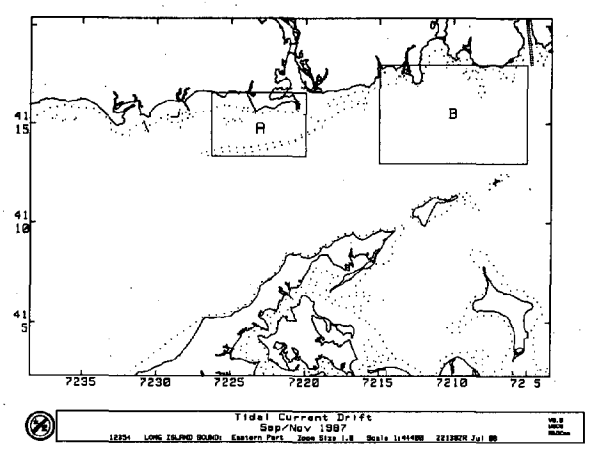

Figure 4 (a). Areas in Long Island Sound where drift tests were conducted

Table 1 shows values for elapsed time of each test,total actual and predicted drift, final position difference, and drift variation between the start point and the final total drift positions. A value called "drift error" is also included. "Final Position Difference" is the difference in position from the final actual drift position to the final predicted drift position. This difference is given in compass bearing and range (polar coordinates, not Cartesian). Drift Variation is the difference between the total predicted drift from the start point and the total actual drift from the start point. Direction drift error is the percentage of drift direction variation over 180° (if predicted drift were

opposite to actual drift, direction drift error would be 100%. Distance drift error is the percentage of the distance drift variation over total actual drift distance.

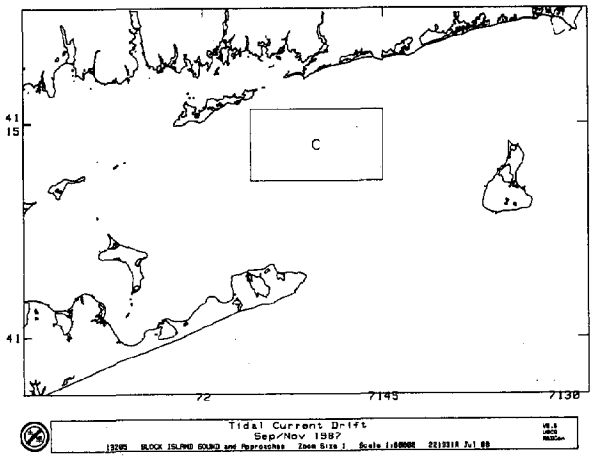

Figure 4 (b). Area in Block Island Sound where drift tests were conducted

Graphic representation of the tests are given in figures 5 (a) through 5 (e). Symbology in these figures is as follows: The position where drift began is indicated by the wide arrow. The track of the actual drift object is shown with the recovery point indicated by a drift object name label (e.g. "B", "DA", etc.). The predicted track is shown with the dead reckoned drift position indicated by a crosshair and narrow pointer.

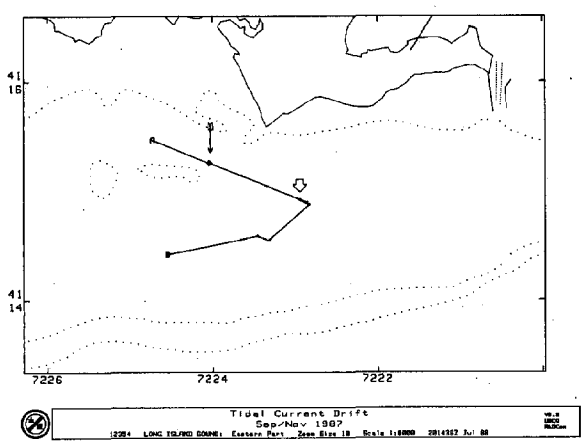

Figure 5 (a): Chart Showing Predicted Drift (A) vs. Actual Drift (B) for 14 September 1987

14 SEP 87	ACTUAL TRACK	B	
	PREDICTED TRACK	A	
	TOT ACTUAL DRIFT	248	@ 1.3 NM
	TOT PREDICTED DRIFT	293	@ 0.9 NM
	ELAPSED TIME	2 h 27 m	
	FINAL POS DIFFERENCE	025	@ 0.9 NM
	DRIFT VARIATION	45°	@ 0.4 NM
	DRIFT ERROR	25 % DIRECTION	
		31 % DISTANCE	
16 SEP 87	ACTUAL TRACK	D	
	PREDICTED TRACK	C	
	TOT ACTUAL DRIFT	085	@ 2.5 NM
	TOT PREDICTED DRIFT	086	@ 0.8 NM
	ELAPSED TIME	1 h 46 m	
	FINAL POS DIFFERENCE	265	@ 1.7 NM
	DRIFT VARIATION	1°	@ 1.8 NM
	DRIFT ERROR	<1 % DIRECTION	
		70 % DISTANCE	
17 NOV 87	ACTUAL TRACK	DA	
	PREDICTED TRACK	G	
	TOT ACTUAL DRIFT	060	@ 3.6 NM
	TOT PREDICTED DRIFT	067	@ 3.2 NM
	ELAPSED TIME	2 h 58 m	
	FINAL POS DIFFERENCE	197	@ 0.6 NM
	DRIFT VARIATION	7°	@ 0.4 NM
	DRIFT ERROR	4 % DIRECTION	
		11 % DISTANCE	
18 NOV 87	ACTUAL TRACK	X8	
	PREDICTED TRACK	F	
	TOT ACTUAL DRIFT	095	@ 5.4 NM
	TOT PREDICTED DRIFT	076	@ 5.1 NM
	ELAPSED TIME	2 h 14 m	
	FINAL POS DIFFERENCE	346	@ 1.8 NM
	DRIFT VARIATION	19°	@ 0.3 NM
	DRIFT ERROR	11 % DIRECTION	
		6 % DISTANCE	
19 NOV 87	ACTUAL TRACK	X9	
	PREDICTED TRACK	H	
	TOT ACTUAL DRIFT	086	@ 4.0 NM
	TOT PREDICTED DRIFT	069	@ 4.2 NM
	ELAPSED TIME	3 h 12 m	
	FINAL POS DIFFERENCE	357	@ 1.3 NM
	DRIFT VARIATION	17°	@ 0.2 NM
	DRIFT ERROR	9 % DIRECTION	
		5 % DISTANCE	

TABLE 1.

COMPARISON OF ACTUAL DRIFT TO PREDICTED DRIFT

The first test was conducted in Long Island Sound on 14 September 1987 (Area A in figure 4 (a)). The drift trajectories in figure 5 (a) show a sizeable difference in drift direction (the greatest for any of the tests) between predicted and actual drift. Initially, the actual drift shows more motion to the east during the last stages of the ebb current, with the direction of the westward drift (flood current) approximating the natural channel flow between the shoal area to the south of the actual drift trajectory and the Connecticut Coast. Winds were very light and variable before and during the test.

A test was conducted on 16 September 1987 in the northern portion of Area B of figure 4 (a). The drift trajectories for this test are shown in figure 5 (b). This test resulted in the greatest distance drift error of all the tests. The test occurred during the final one-third of the ebb cycle. Again for this test, winds were very light and variable before and during the test. In this area, the nearest TCS used is located two-thirds of the way from the drift start point to the point of land immediately to the north. The increase in current gradient as distance from the shore increases appears to be the major factor for the large difference in total drift distance. In fact, the predicted values of current show a decrease from 0.4 knots to 0.1 knots, where actual values show a current diminishing from approximately 1.5 knots to 1.0 knots.

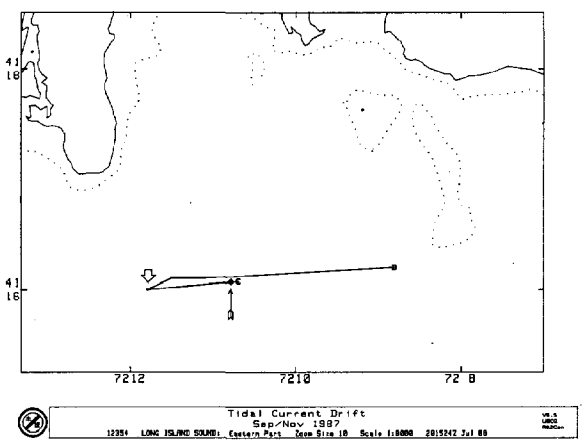

Figure 5 (b): Chart Showing Predicted Drift (C) vs. Actual Drift (D) for 16 September 1987

The smallest absolute difference in final position occurred during the 17 November 1987 test. This test was conducted in an open area (Area C of figure 4 (b)) known to be relatively free of bathymetric or topographic effects on tidal current (water depth in the area is greater than 100 ft). The drift occurred during the mid to later portions of the ebb with predicted currents diminishing from 1.6 knots to 1.0 knots. In addition, any wind-driven current was negligible as wind conditions had been light and variable prior to and during the test. The drift trajectories for this test are shown in figure 5 (c).

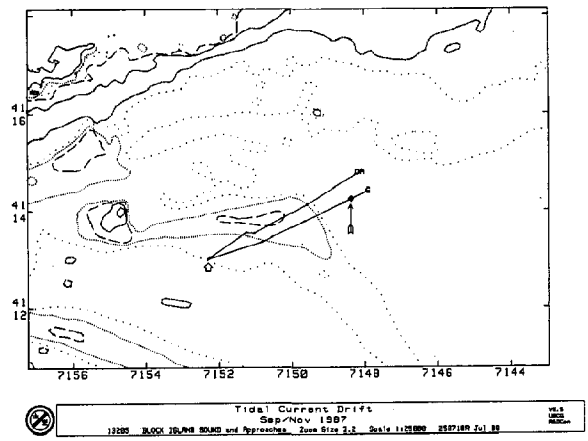

Figure 5 (c): Chart Showing Predicted Drift (G) vs. Actual Drift (DA) for 17 November 1987

A test on 18 November 1987 was conducted in the southern portion of Area B in figure 4 (a). This test yielded the greatest absolute difference between final actual and predicted drift positions, however due to this test having the greatest actual drift distance, distance drift error was only 11%. Drift trajectories are shown in figure 5 (d). This test was conducted during the middle one-third of the tidal cycle, with drift being subjected to maximum ebb velocities. Winds prior to the test were light and variable increasing to 12 knots from the west-southwest towards the end of the test. The most visible result shown is the difference in drift direction. The actual drift track to the east-southeast follows what is often viewed as the prevailing flow of the ebb current exiting Long Island Sound through The Race.

The test on 19 November 1987 (figure 5 (e)) was conducted in the same approximate position of that on 17 November, and near the same time in the tidal cycle. However, predicted currents were higher (2.0 knots diminishing to 1.2 knots), and a moderate westerly wind (10-15 knots) was present prior to and during the test. Though not fully analyzed, this wind may have accounted for a wind-driven current component, yielding actual drift to the right of predicted drift. This test yielded the smallest percentage of distance drift error.

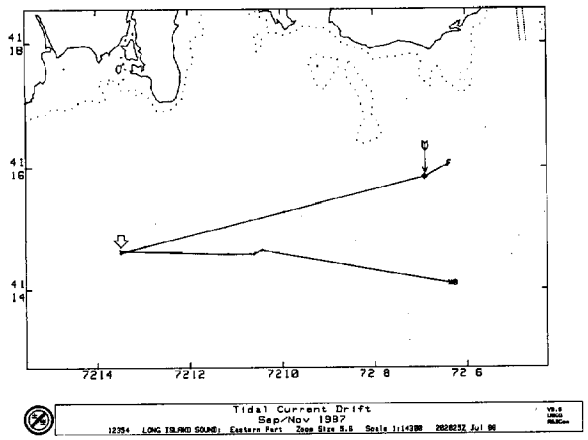

Figure 5 (d): Chart Showing Predicted Drift (F) vs. Actual Drift (X8) for 18 November 1987

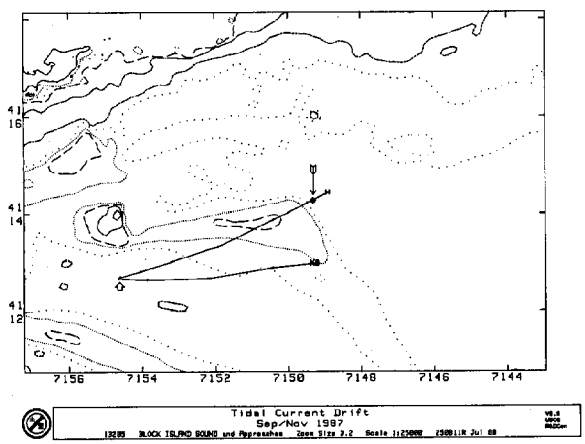

Figure 5 (e): Chart Showing Predicted Drift (H) vs. Actual Drift (X9) for 19 November 1987

5. CONCLUSIONS

Development of this application was to assist a SAR planner in determining the effect of tidal current drift on a search object (the most probable position of the object) and where to begin searching for the object. Thus, one evaluation of this application's effectiveness is how close the object's predicted drift was to the actual drift.

The 17 November test (figure 5 (c)) in open water yielded the smallest final position difference. In order of increasing final position difference, this test was followed by the 14 September test (figure 5 (a)) nearshore, the 19 November test (figure 5 (e)) in open water, the 16 September test (figure 5 (b)) nearshore, and the 18 November test (figure 5 (d)).

Though these absolute values are one measure of effectiveness, the drift error percentages should be evaluated when considering the two factors that might yield uncertainty by using the technique described as mentioned earlier: (1) use of a predicted value for an entire equal interval of the tidal cycle and (2) use of the geographically "closest" tidal current station values.

Three of the tests (17, 18, and 19 November) showed fairly small (less than 15%) distance drift error. In these three instances, drift distance variation was less than 0.5 NM. In these tests, the direction drift error was also less than 15% in all cases. These three tests were conducted in relatively open water. One of these three did show a large final position difference, but due more to drift direction variation than distance variation.

The two tests conducted near the shore showed sizeable drift error. These errors were discussed under the test and evaluation section, but point to the problems associated with using the nearest tidal current station, without any allowance for current gradient (as in the 16 September test), or bathymetrically induced current divergence (as in the 14 September test). In the same light, the 18 November test showed how by relying on the nearest TCS, predicted drift yielded an absolutely large divergence from actual drift.

Though only one test (14 September) was conducted during the change from ebb current to flood, the three open water tests (with thier small distance drift errors) pointed to the validity of using a single current magnitude for an entire equal interval of the tidal cycle.

6. SUMMARY

Though the method described could assist a SAR planner in determining the most probable position of a search object, the planner's "local knowledge" and skill level must be strong enough to be able to relate to the method's shortcomings. This is highlighted in the instructions for use of the Tidal Current Charts. As noted "inference of the current between stations must be done according to the user's experience and local knowledge."

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DRIFTING BUOY DATA QUALITY AND PERFORMANCE ASSESSMENT AT THE NATIONAL DATA BUOY CENTER

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ABSTRACT

The first, large-scale, centralized, drifting buoy, data quality program was initiated in April 1988 by the National Data Buoy Center (NDBC), an agency within the National Weather Service (NWS). This program is leading to improved meteorological observations in data-sparse oceanic areas, and hence can improve operational numerical analyses and prognoses.

All North American drifting buoy reports enter the Global Telecommunications System (GTS) in Washington, DC. The Service Argos U.S. Global Processing Center (USGPC) places the reports in DRIBU format and sends them to the NWS IBM 4341 computer system, where the data are subjected to gross range and time-continuity checks before dissemination on the GTS. More stringent checks, including comparison with climatology and NMC-generated model fields, are then performed at NDBC by data analysts in near-real time. NDBC is cooperating with the National Ocean Service (NOS) Ocean Products Center (OPC), where additional quality control will eventually be performed before the data are used for numerical prediction.

The close monitoring of drifting buoy sensor data permits analysis of system reliability and performance, which can be used in general evaluation of hardware quality.

1. INTRODUCTION

Prior to the mid-1970's, vast ocean areas of the world lacked a sufficient number of *in situ* observations to provide consistent data for reliable meteorological forecasting and modeling. Most available observations were from ships. Problems caused by lack of data were particularly acute in the southern hemisphere, where there is a small percentage of land mass. In the middle and late 1970's, satellite imagery and relatively inexpensive drifting buoys that communicated through satellites began to make practical a greater number of surface observations. Drifting buoy observations from remote areas were first used in great numbers during the First GARP Global Experiment (FGGE) in 1978-79, when several hundred buoys were deployed in the oceans of the southern hemisphere. These *in situ* drifting buoy measurements, combined with early remote sensing by the TIROS-N satellite, where shown to improve meteorological forecast products from both weather centers and local forecast offices[1]. Several other scientific programs have used drifting buoys since that time[2]. Currently, the greatest supplier of drifting buoy observations is the Tropical Ocean and Global Atmosphere Research (TOGA) Program for which approximately 200 drifters have been deployed beginning in 1984. The rate of deployment has been roughly 40 to 50 systems per year; thus, TOGA will sponsor several hundred more drifting buoys through 1995[3]. The technological refinement of hardware, the expansion of measurement capabilities, and the perfecting of inexpensive drifting minibuoys that can be air-deployed through sonobuoy launch mechanisms will probably lead to a great increase in the number of drifting buoy observations through the 1990's. For example, the Experiment on Rapidly Intensifying Cyclones in the Atlantic (ERICA) alone calls for the deployment of 100 minidrifters in just three months during the winter of 1988-89[4].

The need for a formal, centralized program to quality check (QC) drifting buoy data has been recognized for several years. Gilhousen[5] cited several specific instances when poor drifting buoy data caused problems for forecasters, and cited at least one occasion when bad data led to an erroneous solution by operational models. Yet, it is only recently that a formal, centralized program to perform QC on drifting buoy data in near-real time was begun. The need for QC will become more critical as increasing numbers of drifting buoys are deployed.

2. ESTABLISHING A DATA QUALITY PROGRAM FOR DRIFTING BUOYS

The National Data Buoy Center (NDBC), an agency of the National Weather Service (NWS), has operated and maintained a meteorological buoy network since the early 1970's. The Coastal-Marine Automated Network (C-MAN) program extended NDBC's network to coastal land stations in 1982. The initial small, experimental, three-buoy network in 1970 has now grown to approximately 100 land and moored buoy stations, which provide routine operational data to the NWS. The commitment to the importance of data evaluation in early test programs remained with NDBC as its operational mission grew. As a result, NDBC's data quality program is nearly two decades old, and has matured into a program based heavily on automated data checking in real time, combined with near-real-time examination using more stringent automated checks and human evaluation to detect subtle but real errors. NDBC station data have become recognized for high quality[6], and are used by numerous investigators as ground truth in various experiments and research projects.

This experience is being applied to QC of drifting buoy data in real time using a program developed, coordinated, and implemented over approximately one year. The program is designed to monitor and validate measurements received from drifting buoys under control of North American investigators. A means to perform real-time checks was recognized when CLS Service Argos, Inc., announced plans to open the U.S. Global Processing Center (USGPC) in Landover, Maryland. The USGPC, which became operational in late 1987, receives data via satellite from ground receiving stations at Wallops Island, Virginia, Gilmore Creek, Alaska, and Lannion, France. Since April 1988, those observations received from drifting buoys under control of North American investigators are automatically selected by the USGPC and converted into World Meteorological Organization (WMO) DRIBU Code form, then forwarded to the NWS IBM 4341 computer at the National Meteorological Center (NMC), near Washington, DC. Real-time gross error checking is performed on the 4341, using NDBC-developed algorithms, before dissemination on the Global Telecommunication System (GTS). Closer checks of the data are performed within 24 hours at NDBC using a combination of automated and manual procedures (man-machine mix). When errors are noted, an NDBC data analyst directly updates a status file at NMC. This update can remove bad data from distribution on the GTS, or on rare occasions, adjust or rescale data from specific sensors.

Data received from drifting buoys not under the control of North American investigators are routinely processed and disseminated on the GTS by the Argos French Global Processing Center (FRGPC) in Toulouse, France. However, there is redundancy in the Argos system, so that in the event one center ceases to operate, the other can fully process and support worldwide data commitments.

3. DRIFTING BUOY DATA QUALITY CONTROL METHODS AT NDBC

Data QC at NMC in real time is largely automated and is intended to detect obvious errors. More subtle errors, such as sensor bias or scatter,

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require closer scrutiny, which usually involves human intervention and judgement.

A. Real-time Data Quality Checks

Gross QC of environmental and position information is applied in real time. Environmental measurements include sea level pressure, air temperature, and water temperature. Wind speed and direction will soon be added. The automated, real-time checks are very effective in removing data with large errors caused by total sensor failure and transmission problems.

The limits applied to drifting buoy measurements are of two types. The first is based on absolute sensor limits supplied by the manufacturer and confirmed in factory acceptance testing. Table 1 lists absolute value limits of specific parameters. These limits are actually set within a slightly smaller range than the manufacturers' specifications to eliminate transmission of measurements at the sensor limit, which could represent environmental conditions that equal or exceed sensor capabilities. When measurements exceed these limits, they are automatically deleted. The second type of limits is environmental, based upon range and time continuity.

The algorithm to check time continuity is based on a formula that relates the time rate of change of a normally distributed measurement to an autocorrelation coefficient[7]. Using data obtained and analyzed from moored buoys, and an empirically derived correction coefficient, this formula was derived:

$$M = 0.58\ \sigma \sqrt{\Delta T},$$

where M is the maximum allowable difference, σ is the standard deviation of each measurement, and T is the time since the last observation. Under normal circumstances, T is never greater than 3 hours. However, time continuity limits, standard deviations, and climatological limits can be removed in special cases, such as severe storms, where extreme data values exceeding preset limits could be legitimate, but would be lost if limits were applied.

The method for checking buoy positions involves computing accelerations from one report to the next. This is considered a better method than velocity checks, since acceleration is more sensitive to slight position errors than velocity. The acceleration limit selected was 4 knots/hour, or 0.0006 m/sec^2 in either the north-south or east-west direction. Rejected position fixes are not used for subsequent acceleration computations.

B. Near-real-time Data Quality Checks

Beyond automated methods, close attention must be paid to subtle measurement errors that may be reasonable, but are incorrect. These subtle errors are typically related to gradual sensor degradation. A man-machine mix is used at NDBC to examine data failing more stringent criteria than those established for real-time data. To accomplish this, observed data are compared with NMC analysis and "first guess" fields, local analyses, and satellite imagery.

A degraded sensor typically displays increasing scatter or bias. Scatter refers to more random measurement variations that occur when the sensor sensitivity decreases. These are typically the hardest to detect, since the errors may tend to cancel each other out. They are nearly impossible to correct or rescale since, at any given time, measurements may be too high or too low.

Bias, or the tendency of the sensor to display a consistent error relative to the correct value, can be more easily recognized and accommodated

Table 1. Absolute Limits for Range Checks and Standard Deviations Used for Time-Continuity Checks for Real-Time Validation of High Latitude Drifters. Limit Range is Reduced for Low Latitude Drifters in Real Time and for Near-Real-Time QC at NDBC.

MEASUREMENT	UNITS	LOWER LIMIT	UPPER LIMIT	STANDARD DEVIATION
SEA LEVEL PRESSURE	hPa	905.0	1060.0	21.0
AIR TEMPERATURE	°C	−14.0	40.0	11.0
WATER TEMPERATURE	°C	−2.0	40.0	8.6
WIND SPEED	m/s	0.0	60.0	25.0
SIGNIFICANT WAVE HEIGHT	m	0.0	15.0	6.0
DOMINANT WAVE PERIOD	s	1.95	26.0	31.0

By comparing observations with NMC-generated analysis and 12-hour forecast fields, and using monthly statistical summaries compiled by the European Centre for Medium-Range Weather Forecasting (ECMWF), NDBC data analysts can manually evaluate data biases over extended time periods. Sometimes, data can also be compared with other marine reports, such as moored data buoys or ships. After a bias has been reasonably quantified, measurements can be rescaled. This is normally done after permission has been granted by the Principal Investigator, and directly at Service Argos. In this way, Argos files are simultaneously updated at both the Landover and Toulouse processing centers, so that if the USGPC fails, properly scaled data continue to be disseminated by the FRGPC until normal operations resume.

Environmental range and time-continuity limits were provided by the National Climatic Data Center (NCDC), and were based upon archived ship data. The algorithms used are nearly identical to those for real-time checks for both time continuity and positions, except tighter values have been applied. The NMC sea level pressure and air and water temperature analysis fields are compared with the drifting buoy observations. However, it has been noted by Gilhousen[7] that the process of determining sensor bias using NMC-generated analyses and forecasts must be done carefully. He has shown that the NMC numerical models in use tend to be conservative near strong pressure centers. That is, in deep cyclones, the models tend to generate pressures which are not low enough, and in strong anticyclones, pressures which are not high enough. Therefore, it is important that bias determination be done over extended time periods and only during selected meteorological situations to avoid extremes.

A number of graphic data quality tools are used by NDBC data analysts, incorporating latest buoy positions, tracks, and data plots. Time series plots are also produced to help evaluate sensor performance.

Figure 1 shows an example of a time-series plot of barometric pressure data from a buoy compared to NMC-generated analysis and 12-hour forecast values. Note that prior to July 1 the buoy values are consistently at least 15 hPa lower than values in the NMC products. A correction of 15 hPa was applied on July 1, and the bias error was significantly reduced making the observations useful. A second rescaling of 3 hPa was applied in mid-July.

Drifting buoy position plots are also used for QC, by superimposing a specific measurement over analysis or forecast fields, as in Figure 2. This is another easy way for the data analyst to check the quality of observations for nearly any geographic location on earth.

4. EXTENDED BENEFITS OF THE NDBC DRIFTING BUOY DATA QC PROGRAM

A. Logistics and Deployment Support

Considerable effort had to be expended to develop graphic products which could be routinely produced and used by NDBC data analysts for near-real-time data QC. An earlier example showed drifting buoy position and specific parameters plotted with corresponding NMC analysis and forecast fields. Early in the QC program development, other applications for these same graphics were recognized, which are proving helpful in logistical planning and engineering reliability assessment. It was found that some of the basic programs developed for QC support could be used to more easily identify areas where there were not enough buoy reports (Figure 3). The graphics program was further modified to color code active buoys according to age, making it possible to more easily recognize older buoys that are more likely to fail. Existing programs also permit plotting of buoy drift tracks for various time periods. By plotting these regularly, trends can be identified. These features can be subjectively applied to improve or restore network configuration. For example, they are used by TOGA officials and NDBC, the lead agency for TOGA drifting buoy support, for more effective decision-making.

B. Buoy Reliability and Performance

The application of accurate sensor monitoring and rescaling, as described earlier (Sec. 3B), can also extend into engineering hardware reliability analysis and even prolong useful life of sensors and systems. This is being done more and more for the drifters deployed in support of the TOGA Program (Table 2). The typical TOGA-type drifter reports barometric pressure, air temperature, and sea surface temperature. NDBC adopted a simple hardware reliability analysis program that lists each buoy, its date of deployment, the failure date of each sensor, and the failure date of the buoy transmitter.

The program can be used to help spot trends in service life of components and systems. Its application could be extended to determine, for example, length of service of buoys deployed by ship versus by air, length of service based upon deployment location, or buoy life based on

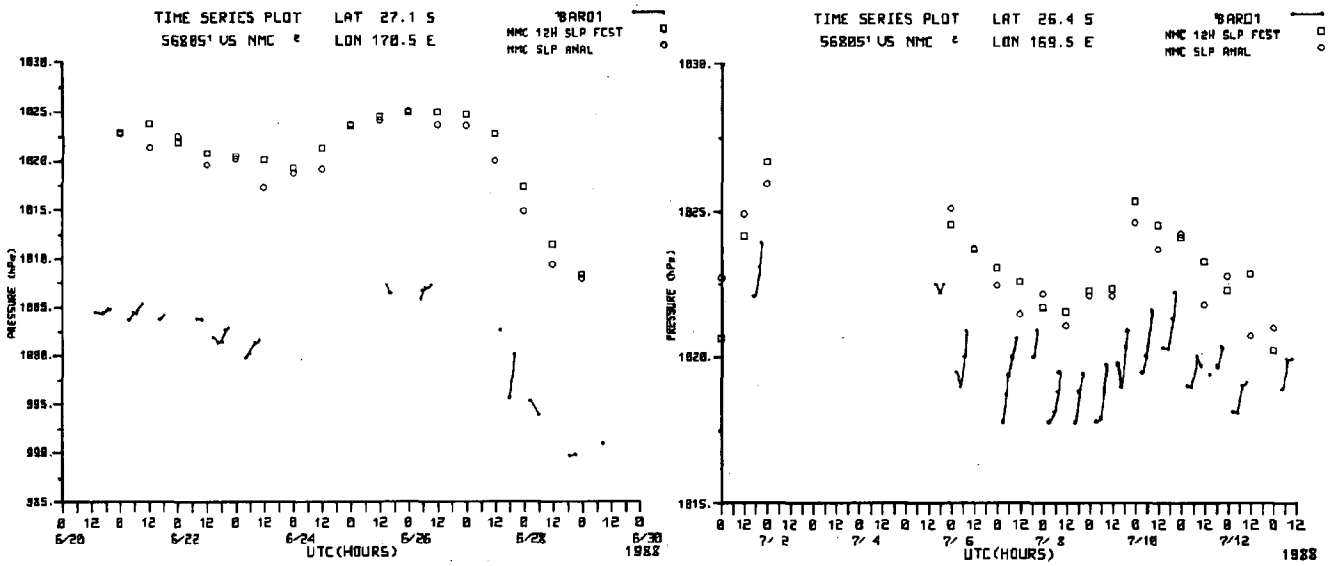

Figure 1. A time series plot of barometric pressure observations from buoy 56805 (small dots connected by solid lines), NMC sea level pressure analyses (o), and NMC 12-hour sea level pressure forecasts (□). Upward trend of each series of drifting buoy pressure observations represents the daily diurnal pressure rise. (a) Between June 20 and June 30, the buoy consistently reported pressure values approximately 15 hPa too low (comparing observations nearest 00 Universal Coordinated Time (UTC) and 12 UTC, which are valid times of NMC products), (b) A 15 hPa rescaling was applied July 1, and low bias is reduced to approximately 3 hPa.

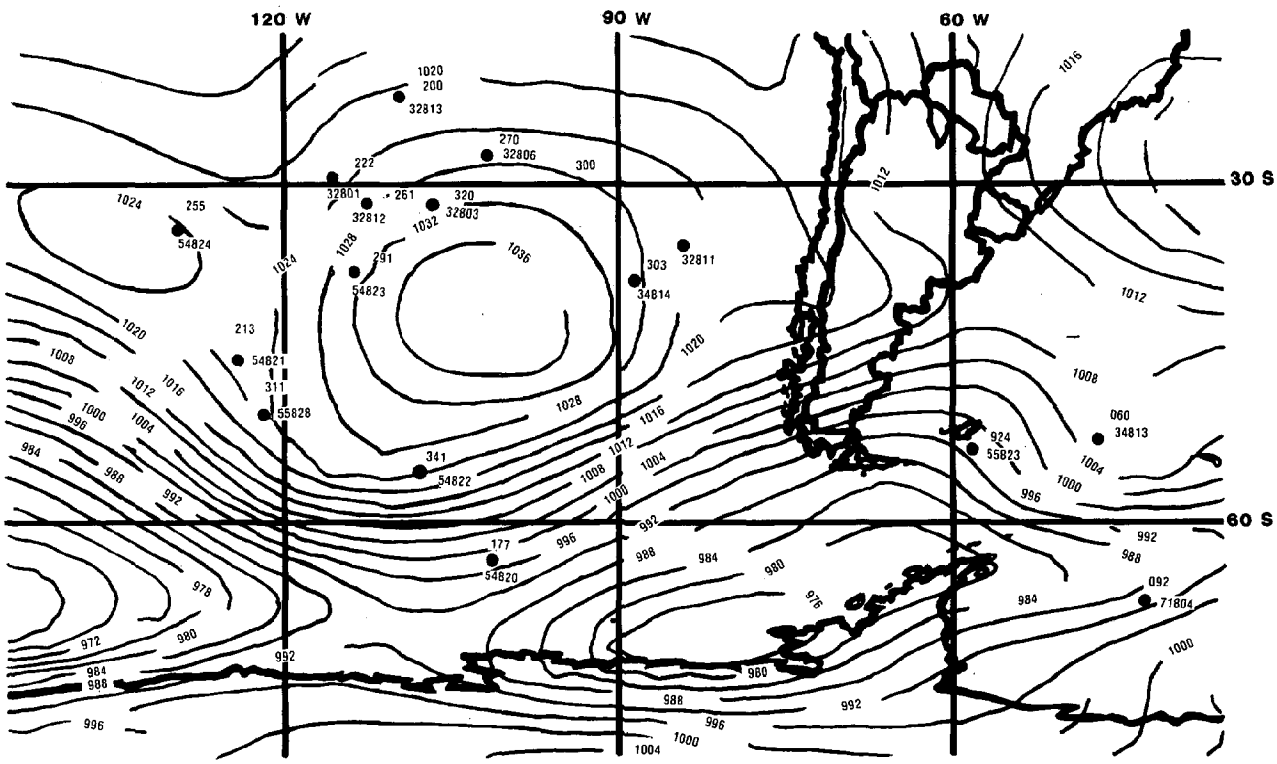

Figure 2. A plot program allows the NDBC data analyst to superimpose observed drifting buoy data with NMC analyses or forecast fields, making it easier to spot data that may be erroneous. In this example, in which TOGA drifting buoy reports are plotted, buoy 55828 (near 50°S 122°W) is reporting a surface pressure of 1031.1 hectopascals (hPa), while the NMC analysis indicates pressure in the area should be approximately 1024 hPa.

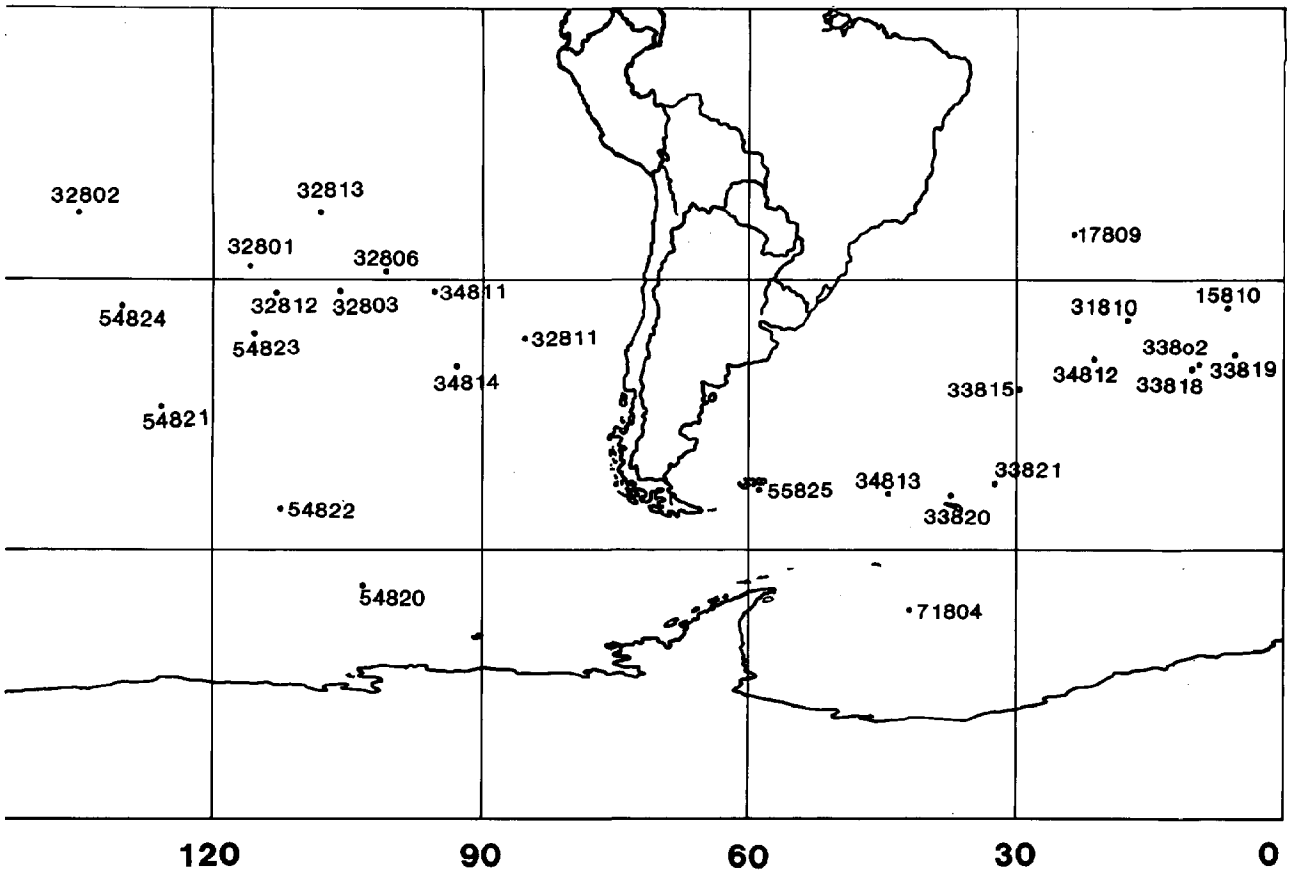

Figure 3. The plot program used for drifting buoy data analysis can also be used by program management officials for deployment planning. In this example, a plot of TOGA drifting buoy positions shows large network gaps east of Argentina, west of southern Chile, and in the south Atlantic east of 30°W.

Table 2. Work table listing each drifting buoy by year of launch, and number of days of service of each component or sensor, including buoy transmitter (Tx), barometer (p), air temperature (Ta), sea temperature (To), and buoy drogue (DROG).

For the month April 1988 (Final Report)

BUOYS DEPLOYED IN 1984

BUOY ID.	WMO ID.	LAUNCH DATE	LAUNCH POSITION	LAST POSITION	Tx FAILURE	P FAILURE	Ta FAILURE	To FAILURE	DROG FAILURE	Tx DAY	P DAY	Ta DAY	To DAY	DROG DAY	REMARKS
6000	17805	11/19/84	35S/000E/W	31.4S/029.9W	05/30/85	05/30/85	05/30/85	05/30/85	05/20/85	192	192	192	192	182	DROG FAILURE
6001	15801	10/31/84	25S/000E/W	27.2S/006.2W	08/16/85	08/16/85	08/16/85	08/16/85	08/16/85	289	289	289	289	289	
6002	15802	11/02/84	21S/009W	22.3S/031.5W	09/11/85	09/11/85	09/11/85	09/11/85	09/11/85	313	313	313	313	313	
6003	31801	11/03/84	21S/018W	32.9S/039.3W	09/06/86	09/06/86	09/06/86	09/06/86	06/23/85	672	672	672	672	232	DROG FAILURE
6004	31802	11/04/84	25S/025W	35.6S/019.0W	04/29/86	04/29/86	04/29/86	04/29/86	04/29/86	541	541	541	541	541	
6005	33801	11/07/84	35S/030W	27.1S/034.5W	04/19/86	04/19/86	04/19/86	04/19/86	04/19/86	528	528	528	528	528	
6007	15803	10/28/84	31S/013W	29.1S/014.0W	07/25/85	07/25/85	07/25/85	07/25/85	07/25/85	270	270	270	270	270	
6010	32801	11/17/84	15S/080W	14.9S/111.2W	03/30/86	03/30/86	03/30/86	03/30/86	03/30/86	498	498	498	498	498	
6011	32802	11/18/84	20S/079W	19.1S/099.6W	04/09/86	04/09/86	04/09/86	04/09/86	04/09/86	507	507	507	507	507	
6012	32803	11/19/84	25S/078W	19.2S/099.6W	04/28/86	04/28/86	04/28/86	04/28/86	04/28/86	525	525	525	525	525	
6013	32804	11/20/84	30S/077W	24.9S/081.6W	02/23/85	02/23/85	02/23/85	02/23/85	02/23/85	95	95	95	95	95	RAN AGROUND
6014	34801	11/28/84	45S/080W	16.1S/093.1W	06/26/86	06/26/86	06/26/86	06/26/86	06/26/86	575	575	575	575	575	
6015	34802	12/06/84	60S/065W	45.2S/043.8E	08/10/86	08/10/86	08/10/86	08/10/86	08/10/86	612	612	612	612	612	
6016	34803	12/13/84	58S/065W	48.4S/022.1E	05/05/86	05/05/86	05/05/86	05/05/86	05/05/86	508	508	508	508	508	
6017	34804	12/22/84	59S/052W	47.8S/014.1E	04/23/86	04/23/86	04/23/86	04/23/86	04/23/86	487	487	487	487	487	
6020	32805	12/07/84	10S/105W	11.9S/138.2W	05/19/86	05/19/86	11/21/85	05/19/86	05/19/86	528	528	349	528	528	AIR TEMP FAILURE
6021	32806	12/10/84	11S/090W	07.9S/136.6W	03/24/86	03/24/86	03/24/86	03/24/86	03/24/86	469	469	469	469	469	
6022	32807	12/19/84	25S/074W	18.2S/105.8W	08/22/86	08/22/86	08/22/86	11/15/85	08/22/86	611	611	611	331	611	SEA TEMP FAILURE
6023	34806	12/01/84	58S/066W	52.5S/023.2E	04/30/86	04/30/86	04/30/86	04/30/86	04/23/86	515	515	515	515	508	REFURB
6037	14801	12/06/84	05S/075E	26.5S/073.0E	05/11/86	05/11/86	12/02/85	05/11/86	05/11/86	521	521	361	521	521	AIR TEMP FAILURE
									MEAN TIME TO FAILURE	463	463	446	449	440	

manufacturer. Further, if data are successfully rescaled to prolong buoy life, total costs are reduced as a result, primarily for mission support to deploy replacement drifting buoys.

5. COOPERATIVE DATA QUALITY EFFORTS

The drifting buoy data QC program within the National Oceanic and Atmospheric Administration will increase over the coming years. The Ocean Products Center (OPC) of the National Ocean Service is beginning the first stage of a three-phase effort to eventually monitor and QC in real time all marine observations[8], including subsurface oceanic measurements. NDBC assisted in the initial development of the data quality software for the OPC. The QC of all marine observations in real time will be an enormous undertaking. Even after the OPC becomes fully operational, NDBC will continue to monitor drifting buoy data in order to detect subtle errors that might pass automated real-time error checks to determine, coordinate, and document the failure or appropriate rescaling of sensors and systems, and to generally assist in the OPC's real-time effort.

6. SUMMARY

The number of drifting buoy observations has increased dramatically since the mid-1970's, and there is a high potential for explosive growth in the number of drifting buoy observations over the next decade. The need for improved quality of drifting buoy meteorological observations has been recognized for several years, and NDBC began the first centralized drifting buoy data quality program in April 1988.

The drifting buoy data quality program operates on two general levels. Data are initially subjected to automated time-continuity and range-limit checks at NMC. Data passing these tests are then subjected to more stringent near-real-time checks designed to eliminate bad data, or rescale observations containing subtle errors, such as those due to gradual sensor degradation.

The potential benefits of the data quality program extend into several areas of the drifting buoy program, including deployment planning, logistics, and engineering reliability analysis.

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COMMERCIAL VESSEL OPERATION IN THE EXCLUSIVE ECONOMIC ZONE: Will the Jones Act Keep Up?

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Committee on Merchant Marine and Fisheries
U.S. House of Representatives

Abstract

Commercial vessel operation in the coastwise trade is limited to American vessels. Applying the intent of these archaic laws to increasingly complex ocean resource exploitation projects has proved an arduous task, especially in light of expanding U.S. jurisdiction offshore. Congressional actions and administrative interpretations in this area are explored.

Introduction

Federal support of the U.S. maritime industry has been a part of American public policy since 1789. Policymakers have long felt that a healthy, homegrown merchant marine is good for jobs and trade promotion, balance of payments, and national security. The support has taken a variety of forms; one of the most common is the practice of cargo preference, where certain cargoes on certain routes are reserved for American ships. The oldest form of cargo preference is the barring of foreign vessels from merchandise carriage in the cabotage trade (or coastwise trade), a policy that began in 1817.[1] Because of its historic evolution, cabotage policy -- for the most part -- affects only transportation services.

The degree of required American involvement in cabotage operations is quite high. The vessel must be U.S.-built, -owned, and -flagged, and vessels which meet these criteria are issued a coastwise license by the U.S. Coast Guard, in essence a ticket to operate in the cabotage trades.[2]

The U.S. Customs Service, in charge of enforcing the cabotage laws, considers them to include the transportation of merchandise and passengers between coastwise points, towing -- in cases where merchandise or passengers are transported -- and salvage, although the domestic vessel requirement for salvaging is limited to internal and territorial waters. The authority for these determinations flows from section 27 of the Merchant Marine Act of 1920 (the Jones Act), the Passenger Ship Act of 1886, and the Towing Act of 1940.[3] The functional scope of U.S. cabotage policy, therefore, is almost entirely based on the concept of transportation. Most recently, the transport of valueless material, such as sewage sludge, contaminated dredge spoil, and other waste, was brought within the purview of the cabotage regime.

The geographic scope of the American coastwise trade, or the coastwise area, is generally considered to include the navigable internal and territorial waters of the states of the United States, including many of its territories and possessions. Further, certain points on the Outer Continental Shelf (OCS) and in the Exclusive Economic Zone (EEZ) are also within the realm of the coastwise area. This will be discussed in more detail later. Therefore, coastwise points include any port or place within U.S. jurisdiction (with some exceptions), as well as some structures and vessels tethered to the OCS.

Background

The Outer Continental Shelf Lands Act of 1953 (OCSLA) extended "the Constitution and laws and civil and political jurisdiction of the United States ... to the subsoil and seabed of the Outer Continental Shelf and to all artificial islands and fixed structures which may be erected thereon for the purpose of exploring for, developing, removing, and transporting resources."[4] This statute established the policy that fixed drilling equipment on the OCS was as much a coastwise point as the port of New York. It was a significant extension of U.S. cabotage policy inasmuch as it meant that any ships trading between the offshore rigs and any other coastwise point must be qualified under American cabotage law.

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An amendment to the OCSLA was passed into law on September 18, 1978 which changed section 4a of the Act by including within federal jurisdiction structures permanently or temporarily attached to the OCS seabed.[5] This change brought anchored vessels, including ships and other floating equipment, within the purview of the cabotage laws, provided they were involved in the recovery of OCS resources. The legislative history indicates that Congress intended no change to existing law as far as artificial islands and structures, fixed platforms, and mobile drilling rigs attached to OCS were concerned.[6] In other words, this equipment was still considered part of the coastwise area; the change made by the 1978 amendment was that any equipment temporarily attached to the seabed for the purposes of resource exploitation was also to be considered a coastwise point.

The 1978 amendment has been interpreted administratively to include such features as marker buoys and capped wells. A marker buoy is secured to the seabed temporarily and is used to mark an offshore site which is to be drilled. The significance of such rulings is that the shipment of drill jackets -- the frame derrick-like structures that hold the drilling platform -- must be performed by coastwise-qualified launch barges if they are brought from the United States to the marker buoy. The agency has also maintained that a capped or plugged exploratory well that will be produced is a coastwise point, regardless of whether there is a marker buoy at that point or not.[7]

In a significant extension of U.S. control over ocean resource exploitation, President Reagan established, on March 10, 1983, an Exclusive Economic Zone (EEZ) extending out to 200 nautical miles from the baseline from which the territorial sea is measured. The proclamation was consistent with the terms of the Third United Nations' Conference on the Law of the Sea, and it assured U.S. jurisdiction over the resources contained within the waters of the zone as well as the subsoil and seabed beneath them.

The extent to which structures and vessels within the EEZ qualify as points or places in the United States for the purposes of our cabotage laws has been a growing concern in recent years. The Customs Service has had an increasingly difficult time applying outdated federal law to ever more complex offshore projects. This is especially true of oil recovery operations, where a plethora of ancillary anchor handling, icebreaking, inspection, and other vessels accompany a rig to an OCS site.

Yet commercial activity of all kinds is on the rise, and the question of applying the Jones Act to those activities is likely to become more pressing as time passes.[8] Most equipment that is employed extracting ocean resources, including oil rigs, sand and gravel mining vessels, OTEC vessels, and others do not fall within the cabotage guidelines, and there is often a high degree of foreign involvement in these operations. Moreover, the vessels which service the processors -- if they are not engaged in a transportation service -- often are not bound by the strict domestic requirements of cabotage law. The question of when a service operation is a coastwise activity becomes the ultimate determinant of "Americanization" of the EEZ. As stated earlier, the only relevant criteria in determining whether these vessels are engaging in a coastwise activity and therefore must be U.S.-built, -documented, and -owned under U.S. cabotage law is whether they are transporting individuals or merchandise between coastwise points.

H.R. 82: Congress Acts to Strengthen Cabotage in the EEZ

H.R. 82, introduced by Rep. Mario Biaggi (D-N.Y.) on January 6, 1987, requires that all valueless material being moved between coastwise points, or between a coastwise point and the EEZ, be transported on coastwise-qualified vessels. Valueless material does not include scrap metal, waste paper, landfill, and similar material that is used as a raw material, or otherwise has usefulness.

On June 7, 1988, the Senate version of the bill (S. 1988) was signed into law. The measure makes two substantive changes to American cabotage policy. First, it effectively places matter of no value on the same level as merchandise and passengers for the purposes of U.S. cabotage law. Second, it extends the existing cabotage regime -- for the purposes of waste transport only -- to the EEZ, without respect to whether the dump site is a coastwise point or not. In essence, it defines the entire EEZ as a coastwise point for the purposes of waste disposal.

H.R. 82 was introduced as a reaction to a decision by the City of New York to contract with a Singapore shipyard for construction of four barges capable of transporting sewage to a deepwater site. At a hearing on the bill on April 23, 1987, Biaggi said that "H.R. 82 specifically deals with vessels used to transport sewage sludge. However, this hearing will give us the opportunity to look just

beyond the particulars of this case to whether we should harmonize the Jones Act with the contemporary concept of U.S. sovereign jurisdiction."

What began as a simple reaction to a single case was quickly expanded, and by the time the bill was reported out of Committee, it had grown to encompass all transport of valueless material within 200 miles. At the same time, requirements for the movement of over-sized platform jackets were relaxed such that if a launch barge of 12,000 tons or more is necessary for the work, a non coastwise-qualified vessel may undertake that employment. This is despite the Jones Act requirement mandating use of American coastwise-qualified vessels in movements from the United States to OCS resource exploitation points. Under the terms of the new law, the barges must be U.S.-flagged, -owned, and -crewed. Only the construction provisions were waived.

to large launch barges was that none were available that qualify under Jones Act rules. In fact, relying on a 1984 Customs Service ruling, McDermott, Inc., a Louisiana jacket fabricator, acquired four non-qualified barges for use in transporting its platform jackets to sites on the OCS. In the ruling, Customs stated that the transportation contemplated was not within the coastwise trade; however, the agency later reversed its position, and held that such transportation was subject to the Jones Act rules. So the legislation was viewed as an equitable solution to the problem faced by McDermott -- namely, having bought four foreign-built launch barges under an understanding that they would be eligible for the intended work.[9]

Another bill that would change the rules of the game in the EEZ is H.R. 3106. Though there is little likelihood of it being considered in the 100th Congress, interested groups should watch for it in the 101st Congress. It is a broad restructuring of the coastwise laws, and would change the definition of both the coastwise area and coastwise trade.[10] The coastwise area would be enlarged to include resource processing vessels or structures in the EEZ without regard to whether they were actually tethered to the ocean floor. The coastwise trade, defined statutorily for the first time under the term "coastwise commerce," would be expanded to include a variety of services not now covered under the coastwise laws, including lodging passengers or property that are enroute from one coastwise point to another, and dredging and salvaging. The latter two activities would be considered coastwise commerce in the EEZ when they are undertaken in conjunction with resource exploration, development, or production.

Conclusion

American cabotage policy with respect to the EEZ is limited to transportation service. Other services provided in the EEZ, as well as transportation service to non-tethered vessels, may be done by foreign-flagged, built, and owned vessels.

In the event of expanding exploitation of EEZ resources, the clear potential exists for a growing employment of support ships, and the recurring issue of protecting U.S. industry versus allowing free trade will present itself to policymakers. Congress has demonstrated in 1988 that it is willing to side with the "protectionists" by including waste transport under the aegis of the Jones Act.

The offshore search for and recovery of resources is likely to continue and to grow in the long term, creating a demand for a fleet of service boats capable of servicing resource processing equipment.[11] Whether Congress will be willing to go beyond transportation to apply the Jones Act rules to non-transportation services remains to be seen. Some maritime groups would certainly argue that such a policy change would provide more shipyard and seagoing jobs, and add to the security posture of the nation.

NOTES

1. Act of March 1, 1817, ch. 31, sec. 4, 3 Stat. 351.

2. Vessel Documentation Act, December 29, 1980, codified at 46 U.S.C. 12102, 12106.

3. Merchant Marine Act of 1920, sec. 27, 46 App. U.S.C. 883. Act of June 19, 1886, sec. 8, 46 App. U.S.C. 289. Act of June 11, 1940, 46 App. U.S.C. 316.

4. Outer Continental Shelf Lands Act, sec. 4(a), August 7, 1953. 43 U.S.C. 1333a(1)). The purpose of the Act was, in part, to see to it that the subsoil and seabed of the OCS "appertain to the United States and are subject to its jurisdiction, control, and power of disposition ..." Id. sec. 3.

5. Outer Continental Shelf Lands Act Amendments, September 18, 1978, sec. 4(a), 43 U.S.C. 1333(a).

6. U.S. Congress, House, House Report No. 95-590, p. 129; Conference Report No. 95-1474, p. 80, 124 (note 1)).

7. U.S. Customs Service, C.S.D. 81-214, May 6, 1981.

8. See for example, "On Ship Off Alaska, All That Glitters is Gold From Sea Floor," The Wall Street Journal, Sept. 18, 1987, p. 11; "Offshore Phosphate Mining Could Pay Off, Report Says," The Virginia Pilot, Oct. 17, 1987, pp. B1, B4; "Tenneco Unit to Go Off Alaska In $70 Million Search for Oil," The Journal of Commerce, Sept. 16, 1987, pp. 1A, 10A; "Dredging the Bering Sea for Some of What Glitters," The New York Times, Oct. 13, 1987, p. 21; "Trash Disposal Problem Besieging Philadelphia," The New York Times, February 20, 1988, p. 7; "Gulf of Mexico Drilling Shows Signs of New Life," The Journal of Commerce, June 19, 1987, p. 15.

9. U.S. Congress, House, Sewage Sludge Disposal, House Report 100-219, July 14, 1987, pp. 5-6.

10. U.S. Congress, House, H.R. 3106, 100th Congress, p. 3.

11. Burroughs, R.H. (1984), "Offshore Supply Vessels: An Emerging Maritime Industry," Maritime Policy and Management, Vol. 11, No. 4, pp. 269-276.

The views expressed here are solely the author's, and do not necessarily represent those of his employer.

OPPORTUNITIES FOR DEVELOPMENT: A GROWTH SCENARIO AND SITUATION ANALYSIS OF HAWAII'S OCEAN INDUSTRIES

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ABSTRACT

Hawaii's ocean industries consist of aquaculture, commercial fishing, ocean research, seafood marketing, ocean recreation and maritime. A growth scenario for the ocean industries over the five-year period 1986-90 is developed and a situation analysis is conducted. Total direct revenues and employment for the industries as a whole are projected to increase from about $900 million and 10 thousand employed in 1986 to about $1.4 billion and 13 thousand employed in 1990, an increase of 53% in revenues and 24% in employment. A constant growth rate through 1990 is anticipated for each of the industries except for seafood marketing which is likely to decrease. The ocean recreation industry will realize the greatest overall economic gains. Results of this analysis have implications for policy formulation pertinent to industry, education and government.

1. INTRODUCTION

Economic activities involving the ocean in Hawaii are highly diversified and make up six industries composed of multiple sectors. A comprehensive analysis of the ocean industries was recently completed [1,2]. As part of that analysis, several portfolio models were developed to better visualize the relative attributes of the industries and their principal sectors. Additionally, general strategies and tactics to help facilitate the industries' further growth and development were broadly outlined.

Collectively, the ocean industries are equal in size to and growing faster than a number of Hawaii's more commonly recognized industries [1,2]. As of 1986, ocean industries generated estimated total direct revenues of about $900 million and total employment of approximately 10 thousand persons (based on recent revisions). During 1980/81 - 1985/86, the only period for which comprehensive data are available, the ocean industries realized an average annual rate of revenue growth of about 12% (in nominal terms). By comparison, the Hawaii Gross State Product grew at an average annual rate of 6.6% during essentially the same time period [3].

It is now clear that the growth of Hawaii's ocean industries is helping to advance the State's general policy goal of increased economic diversity and stability [4]. It is less clear, however, what the likelihood might be of continued high growth among the ocean industries and what the economic outcomes of any such continued high growth might be.

This paper uses the rudiments of the previously developed (and updated) ocean industries portfolio model [1] to depict a constant growth scenario for the five-year period 1986-90. Critical factors impinging upon the scenario are evaluated as part of a situation analysis. Results stemming from the analysis have policy implications that pertain to industry, education and government, and are briefly discussed. This exercise in foresight serves to further refine and strengthen the State's strategic orientation to ocean resources development in Hawaii.

2. INDUSTRY CATEGORIES

The categorization of Hawaii's ocean industries is based on types of activity that are sufficiently alike to be recognized as specific entities and to respond to similar market forces and policy actions. The categories tend to follow existing lines of administrative responsibility within State government in Hawaii and are well-suited for the purpose of general comparison and analysis as presented in this paper. A succinct description of each of these industries follows; elaboration is provided elsewhere [1,2].

The aquaculture industry is composed of two sectors: a) commercial production, and b) research, training and technology transfer (R,T&TT). More than 20 different species from fresh, brackish and salt water were produced commercially in 1986. The R,T&TT sector involves State and Federal agencies and private consulting companies.

The commercial fishing industry is dominated by the catch of tunas, other pelagics, bottomfishes and lobsters. The marine aquarium fish trade is treated as a subset of commercial fishing. It is

organized into segments comprising collectors, importers-exporters or wholesalers, and retailers.

The ocean research industry is composed of a broad spectrum of entities ranging from small private consulting firms to diverse government agencies and the University of Hawaii. Presently, the industry is heavily institutional in make-up. Research on virtually every important facet of ocean activity is carried out in Hawaii.

The seafood marketing industry is particularly complex. The total volume and variety of seafood products bought and sold is large and the number of marketing participants and transactions is high. The major portion of sales are imported seafood products. The revenue values reported here do not include local revenues of commercial fishing or aquaculture production.

The ocean recreation industry is highly segmented and dynamic. The sectors involved include: inter-island cruise ships, tour boats, dive shops, surf shops, charterboat fishing, recreational fishing, personal boating, major yacht races, competitive ocean swims, Hawaiian canoe races, and wind-, board-, and body-surfing events.

The maritime industry is composed of two sectors: a) shipbuilding and repairing, and b) ocean transportation (cargoes). Being an island state, Hawaii relies on the ocean transportation sector to carry about 99% of all incoming cargo. The revenues and employment presented do not include the Pearl Harbor Naval Shipyard.

3. GROWTH SCENARIO

A. Methods

Ocean industry revenue and employment estimates for 1986 and average annual revenue growth rates representative of 1981-86 were based on previous research [1,2] and recent updates and revisions. Revenue projections for the years 1987 through 1990 were calculated by multiplying each previous year's revenue estimate by the average annual revenue growth rate for each industry. This calculation is illustrated in formula (1) below.

Employment projections were calculated in a similar manner but with one important difference. The expected consumer price inflation rate for each year was subtracted from the average annual revenue growth rate to calculate the average annual employment growth rate. This value was in turn multiplied by each previous year's employment estimate. This calculation is illustrated in formula (2) below. This process is a simple but effective way of estimating employment based on real dollar revenues per employee.

(1) $(R_1)(1+G_1) = R_2$

(2) $(E_1)(1+G_1-I_1) = E_2$

R_1 - Previous Year's Revenue Estimate
E_1 - Previous Year's Employment Estimate
G_1 - Average Annual Revenue Growth Rate
I_1 - Expected Consumer Price Inflation Rate
R_2 - Current Year's Revenue Estimate
E_2 - Current Year's Employment Estimate

These calculations assume a constant growth rate for 1986-90. A constant growth rate implies that demand will grow as it has in 1981-86 more-or-less without interruption and that there will be no productivity growth, i.e. no increase in the ratio of output to employment.

B. Results

According to the growth scenario (Fig. 1), industry rank order based on revenues and employment will change little between 1986 and 1990 (Table 1). The aquaculture industry will remain the smallest of the ocean industries both in terms of revenues and employment. The maritime industry will remain the largest in terms of revenues. The ocean recreation industry will continue to have the highest employment. Although employment rank reversals for the seafood marketing and maritime industries are indicated in Table 1, such an eventuality is considered unlikely in view of the results of the situation analysis for seafood marketing that follows.

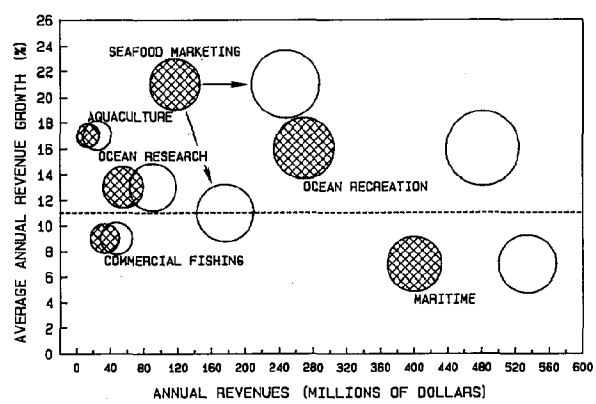

Figure 1. The Hawaii ocean industries growth scenario. Circle area is proportional to employment. Hatched circles represent 1986 estimates; open circles represent 1990 projections. Two alternate growth rates for seafood marketing are indicated as per the Situation Analysis and Discussion sections. The horizontal dashed line divides the figure into regions of high and low growth based on the Hawaii ocean industries portfolio model [1].

Revenue gains in absolute terms will be higher for ocean recreation, maritime and seafood marketing than the other ocean industries; employment gains will be higher for ocean

Table 1. Gross estimates and ranking of direct revenues and employment for Hawaii's ocean industries based on the growth scenario (in millions of dollars and numbers of employed persons).

Industry	Revenue Growth(%)	Revenues Estimate 1986	Revenues Estimate 1990	Revenues Rank[a] 1986	Revenues Rank[a] 1990	Employment Estimate 1986	Employment Estimate 1990	Employment Rank[a] 1986	Employment Rank[a] 1990
Aquaculture	17	$13	$24	6	6	423	651	6	6
Commercial fishing	9	33	47	5	5	689	818	5	5
Ocean research	13	55	90	4	4	1,342	1,823	4	4
Seafood marketing[b]	21 (11)	116	247 (176)	3	3	2,108	3,744 (2,665)	3	2 (3)
Ocean recreation	16	269	481	2	2	2,970	4,415	1	1
Maritime	7	400	534	1	1	2,454	2,726	2	3 (2)
Total	12[c](11)	$886	$1,423 (1,352)	--	--	9,986	14,177 (13,098)	--	--

[a] 1 = highest, 6 = lowest
[b] ( ) Alternative projection based on the situation analysis
[c] Weighted mean

Table 2. Absolute gains in revenues and employment for Hawaii's ocean industries between 1986 and 1990 based on the estimates in Table 1.

Industry	Revenue Gain[a]	Employment Gain[b]
Aquaculture	$11	228
Commercial fishing	14	129
Ocean research	35	481
Seafood marketing[c]	131 (60)	1,636 (557)
Ocean recreation	212	1,445
Maritime	134	272
Total[c]	$537 (466)	4,191 (3,112)

[a] Millions of dollars
[b] Numbers of employed persons
[c] ( ) Adjusted values based on the situation analysis

recreation, seafood marketing and ocean research (Table 2). Aside from the seafood marketing values which required adjustment and will be explained in Section 4-D, the ocean recreation industry will account for the greatest absolute increases both in revenues and employment and will realize the greatest economic gains among the ocean industries. Overall, the ocean industry totals are projected to increase by 53% in revenues and 24% in employment between 1986 and 1990 based on the adjusted estimates in Table 1.

Of particular note, the projected employment gains for aquaculture and ocean research are comparable in magnitude to or exceed the employment gain for maritime (Table 2). Yet maritime has annual revenues and employment far in excess of either of these two other industries (Table 1). The most salient feature of the growth scenario would appear to be the considerable degree to which the larger industries grow apart from the smaller based on revenues (Fig. 1). However, roughly equal contributions to the Gross State Product probably will be made by these three industries in view of their similar employment gains. The significance of making such distinctions in regard to economic impact should not be overlooked.

4. SITUATION ANALYSIS

Specific attention is paid to what we consider to be the critical success factors associated with each of the ocean industries and their principal sectors. Where possible, published data sources and technical literature constitute the primary basis of our analysis. In addition, we have relied on interviews with industry leaders, technical experts and program administrators to provide further perspective.

A. Aquaculture

Revenue growth in the aquaculture industry is expected to approximate the 1990 scenario projection of $24 million resulting from the average annual rate of 17%. The production sector, which had revenues of $3.6 million (producer product value) in 1986, is expected to grow at a rate significantly greater than 17% while the research training and technology transfer sector (R,T&TT), with revenues of $9.7 million (project value) in 1986, is expected to grow at a rate somewhat less than 17%.

Expected production sector growth acceleration by 1990 is attributed to expansion of operations

that are now in the pilot phase of commercial production. Production technologies and markets for these products have been reasonably well established and expansion will accomplish economies of scale. The critical success factors are expected to be premium market price and technological competence.

The major disadvantage in Hawaii is higher production and transportation costs relative to other areas of the world. This disadvantage will be offset by taking advantage of Hawaii's superior position in terms of market image, market logistics (east/west), production technology and natural resources such as warm climate and clean water. As a result of these factors, Hawaii is likely to be one of the few areas that will supply the U.S. Mainland with fresh cultured tropical seafood at a premium price. Current trends in fresh seafood consumption in Mainland markets support the assumption that consumers are willing to pay higher prices for quality and variety.

Star performers in the production sector are likely to be marine shrimp, freshwater prawns, abalone, macroalgae, microalgae and red tilapia. These products have developed production technologies, appear to be economically feasible and should be able to enter specialty markets for fresh product on the U.S. Mainland and in Japan. The key to success will be to avoid competition with lower cost commodity products from commercial fishing and foreign aquaculture production and to meet production cost expectations by relying on farm management technology.

Growth in R,T&TT is expected to drop below 17% as a result of competing priorities in State and Federal research dollars, Hawaii's lack of infrastructure with which to conduct training and perform farm-scale research, and increasing competition from other areas in consulting. However, this outlook could improve should Hawaii decide to set up permanent, large-scale research and training facilities. Such infrastructure would allow increased training revenues, a better image for Hawaii technology and increased numbers of skilled workers with which to staff the production sector and conduct consulting.

B. Commercial Fishing

Revenue growth in the commercial fishing industry is expected to approximate the 1990 scenario projection of $47 million resulting from the average annual rate of 9%. However, this level of growth will be maintained through increased landings of aku, ahi and other pelagic species, which will offset declines in the catches of lobsters and bottomfishes.

Hawaii's commercial fishing industry is composed of five principal sectors based on the species groups targeted (lobsters, bottomfishes, aku, ahi and other pelagics). The growth potential of the lobster and bottomfish sectors will be affected primarily by the resource condition of the stocks, which could be limiting in the near term. By contrast, the growth potential of the aku, ahi, and other pelagics sectors will be affected primarily by market factors such as consumer preference and demand and Hawaii fleet size and technology adoption, which could increase greatly over 1986 levels.

Hawaii's lobster fishery is based in the Northwestern Hawaiian Islands and has been "fishing down" essentially unexploited stocks of spiny and slipper lobsters since its inception in 1977. The long-term maximum sustainable yield (MSY) of legal-size spiny and slipper lobsters [5] is estimated to be 33% of the 1986 harvest level [6]. This situation suggests that the catch rates and total landings realized over the 1981-86 period very likely cannot be maintained. Instead, total landings are expected to stabilize under long-term equilibrium conditions around the MSY estimate.

Declining catches and catch rates in 1987 [6] and the sensitivity of fishermens' net revenues to relatively small changes in catch rates [7], further indicate the likelihood of reduced revenue growth in this sector. An added factor, ex-vessel price, also affects revenue outcomes but is less predictable. Price is determined outside of Hawaii since lobsters are an internationally traded commodity. Although price has consistently increased as the fishery has matured [6] and all indications suggest a positive market outlook for Hawaii lobsters [8], a price reversal combined with lowered catch rates could substantially reduce revenues relative to expectations based on the level of stock abundance alone.

Bottomfishing in Hawaii is based on catches from two relatively discrete regions, i.e. the Main Hawaiian Islands (MHI) and the Northwestern Hawaiian Islands (NWHI). In general, 1986 harvest levels in the MHI are believed to be near MSY and the fishery is considered to be stable, whereas 1986 landings of bottomfish from the NWHI exceeded the best available estimate of MSY by 18% and the fishery is considered to be in a state of disequilibrium [9]. There is evidence of overfishing for some of the most important bottomfish species in the MHI, which is both economically and biologically undesirable, but there is additional capacity to encourage further exploitation of certain other species [9].

Conditions overall suggest a reduction in the rate of revenue growth of this sector as stock abundance is reduced and overfishing occurs. However, the degree of revenue reduction owing entirely to stabilization of catches at a lower equilibrium level will be moderated somewhat by a positive price effect owing to domestic market growth in relation to a growing Hawaii population [10]. By contrast, bottomfish imports, which realized a substantial 46% per year growth rate between 1984 and 1987 and accounted for approximately 20% of the Hawaii market in 1987

(based on weight), will pose significant price competition to Hawaii bottomfish landings [11].

The aku (skipjack tuna) and ahi (yellowfin and bigeye tuna) fishing sectors are perceived to have the greatest potential for expansion among Hawaii's commercial fisheries [12,13]. Future growth depends primarily on economic factors rather than on the status of the stocks. Whereas there are no precise estimates of MSY for these species, there is no solid evidence for a decline in their abundance [12,13]. Expanded markets, consistently high product quality, and product forms with a long shelf life to absorb peak production during the summer are seen as the most important factors contributing to increased revenue growth [14,15]. Assuming that these favorable market conditions can be realized, and there are growing signs that they will be, the contraction and decline of the aku sector that occurred during 1981-86 should reverse and the expansion of the ahi sector that occurred during the same time period should accelerate.

Less is known about the stocks that compose the other pelagics sector. However, this sector appears not to be as resource-limited as the lobster and bottomfish sectors. Landings of the principal species (mahimahi and ono) continue to increase and market demand remains strong [16]; the catch rate for many billfish species meanwhile shows no evidence of decline [17,18]. Accordingly, we conclude that the average annual rate of revenue growth for this sector during 1981-86 will remain more or less constant through 1990 or possibly increase.

C. Ocean Research

Revenue growth in the ocean research industry is expected to approximate the 1990 scenario projection of $90 million resulting from the average annual rate of 13%. National research and development (R&D) funding trends (all expenditures, not just ocean research) estimated through 1988 suggest little overall change in the average annual rate of revenue growth (in nominal terms) from that realized during 1980-85 [19]. Since 1980, most of the gain in national R&D support is attributable to major increases in Federal defense spending. Sources of national R&D support include the Federal government, private industry, the academic sector and other nonprofit institutions. The Federal government and private industry are expected to continue to provide on the order of 97% of the total R&D funds spent. During 1980-85, industry support for R&D slightly exceeded that of the federal government, whereas a slight reversal of that trend is emerging for the 1986-90 period.

Hawaii's ocean research industry is dependent for funding upon Federal sources which provided 93% of the total in 1980 and 86% in 1985 [20]. As examples of proposed spending, pending Federal legislation would authorize an increase of up to 7% for basic research in defense funding (HR 4264 compromise bill) and an increase of up to 19% in National Science Foundation funding (HR 4418, S 1632) for fiscal 1989 (status as of July 14, 1988). The National Sea Grant College Program, however, may be allocated continued level funding for fiscal 1989 despite an authorized increase of up to 32% [21]. Collectively, these three sources accounted for 82% of total Federal funding for ocean research in Hawaii during 1980-86 [20]. The overall Federal funding picture for ocean research is greatly complicated because appropriations are scattered across numerous other agencies in addition to these.

Certain circumstances introduce a considerable degree of uncertainty into this picture as well. First, the fiscal 1989 Federal budget and subsequent Federal budgets will be greatly affected by the increasing pressures being placed on non-defense discretionary spending to reduce the budget deficit to zero over the next five years [22]. Accordingly, non-defense Federal R&D funding will be in increasing competition for a bigger piece of a smaller pie. Second, there is a growing politicization of decisions about spending Federal research dollars by Congress in contrast to traditional merit-review procedures [23]. This trend is expected to increase in years to come as lawmakers become persuaded that economic vitality and competitiveness - local, as well as national - is closely tied to investments in R&D [24] and try and get special projects earmarked for their states. Finally, the presidential election later this year will play a big role in Federal spending patterns and could dramatically change the general budget environment.

At the State level, a slight increase in growth rate seems likely for the State research sector, as the Hawaii State Legislature seeks a leading role on issues involving ocean resources use and development [25]. Accelerated growth is possible for the university research sector, given the recent establishment of the new School of Ocean and Earth Science and Technology which is expected to significantly strengthen Hawaii's competitive position in obtaining Federal funds for ocean research [26]. However, the greatest potential for further growth has been demonstrated by the private research sector [2].

Future increases in revenue growth for private sector ocean research will depend largely upon innovation and entrepreneurship of "home-grown" companies and upon U.S. Mainland firms relocating or expanding their operations to Hawaii. Opportunities for foreign investment in this sector should increase, but will be influenced strongly by the strength of the U.S. dollar against foreign currencies. While Hawaii has certain comparative advantages based on the attributes of its ocean resources, e.g. unpolluted ocean water, close-in access to deep ocean water and warm ocean water there are obstacles to be overcome, e.g. distance from markets, availability of financing and venture capital and cost of living [20,27]. With State marketing and facilities support for ocean

research increasing, however, this sector is expected to continue to perform well through 1990.

D. Seafood Marketing

Revenue growth in the seafood marketing industry is expected to be less than the 1990 scenario projection of $247 million resulting from the average annual rate of 21%. We see the rate of increase of seafood sales in Hawaii decelerating through 1990 and converging on the projected national annual rate of growth of about 11% during 1980-90 (Fig. 1)[28,29].

Seafood marketing in Hawaii is a complex process [30,31,32,33]. The trend since about 1980 is toward an even greater complexity and sophistication with the industry largely serving three distinct markets: Hawaii, the U.S. Mainland and Japan. The latter two represent specialized export markets in high-valued product, most notably fresh tuna.

Seafood sales in the Hawaii market are roughly expected to grow 10% per year through 1990. Growth in the Hawaii market appears to be strongly related to increases in per capita seafood consumption and to a lesser degree population and price inflation. The major cause of the earlier higher growth rate, a boom in the popularity of seafood which changed national eating trends, already has had the principal effect of raising the overall level of seafood consumption.

Increases in per capita consumption in Hawaii apparently have resulted from the combination of increased numbers of seafood consumers and an increase in frequency of consumption [34,35]. The proportion of Hawaii's resident population that eats seafood grew from 89% to 94% between 1983 and 1987. Significant increases in frequency of consumption by both heavy and light users also occurred during this period. With Hawaii's per capita consumption substantially above the national average to begin with [36], we expect a slower rate of increase through 1990.

Hawaii's total de facto population grew at an average annual rate of 1.7% during 1980-85 and is projected to grow at 2.2% per year during 1985-90 [37]. Notably, the number of visitors present in the population grew at an average annual rate of 3.9% during 1980-85 and is projected to grow at 6.4% per year during 1985-90 (about 4% for 1987-90)[37]. Price inflation grew at an average annual rate of 5.2% during 1980-85 [3] and is expected to grow at 4.6% per year during 1985-90 [38]. Accordingly, Hawaii's total de facto population will continue to grow at essentially the same rate and inflation will remain relatively low throughout the 1985-90 period. The increasing proportion of visitors within the population, however, will increase the relative importance of the restaurant segment which could provide the greatest impetus to further growth in the Hawaii market.

Exports to the U.S. Mainland market are likely to grow on the order of 10-15% per year through 1990, with tuna sales eventually dominating. Bottomfish, lobsters and most other locally produced fish sold in this market are resource limited and further rapid growth is not anticipated as a consequence. One area which has not been accorded much attention, but which is growing in importance, is the brokerage or transfer of bottomfish and pelagic species from the Pacific Islands through Hawaii to the U.S. Mainland. Another area of uncertain, yet promising, outlook is the introduction of fresh skipjack tuna (aku) into the U.S. Mainland market. These latter two possibilities could generate stronger sales growth through 1990 than currently is anticipated.

Fresh tuna's popularity, particularly yellowfin, has increased dramatically throughout the U.S. Mainland and the trend is expected to continue. In Hawaii, yellowfin typically is caught by the handline fleet, but suffers from quality control problems related to tuna "burn" [39]. Burnt tuna is less desirable for consumption as sashimi (raw fish), but is acceptable for grilling. Competition from Florida primarily, but also Taiwan, the Philippines and Ecuador is likely to capture the major share of the U.S. Mainland tuna market. All of these locations have distinct advantages in pricing while Florida tuna is additionally known for its excellent quality. Improvements in quality, which are attainable based on current knowledge [39], would improve Hawaii's competitive position. The market, however, is growing rapidly and even with pricing and quality disadvantages, Hawaii is likely to see good growth in yellowfin tuna sales.

Exports to the Japan market are not completely understood and no firm estimate of the direction of future sales is possible at present. The primary factor affecting the rapid growth in sales since 1986/87 appears to be the high valuation of the yen against the dollar. Attractive dollar prices in concert with limited fish supplies have drawn Japanese buyers to Hawaii in recent years. Potential long-term working relationships with the Japanese have developed out of the resulting sales. Sales are expected to increase as relationships improve, provided the exchange rate remains strong. Sales growth is likely to parallel growth in the Hawaii longline fleet, the primary source of the preferred fish, bigeye tuna. Since growth in the longline fleet can be financed quickly by investment, it is thought to be capable of rapid expansion. Reportedly, the fleet will increase by about 18 vessels (42%) this year.

Currently, Japan has little interest in Hawaii's other kinds of fish. This may be due to the relatively high prices, seasonality of availability or undeveloped tastes for Hawaii fish on the part of Japanese consumers. Very little Hawaii yellowfin tuna is sold to Japan. Supplies from other sources are cheaper and adequate while the Hawaii supply suffers from quality control problems as previously noted.

Should the existing currency situation continue, however, one would expect that long-term growth in this market could be realized, especially if trade and consumer promotion were conducted in Japan.

E. Ocean Recreation

Revenue growth in the ocean recreation industry is expected to approximate the 1990 scenario projection of $481 million resulting from the average annual rate of 16%. The ocean recreation industry in Hawaii is dependent upon tourism. Thus for the most part, growth in this industry is determined by such factors as visitors present and visitor expenditures. The average annual percent change in estimates of these factors is projected to be about the same during 1985-90 as during 1980-85 [37].

However, a number of factors of increasing importance could act to dampen this growth. Although we do not anticipate that these factors will exercise overriding influence by 1990, their effects already are being felt. These factors include limited infrastructure and facilities, user conflicts, access and allocation issues, resource overuse and degradation, increasing concern for consumer safety, diminishing availability of affordable liability coverage for the industry and soaring property valuations at popular coastal ocean recreation locations [e.g. 40,41,42,43]. These factors are significant and far-reaching and are expected ultimately to trigger regulatory and public policy changes of considerable consequence to the industry.

In a different vein, a number of emerging trends associated with market forces also are likely to induce some restructuring of the industry, but in ways which will accommodate increased growth and generate additional capacity. First, further niche differentiation and segmentation of markets will occur due to continuing development of new marine technologies. New products and services will result, for example, from continued miniaturization and computerization of equipment and further design and materials innovations in manufacture. Examples of "next generation" equipment poised to appear on the Hawaii scene are a variety of minisubmarines to be priced competitively in the range of upscale recreational fishing boats.

Second, the cruise ship and tour boat sectors serve as highly visible examples of areas where major new capital infusion is leading to greater market segmentation and increased capacity. The two currently operating inter-island cruise ships were refurbished in 1987; a new entrant underwent refitting in 1987 and is scheduled to begin service in 1988. All-day luxury touring around Kauai aboard a 130-foot custom motor yacht began service in mid-1988. A 131-foot SWATH (Small Waterplane Area Twin Hull) vessel is scheduled to begin inter- as well as intra-island commuter ferry service in conjunction with conducting regularly scheduled tours in mid-1989. Further, businesses offering submarine tours to visitors recently have begun or are in the process of becoming established on the islands of Oahu and Hawaii.

Third, consumer demographics are changing in ways which also will necessitate shifts in market focus and which will have varied impact among the various ocean recreation industry sectors [e.g. 44]. For example, we see increases in the following consumer categories: the middle-age population (as the "baby boomers" mature) and the over-50 age group; working women; affluent dual-income households; and Japanese visitors (the number of which is forecast to double by 1991 [45]). Key attributes generally associated with these changes include: greater personal discretionary income; a transition towards less strenuous forms of recreational activities; reorientation of priorities from self to family; and a larger foreign visitor segment that is increasingly more selective and value-oriented. In view of these changing demographics, we might see, for example, greater growth than expected in the cruise ship and tour boat sectors than in the surf shop sector, compared to the estimates based on recent growth rates alone.

The effect of these emerging trends will be more noticeable among individual industry sectors than the industry as a whole. While we believe these trends will play a significant role in restructuring the industry, and may be having an effect already, we do not anticipate major related change to occur overall until sometime beyond 1990.

F. Maritime

Revenue growth in the maritime industry is expected to approximate the 1990 scenario projection of $534 million resulting from the average annual rate of 7%. As already noted, the maritime industry consists of two sectors: a) shipbuilding and repairing, and b) ocean transportation (mainly cargoes and related support activities). The ocean transportation sector dominates the industry in terms of revenues and employment and for the most part determines overall maritime industry revenue growth.

The ocean transportation sector is dominated in turn by one major carrier, Matson Navigation Company Inc., which normally earns about 70-80% of Hawaii's cargo transportation revenues [46]. One other shipping company with a 15-25% share and several barge carriers with about 5% between them account for the rest. Matson revenues grew at an average annual rate of 7.5% from 1982 to 1986 [47]. Projected maritime industry growth rates thus are based on the historical growth of this industry leader. Of note, Alexander & Baldwin Inc., owner of Matson, was the most profitable transportation-related company in the U.S. during 1987 [48].

The shipping companies offer containerized, five-day service from the U.S. West Coast to Honolulu. The barge carriers offer lower-cost service that takes 9 to 11 days and consists of a mix of containerized and palletized break-bulk shipments. Significantly, the Mainland to Hawaii market is considered to be as big as many of the U.S. export markets to Asia and Europe. Inter-island (i.e. intra-state) cargo shipments are provided largely by barge carriers.

Cargoes consist of supply cargoes (every day supplies for the population base) which do not vary much in volume and trade cargoes such as cars, building materials, chemicals, equipment and household goods. Matson, for example, generally ships the supply cargoes while both Matson and the barge carriers compete for the remainder. Supply cargoes have the advantage of a steady predictable volume whereas the volume of trade cargoes varies considerably based on a variety of economic conditions.

Revenue growth in the ocean transportation sector is determined mainly by three basic elements: population growth, inflation and to a lesser extent price variance resulting from competition. Growth is thus largely a function of derived demand. Hawaii's total de facto population has been growing at approximately 2% per year since 1980 and is expected to continue at roughly the same rate through 1990 [37]. Inflation has been growing at about 5% per year over the same time period [3] and is expected to grow at 4.6% per year through 1990 [38]. Population growth and inflation largely have determined cargo revenue growth in the past with cargo shipping price varying primarily among the barge carriers. We do not see these elements differing in any major way during 1986-90.

Hawaii's overall ocean cargo capacity has expanded significantly since 1986. Matson has initiated a major and continuing fleet upgrade and new capital has been infused in Hawaii's principal provider of inter-island barge service. However, a number of factors have developed recently that could affect revenue growth in the industry in ways which are uncertain at this time. These include a 1988 ruling by the State Public Utilities Commission to reduce some inter-island shipping rates and impending competition in containerized ship cargo as early as 1989, subject to approvals by the U.S. Maritime Administration. Also, a plan has been developed and actions initiated to market and promote Hawaii's commercial harbors with results that have yet to be determined [49]. Further, inter-island commuter ferry service between Oahu, Molokai and Maui was initiated late in 1987, although the Molokai-Maui route is partially subsidized by the State. There also are plans for privately operated intra-island commuter ferry service on Oahu that could begin as early as 1990.

5. DISCUSSION

A relatively constant growth rate through 1990 seems likely for five of the six ocean industries, based on the situation analysis. The possible exception, seafood marketing, is likely to decrease in growth rate to 11% annually through 1990 based on nationally projected seafood sales. Consequently, we have included the revenue and employment projections for seafood marketing at this lower rate of growth in Fig. 1 and Tables 1 and 2 to depict the range of outcomes possible for this industry. With this adjustment, the growth scenario is believed to afford a realistic look at the revenue and employment gains that are likely to accrue to the ocean industries through 1990.

The growth scenario and situation analysis together enable one to better anticipate the kinds of socioeconomic impacts that are likely to accompany further development of the ocean industries. These impacts have extensive public policy implications involving all levels of government in Hawaii - Federal, State, and County. Consider for example: a) whether current education and training programs are adequate to prepare workers for the job opportunities created by ocean industry growth; b) whether existing government services and facilities are adequate to meet the demands of heightened business needs and increased commercial ocean use; and c) whether the present regulatory framework is adequate to provide for compatible use among growing commercial and noncommercial ocean interests as well as to guard against ocean resources overuse and degradation.

Hawaii's primary economic and business development aim is to diversify and strengthen the current economic base and to provide high levels of employment and job enhancement opportunities [50]. Industry and business opportunities are being analyzed and prioritized to determine their relative compatibility as prime business candidates to be marketed by the State. The large size and high growth potential demonstrated by the ocean recreation and seafood marketing industries make them prime candidates now; being smaller, the aquaculture and ocean research industries appear more promising over the long-term. However, the manner in which issues such as the above ultimately are resolved will bear considerably on Hawaii's ability to expand existing ocean industry activities, attract new ocean-related businesses and become more competitive in national and international markets for the products and services produced.

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OUTSIDE INFLUENCE ON PORT OPERATIONS: THE INSIDER'S PERSPECTIVES

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ABSTRACT

This study views outside influences of regulation at the local, state and federal levels, planning restrictions, and group influence as they are perceived by port managers. Using survey data collected from among port managers in the Southern U.S., these aspects of outside influence are investigated to provide a basis for understanding how predisposed port operators are to activities of external actors who act as partners in this area of marine interests.

INTRODUCTION

Regulatory and pluralistic influences affect many different aspects of U.S. seaport operations. These influences have gained the attention of numerous scholars, which in turn have produced a large body of work on how these influences affect port operations (1). This study provides a different view of the effect outside influences have on port operations by investigating the perceptions which port operators hold about outside influences. Using survey data collected by the Coastal Zone Management Studies program at The University of West Florida in early 1988, perceptions about regulatory and pluralistic influences on port operations are investigated. Research into how regulatory and pluralistic influences affect public administrative functions is of obvious importance. Research investigating the perceptions which administrators (port operators in this case) hold about regulations, the general public, and public and special interest groups is seriously absent. Studies assessing the view of the insider have been scant, either investigating the interactions between decisionmakers and interest group leaders (2) or are minor parts of larger studies wherein passing attention is paid to agency perceptions of the general public (3;4).

The insider's view is important for several reasons. First, it has been suggested that regulation originating from all levels of government has placed new restrictions on port operations, thereby reshaping their operating environment. Earlier laissez-faire behavior in the port operations arena has given way to a more controlled and strictly monitored setting (1). Thus, it is important to consider the degree to which port operators, who contend with regulatory influences on a daily basis, feel that regulation has hindered their operating abilities. This study investigates this issue by looking at the perceived impact of regulation across two dimensions, namely, general environmental regulatory influence and initiatives related to growth management. General regulatory impacts are important to the overall level of port growth and development (5), while initiatives related to growth management are increasingly emerging, especially in the southeastern United States (6).

A second reason for investigating this area is that the relationship between port operators and pluralistic interests (e.g., trade interest groups, environmental groups, real estate developers, economic development groups, the general public, business and industry) is poorly understood. Port operators are often caught in the cleft between opposing interest group demands. For example, business and economic development interests typically support large-scale projects such as the dredging of the Pensacola Pass and Pensacola Bay in Florida to allow homeporting of the large aircraft carrier the U.S.S Kitty Hawk in light of the deployment of men which the carrier will bring into the community. In contrast, environmentalists struggle to preserve endangered species or protect sensitive coastal and estuarine beaches from dredge projects. The self-styled public interest groups are wont to claim that special interests may have too much influence with port operators, whereas special interest groups are inclined to think they have little access to port operators and believe that port operators often succumb to well-intentioned, but ill-informed public interest group pressures. Determining which interests are perceived to bring their pluralistic wares to bear in the

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port operations arena, from the perspective of the port operator, would help to determine if operators, as a whole, exhibit very narrow feelings about groups involved in their purview or whether they see a broad spectrum of external group actors having an impact.

THE POLICY SETTING

Communities have traditionally developed in those areas where goods can easily be transported. Access to safe harbors, for example, was a key factor to the growth and location of many early American cities such as New York, Boston, and Baltimore. These cities developed particular areas to attract the shipping industry thereby providing an economic base for the growth of their community (7). During the past 25 years, significant changes have occurred in cargo and passenger transportation, as well as in the economic role of urban areas and central cities in general. These changes have had, and will continue to have, significant impacts on the social, economic and physical aspects of port areas in large cities (7;5).

The influence of the port on community development is extensive, most notably in regard to surrounding lands. Port activities have greatly determined the economic and social structure which its surrounding lands take. Restaurants, lounges, hotels, boutiques, and various other service establishments, typically locate near ports to service port needs and benefit from the commercial activity associated with ports. Similarly, industrial firms locate near ports to facilitate the receipt of raw materials and the eventual shipment of finished products. Residential neighborhoods follow and, in the past, were built in the vicinity of ports for dock workers and homeport crews. Railroads, the primary mode of onshore shipping until more recent times, also acquired large parcels of land adjacent to ports in order to facilitate the direct movement of goods. When ports are viewed collectively throughout the United States it is evident that the very nature of ports and their activities has greatly influenced community development. These influences combined with changes in marine transportation technology and the economic function of central cities has exerted a substantial effect on the nature and character of port activities, particularly that of the urban port.

For every major change in shipping technology, ports must alter their operations as well as their structures to accommodate these changes and remain competitive. For example, to accommodate containerized cargo, ports have been faced with a number of issues. It is necessary to acquire land adjacent to the port for storage of containers (from 30 to 50 acres). This move is exceptionally difficult and expensive for urban ports close to downtown areas where land is typically scarce and costly. As a consequence, ports are finding it necessary to either shift operations to available land away from the port itself or create new land via landfill (8). Over the years, this and other changes in technology have led to the development of new environmental standards at the national, state and local levels which have placed limitations on many of the development intentions of ports; intentions designed to stimulate the port economy but inevitably became part of the conflict between development, conservation and preservation. These limitations imposed by environmental considerations have created new cost for ports which previously had not been part of their accounted cost structure.

Ports have obviously been surrounded by special interest groups (i.e., barge operators and tugboat operators). With the introduction of environmental issues, however, a greater number of governmental agencies as well as private actors have become involved in the social and political agenda attendant to port development decisions. Traditionally, many port authorities have acted as private firms meeting competition by reacting to the interactions of market and technological changes. Environmental concerns about port development have altered the role of port authorities which now find themselves managing the social conflict occurring between commercial and environmental interests in the port zone. Port authorities increasingly find that their functions place them in a situation of having to satisfy a myriad of conflicting forces. On one side, they want efficient development of new projects (e.g., container storage facilities). On the other side, environmental concerns force ports to be adaptive in their development paying close attention to possible environmental impacts and seeking effective mitigation which allows for development (8;9;1). As environmental concerns have grown, more policies have been created to deal with the effects of port operations and development on the environment, including the quality of air and water, landfill management and disposal of dredged material. For those deepwater ports involved in receiving, pumping and storing of petroleum products there is a plethora of issues to consider (e.g., safety precautions to guard against oil spills which would not only destroy marine life but would also disrupt the tourist industry). Many argue that the increasing number of environmental and political issues which ports must deal with are making it more difficult for port authorities to act efficiently (10,11,12). Thus, it is both timely and important to address concerns about environmental regulation and the role of interest groups on port operations.

METHODS AND PROCEDURES

The results reported in this study are based on a mail survey questionnaire designed from a review of the literature regarding port operation and the impacts of regulation and pluralistic activity (1). The data collected for this portion of the study were obtained via a mail questionnaire survey distributed to twenty-nine port mangers in the states of Texas, Louisiana, Alabama, Mississippi and Florida. The survey included two mailings: an initial survey mailing and a follow-up survey mailing approximately one month later. The questionnaire consisted of thirty-three questions, requiring careful thought as well as knowledge of the issue area (a copy of the survey is available upon request). Of the twenty-nine surveys mailed, twenty-five responses were obtained resulting in a response rate of eighty-six percent, reflecting a return which allows for generalization of the results across the geographic region of the Southern U.S.

FINDINGS

Table 1 reports frequencies about the attitudes which port operators hold regarding the effect of environmental regulation on port growth and development. This first consideration addresses whether or not port operators see environmental regulation in a negative or a positive way, and which jurisdictions are seen as being more stringent in regards to environmental regulation. Both Federal and State levels of government receive equal responses in categories 4 and 5 of the scale, those categories which view environmental regulation by these government entities as being a hindrance to growth and development. These responses represent a forty percent sum for each across the two response categories, as compared to only 12 percent for local government in the same categories. By looking at mean responses we can also see that state government is viewed as the most limiting on growth and development through environmental regulation (mean=2.84), followed closely by the federal government (mean=2.76) with local government viewed as the least limiting (mean=2.16). These findings suggest that state government has placed the largest set of environmental regulations upon the operations of ports. Local jurisdictions often are more inclined to be motivated by economic development concerns than environmental protection, and have often acted through less regulation or relied on state or federal regulation. As such they are seen in a different light. Further, since it is the state and federal jurisdictions which are more active in the environmental regulation issue area, most laws concerning the environment are designed to address concerns of large regions versus specific concerns limited to local jurisdictions. It is somewhat surprising, however, that state government is seen as more hindering than the federal government which is generally considered to be the primary source of environmental regulation (13).

Table 2 reconfirms that state government is viewed as the most active in the environmental regulation related to port operations. Growth Management initiatives have been heralded as the most significant measures to insure sound environmental management, particularly in the southeastern United States. Over two-thirds, 72 percent of the responding port operators, note that their states have undertaken growth management initiatives. Inasmuch as growth

TABLE 1

EFFECTS OF ENVIRONMENTAL REGULATION ON PORT GROWTH AND DEVELOPMENT

Regulatory Influences of Federal, State and Local Government

QUESTION: To what degree to you feel environmental regulation at each level of government has hindered the growth and development of your port?

		Response Categories (%)					
	No Answer	1 A Little	2	3 Some	4	5 A Great Deal	Mean Response
Federal	8.0	24.0	8.0	20.0	24.0	16.0	2.76
State	8.0	20.0	8.0	24.0	24.0	16.0	2.84
Local	8.0	28.0	24.0	28.0	4.0	8.0	2.16

N = 25

TABLE 2

REGULATION BY COMPREHENSIVE GROWTH MANAGEMENT

QUESTION: Which of the following levels of government in your state have undertaken comprehensive growth management initiatives with which the port must comply?

Response Category	Frequency		Percentage	
	(Yes)	(No)	(Yes)	(No)
State Government	18	7	72.0	28.0
County Government	8	17	32.0	68.0
Regional Government	4	21	16.0	84.0
City Government	4	21	16.0	84.0

management is seen as closely linked to environmental regulation, and with the continued interest in growth management outside the southeast, witnessed by the recent initiative in Orange County, California, it may be safe to say that this form of outside influence can be expected to increase. While states have taken the early lead in this area, local jurisdictions can be expected to take on an increasingly more active role in insuring the implementation of growth management goals and objectives. Further, as is the case in Florida, ports will be asked to become involved in the growth management process by developing their own planning documents in conjunction with neighboring jurisdictions. As part of this process they can be expected to experience the pressures which can be levied by various interests who have a stake in growth management at the local level.

Table 3 illustrates the degree to which port operators feel internal management affairs are affected by the involvement of eleven types of external actors. Given that the port is an important economic entity wherever it is located it is not surprising that Business and Industry records the highest percentage in the "A Great Deal" category, 32 percent. In terms of mean responses, Business and Industry, Federal Agencies, and Chamber of Commerce or economic development groups all record the highest scale means, 3.24, 3.36, 3.08, respectively. It is interesting that state agencies and state government officials are not seen as affecting internal management affairs since they are seen as strong forces in the environmental regulation area.

SUMMARY AND CONCLUSION

It has been suggested that significant technological, economic, and group influences have shaped contemporary ports and their operations. This paper has investigated how port operators, the "insiders", view two of these factors--environmental regulation and pluralistic influences. The survey research reported here, which was conducted as part of the first step in a national study of port operators, has shown at least among port operators in the southern United States, that their respective states are seen as having the greatest environmental regulatory influence which affects port operations. Among outside forces which effect internal management decisions, business and industry is seen as having the most affect while the federal government, in contrast to state or local governments, was seen as placing more pressure on internal management. The findings presented here are preliminary in some respects, since each case related to the events and administration of a port in a specific locale can yield results independent of those derived from survey data based analyses. Local political settings, the size of the jurisdiction, pro-environmental versus pro-development orientations among government agency representatives, the varying strength of group interests, the role the port plays in the livelihood of the community and the individual characteristics of the individual port operator, can render results of regional surveys inapplicable in the aggregate. Recent trends in the strength which outside forces such as environmental regulation and group interests can bring to bear on port operators may, however, give rise to considerable conflict putting the port operator against outside influences as they struggle to remain competitive.

TABLE 3

Effects Of Eleven Types of Political Actors On Internal Management Affairs of Ports

Question: To what degree are internal management affairs affected by the involvement of each of these actors?

	(Percentage %)						
	No	1	2	3	4	5	
Actors	Answer	A Little		Some		A Great Deal	Mean Response
Local government officials	4.0	16.0	12.0	44.0	12.0	12.0	2.80
Local Agencies	4.0	24.0	28.0	28.0	12.0	4.0	2.32
State government elected officials	4.0	12.0	24.0	48.0	8.0	4.0	2.56
State Agencies	4.0	12.0	20.0	32.0	24.0	8.0	2.84
Federal Agencies	4.0	12.0	12.0	24.0	24.0	24.0	3.24
Interest groups (other than environmental)	4.0	48.0	8.0	20.0	16.0	4.0	2.08
Environmental interest groups	4.0	20.0	12.0	20.0	36.0	8.0	2.88
Business and Industry	12.0	8.0	4.0	16.0	28.0	32.0	3.36
Real Estate Developers	8.0	44.0	24.0	16.0	8.0	0.0	1.76
Chamber of Commerce or economic development groups	4.0	12.0	16.0	24.0	28.0	16.0	3.08
General public	4.0	36.0	12.0	28.0	20.0	0.0	2.24

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USE OF SYSTEMS ANALYSIS TECHNIQUES IN OCEAN RESOURCES DEVELOPMENT

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Introduction

There is a growing need for the engineer, scientist, and administrator to better understand the kind of overall, across-the-board planning problems involved in the development of coastal and off-shore resources. Of primary concern is the awesome problem of maintaining, even improving the quality of the marine environment. The waters that ripple and break on any shore are a part of vast regimes which are international, yes global in character, covering about 70% of the world and touching countless lands. The bigness of this water phenomenon calls for an overall perspective that must meet the challenge of size and complexity. It is particularly important that coastal countries should approach water questions with the kind of analytical and managerial knowledge that can cope with large, interacting problems. Governmental bodies as well as private industries are finding that the use of systems analysis techniques can lead to sounder decisions.

Principles will be set forth on maintaining and improving the quality of the marine environment, with considerations of cost in so doing. In making the analysis, an early step is to identify specific needs and appropriate roles. A next step is to lay out alternatives for achieving objectives both within a given organization and external to it. The alternatives may be appraised through their costs and benefits. But, how do you make choices between goals when resources are limited? Each proponent of an aspect of water technology usually believes that his field must be greatly enlarged in the near future. How can we gather the data, accomplish the evaluation, and do the planning that will make rational choices possible?

Management by Objectives

This process may be called "Management by Objectives" and is a widely accepted management technique. Why? Because MBO gets results! Indeed, managers are judged by the results they achieve. MBO is a systems approach to management that focuses on growth opportunities. It aligns a manager's need for self-development with corporate goals so that teamwork replaces the divergent activities that often characterize the operations of an industrial or governmental organization. Managing for results is organized around three basic elements:

1) A clear statement of objectives that ate verifiable and can be achieved.
2) A plan to achieve these objectives, including the individual steps required and when each step may be taken.
3) A method for keeping account of these plans and steps to make certain that they are being followed and, if not, what corrective actions should be taken.

The objectives as well as the steps leading to their achievement must be clearly verifiable. Wherever possible, objectives should include quantitative measures of achievement. Also, an objective should be expressive of its direct impact on the public. But deciding what the objectives are is only half the battle. The plans for achieving these objectives must be developed as well as a method for checking progress. It must be understood that MBO involves people-to-people communication. Objectives are not necessarily imposed from above. They should be developed at the working levels through personal consultation with the individuals who are responsible for their achievement.

Relevance of Zero-Base Budgeting

In the strategy for linking MBO into detailed action, one technique is known as "Zero-Base Budgeting." At the national level it has become a management process that provides for systematic consideration of all programs of a given agency in the formulation of budget requests. The central concept or key to ZBB's full utilization is that this management tool requires the participation of managers at all levels in the planning and evaluation processes. As with MBO, we could say that ZBB's objective is to compare alternative uses of scarce resources. In a real sense, the job of an executive is to make these comparisons in order to decide how best to exploit them, then to move forward in implementing the best alternatives. Thus, ZBB can be combined with MBO to become an important component of systems analysis for improving the decision-making process.

The Intergovernmental Interface

With respect to intergovernmental relations, actions would be taken to formalize the framework within which well-controlled exploitation may take place. The term "intergovernmental" is used here because the rules must be laid down for various levels of jurisdictions from metropolitan through state (or province) and regional to national and international. Among the coastal districts there is growning concern over jurisdiction of the sea floor along the coastlines and out onto the continental shelves. Boundary problems are certain to increase, particularly in areas of higher population and resource use.

There have been fears that rapidly advancing technology in the ocean might result in anarchy unless the serious questions of jurisdiction can be resolved. Our sea technology is bringing us closer to total undersea capability at various depths of the world ocean. It is important to increase our knowledge and develop the roles or regimes for governing the exploitation of resources in off-shore areas that are beyond present national jurisdiction. The complex problems of these vast areas have been studied by lawyers, diplomats, engineers, geographers, oceanographers, economists, and others, under the subject known as "Law of the Sea." The result, of course, was the United Nations effort to develop rules for exploiting the ocean.

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Problems Impeding Exploration

One of the purposes herein is to identify some of the contributions that can be made in the analysis of coastal and ocean exploration problems by scientists and engineers within the current state-of-the-art. In setting forth these critical questions the following might be included:

1) Storms at sea and along the coastline, including hurricanes, typhoons, and other types of storm surges.
2) The movement of waste products through the waterways of the coastal belt into the ocean which becomes the sink for all pollutants.
3) Damaging and costly interference with ecological balance from unwise exploitation of resources of the coastline and adjoining areas. Here, estuaries and salt marshes become critically important.
4) As aforementioned, the improper and inefficient use of coastal space through inadequate boundary demarcation. At one end of the spectrum this creates problems between nations while at the other end, disputes between shell fishermen often result in costly law suits.

In evaluating the existing situation it is well to search out and delineate the specific problems which obstruct the achievement of objectives.

Selecting Meaningful Objectives

As discussed above, under "Management By Objectives," an essential first step in the analysis of coastal problems is the formulation of goals and objectives. But in dynamic economic development, what types of statements can be made concerning them? Listed below are some objectives which would have unanimous acceptability:

1) Developing ways of opening up the coastal areas for exploration and development, such as improved maps, charts, and geodetic control.
2) Maintaining and improving the quality of the coastal environment in order to promote and protect the ecological balance.
3) Clarifying the problem of jurisdiction in increasingly complex boundary situations which will become more prevalent on local, state, regional, national, and international bases. (Boundaries between claims, leases, etc., of competing companies will need ever sharper and more accurate delineation.)
4) Protection of life and property from coastal storms and storms at sea through improved marine environment prediction and knowledge.

In proposing progress for coastal development, systems analysis would help make specific and quantitative the objectives to be attained through measuring the dimensions of relevant national needs and estimating the cost of meeting them. In particular, the analysis helps to find out exactly what may be accomplished, to identify alternatives and provide a basis for choosing among them. Stating the objectives in meaningful terms would be difficult for this may question the very existence of an activity. The value of agreed upon, clearly-stated objectives is that techniques can then concentrate on the relatively straightforward effort required for achieving the objectives.

Although the above discussion may seem detailed, it cannot be over-emphasized that if objectives are not correct, subsequent analyses will almost certainly be fruitless. If wrong objectives are specified, then the most ingenious selection of sophisticated techniques and criteria or measures of effectiveness coupled with mountains of data processed on the most advanced computers will all be wasted. Specific, realistic objectives for coastal programs may be difficult to formulate but the effort made in this direction will certainly lead to improvements and a better look into the future.

Criteria or Measures of Effectiveness

An intermediate step is to analyze the output of a given program in terms of the objectives initially specified. In other words, there would be a reasonable description of outputs underlying the objectives, that is, services and products emanating from the program. In considering both "objectives" and "criteria" it is important to understand that these terms are to be concerned with "ends" rather than "means." That is, they are intended to reflect what ultimately is to be accomplished and for whom, not the ways to accomplish such objectives. The establishing of objectives and criteria are interacting processes; the selecting of criteria may even suggest the need for revision of the objectives. These criteria may be referred to as measures for determining effectiveness.

Criteria as explained above, should have the following general properties:

1) Each criterion should be relevant and important to the specific problem for which it is to be used.
2) The criteria so used should consider all major effects relative to the objectives. A sufficient number of criteria should be included to cover all major effects.
3) Ideally, each of the criterial should be capable of meaningful quantification.

Selection of Alternatives

A crucial next step has to do with program alternatives or what may be considered as the best methods of accomplishing an agreed set of objects. In this, we analyze alternatives seeking those which have the greatest effectiveness in achieving the specified objectives or which achieve those objectives with the least cost. In this process, the programs are considered not as ends in themselves, but rather as means to higher objectives and in competition with other and possibly more effective programs. It is this competition among alternatives which is a crucial device for testing the effectiveness of existing and proposed programs.

Supportive Analysis

The next step concerns the analysis process which is in support of the objectives and alternatives described above. Although many different kinds of analyses may be performed, it is useful to distinguish two levels; one which may be considered as a preliminary or more rigorous analysis. The latter would be a more refined, detailed type of analysis.

A less-rigorous analysis can be carried out where the more detailed studies are not possible. Much of the relevant analytical work done thus far has resulted not from the various kinds of sophisticated technical analyses but from penetrating questions.

Much can be derived from the dialogue, or questioning and response among the decision-makers, the proposal-makers, and the analysts. Where appropriate factual data are not available, one has to rely on whatever analyses can be found.

Program analysis is not easy, whether it is done at the less rigorous level or using the more refined methodology. Some of the most important limitations on the carrying out of these analyses are: (1) The problem of defining the real objectives; (2) the presence of multiple benefits; (3) inadequacies of data relevant to the analysis; and (4) difficulties in considering costs and benefits over a long period as well as a single point in time.

Quantitative estimates are not the only elements of systematic analysis. Human factors and intangible elements must not be ignored. Systematic analysis is designed to: (1) Uncover the relevant issues; (2) identify the specific assumptions, and factual bases upon which alternative recommendations rest; and (3) trace out the consequences and costs of each alternative.

Socio-Economic Evaluation

The systems approach should be addressed not only to the furtherance of scientific and engineering efforts but to analyze the effects of coastal exploitation upon society. Thus, before we embark upon scientific efforts in the coastal zone we would be well-advised to make analyses of their anticipated costs, together with social and economic benefits. This admonition applies particularly to competing programs. Systematic commitment of resources depends upon a balanced program of: (1) Science, engineering, and technology; (2) services; and (3) socio-economic evaluation. We have consistently downgraded the last, yet without analysis of human impacts we risk developing service without focus or with potentially dangerous results.

Conclusion

Through systems analysis we are able to assess the costs of achieving objectives against the benefits to be expected, thereby making possible a more intelligent, efficient use of the resources available. This process should be viewed in the wider context of the coastal environment which is at once both urban and non-urban in character yet encompassing much wider regimes.

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MARINE FIELD PROJECTS:

TEACHING IS THE EASY PART

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ABSTRACT

Marine Field Projects is a 9 credit course that serves as the principal field experience in the undergraduate curricula in the oceanography and ocean engineering program at the Florida Institute of Technology. Students participate in biological, chemical, or physical oceanography projects or ocean engineering construction projects under faculty and graduate student supervision. Integral to this experience is a five day cruise aboard the R/V Osprey, F.I.T.'s 95' coastal research vessel, over the continental shelf, Gulf Stream, and the nearby reef systems of the Bahamas. This presentation highlights some of the logistical, economic and academic considerations inherent in operating such programs, with particular emphasis on the sea program.

Beginning in 1989, improved and enlarged accommodations aboard the Osprey, acquired in 1986, will allow F.I.T. to open this program to students from other colleges and universities seeking ocean field experience. Toward this goal, the 1988 program included students from departments other than O&OE, within F.I.T. to assess the impact of non majors on the program, and to ensure that non majors will be able to participate fully and productively.

Students prepare to take plankton samples in the Indian River lagoon

INTRODUCTION

Florida Institute of Technology is one of very few universities offering undergraduate degrees in oceanography and ocean engineering. In doing so it accepts the responsibility to provide meaningful field experience in those areas to its students. (Graduate students at many institutions are expected to pick up this experience in their research, if at all.) F.I.T.'s location on the Indian River Lagoon allows day trips into the field year round, and many introductory and advanced courses take advantage of this. For the last ten years, however, Marine Field Projects, ordinarily taken by students during the summer between junior and senior years, has provided this experience in the most concentrated and intense format.

DESIGN AND PERSONNEL

MFP is an 8 week course, meeting daily, Monday through Friday. The first week is primarily dedicated to organization, assigning students to project groups, testing their swimming ability, checking them out to safely use small outboard boats, and teaching them the correct use of the field sampling and collection instruments necessary for their work. In weeks two through seven, students will typically gather at 8 AM to organize and then disperse in groups to field sites to gather data, tend research installations, collect samples, make observations, or construct their engineering projects, as dictated by their majors. During the eighth week students hold a "conference" at which each group will present a paper, detailing the results of their research efforts. For the engineers, this will include a demonstration of their project in service. For example, the 1988 engineering project culminated in a regatta, in which the different engineering teams raced the human powered submersibles they had built. Ultimately, the winning sub will enter a national competition for such vessels built by engineering students around the country.

Enrollment for this program has varied from 40 to 70+ and has seen corresponding changes in the numbers of faculty and graduate students involved. Major sections are oceanography, led by

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a faculty oceanographer; ocean engineering, led by a faculty ocean engineer; and the ocean cruise, which is part of the curriculum for students from both oceanography and ocean engineering, led by the supervisor of marine operations and captain of the Osprey, me. Within the oceanography and ocean engineering sections students are divided into groups of about eight, each working directly with a graduate assistant, under the overall direction of the O or OE faculty member. During the middle weeks, two to seven, one to three students will leave each working group to form the science party going aboard the Osprey for the week. Aboard ship, in addition to the captain and operating crew, there are two graduate assistants, one engineering and one oceanography. As is evident, personnel requirements for this course are high.

COURSE CONTENT

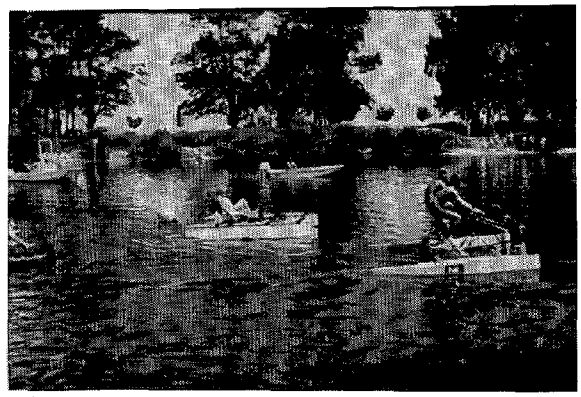
Particulars of the six week oceanography projects will change from summer to summer, but typically include field sampling, lab processing, organization and analysis of data, and final presentation. Field sites may be the local fresh water creeks, a variety of sites on the Indian River Lagoon, or the nearby oceanfront dune and beach systems. Access to the inland water sites is through use of small outboard boats, and by the 63' inland research vessel DELPHINUS.

Ocean engineering projects have included the design and building of human powered submersibles (1988), human powered surface craft (1987) and a variety of other working craft and submersible instrument platforms.

On the ship, oceanography exercises have typically included hydrocasts, CTD and XBT deployment, bottom sediment sampling by core and grab, benthic sampling by otter trawl, plankton towing, in water coral reef and sargassum community observations, shark tagging in cooperation with the NMFS, and magnetometry and hydroacoustics demonstrations. Ocean engineering exercises might include ship stability demonstrations and calculations, monitoring of hull potential as an indicator of hull corrosion, ship performance sea trials for determinations of speed and fuel consumption curves, underwater salvage and refloating, and surveying techniques. The shipboard experience is the only chance students get to "crossover", and work with and in the opposite discipline (oceanographers with ocean engineers and vice versa).

When it can be done without compromising the teaching character of the cruise, ongoing research projects of the faculty and graduate students are incorporated in the cruise curricula. In this way several graduate students have benefitted from the opportunity to collect samples using ship time which might otherwise have been prohibitively expensive. At the same time, the MFP students gain real world, real time research experience, and the knowledge that their efforts have value beyond their own learning. In recent years fruits of this collaboration have included published studies on ciguatera vectors, descriptions of new species of amphipods, and published studies of the composition of Indian River Lagoon sediments.

In the week following their shipboard experience students will work under the direction of a graduate assistant to organize and interpret the data gathered on their cruise, for inclusion in the final report.



Engineering students race the human powered craft they designed and built

LOGISTICS AND MURPHY'S LAW

When classes leave the classroom, every step requires prior arrangement, facilities and, generally, money. For the projects near the campus, vans for transportation - drivers (with chauffeurs licenses), and coordinating the use of sampling apparatus (which are frequently in demand for more than one activity) are the primary challenges. Use of the vessels is coordinated through the marine operations staff, which also fuels and maintains the fleet. For the ocean cruise weeks, add to the above provision for food (insuring that vegetarians and persons with particular medical dietary considerations are accommodated) and clearance and entry of the vessel with customs and immigration authorities for the United States and the Bahamas, for those trips which stop at any foreign port. This latter requires that the foreign host country be queried on its visa requirements for foreign students. As F.I.T. has students from over 80 countries around the world this becomes involved. Visas are occasionally difficult and always slow to obtain, and efforts must be initiated weeks in advance. U.S. immigration authorities should also be consulted in advance to arrange the I 20 forms to reenter those with student visas to the United States.

Vessels entering foreign waters must also obtain a research permit for their activities in those waters. These can be negotiated directly with the Bahamas, which we did for many years, but are more satisfactorily handled through the State Department, as we have done in the last few years. Either way, it pays to begin the process at least six months in advance.

Students lower a niskin bottle at an ocean station

Field courses require a careful assessment of current insurance coverage to determine whether any more need be added. Sometimes activities which are covered in the U.S. will require a rider for that coverage to be effective in another country, and at a more basic level some things, for example diving, may be excluded entirely from standard coverage.

It is anticipated that some of the field equipment will break down, and provisions are made for that in advance. For critical pieces of gear, that may be a second unit, while for others it may involve substituting another measurement, or knowing where to get another instrument in a hurry. Even more inconvenient than switching gear to meet contingencies, however, is switching programs, as may become necessary due to weather.

MFP is offered in the summer partly so its heavy time demands will not interfere with other coursework (students generally take MFP alone, i.e., not at the same time as any other courses) but also because that is the time of the most settled weather. While Florida winters are benign by comparison with the rest of the nation, it is typical that from about late October through April cold fronts will come through with some wind and fury about once a week. For the two to five days they exert their effect, the weather offshore is such that vessels under 100' are severely limited in what they can do. Summer is generally, though not always, free of such patterns, and we ordinarily can do our teaching unimpeded by the conditions that break gear and sicken scientists. Rarely, (as in July, 88) such a system does strike in the summer, and even more rarely, an early season Hurricane will threaten the area. In such times the OSPREY cruise plan is necessarily radically changed. A backup plan to be carried out in inland waters has been developed to deal with such events, but is recognized as a difficult accommodation at best. More typically the summer pattern of warm days punctuated by afternoon thunderstorms interferes with the offshore work not at all, merely encouraging the Melbourne based projects to finish field work in the morning hours, and be doing lab work in the afternoons.

ECONOMICS

The costs of personnel, transportation, lab supplies, project supplies (materials for the engineering projects) food, and ship operations make this a very expensive course to conduct. As a private school F.I.T. must pay its bills, but MFP is not how we do it. In fact, even though a small 'lab' fee is added to the customary tuition for this course, many times it operates in the red, but is continued for a variety of reasons. Even if offered at a loss, such a course is necessary if undergraduate programs in oceanography and ocean engineering are to be offered in good conscience. In marketing terms it can also be thought of as a 'loss leader' item, whose high profile and attractiveness act as a magnet, bringing students to the school. Such values help to offset the high dollar cost.

PROSPECTS

Current enrollment figures do not fully utilize the potential for Marine Field Projects. The limit on total class size is currently the capacity of the ship to carry students in the middle weeks of the course. The availability of the R/V Osprey, with its enlarged capacity, has made it possible to contemplate offering MFP to a limited number of students from other colleges and universities, either as groups or as individuals. Toward that objective, during the 1988 program, a limited number of students from the science education curriculum at F.I.T. were enrolled in the course to determine the impact of outside students on the MFP students from Oceanography and Ocean Engineering, and to assess how well students with a basic science background but no oceanography would be able to keep up with and benefit from participation in the program. Thus far results have been most encouraging in both areas, and plans are moving forward to invite students from other schools for the 1989 program.

Research team taking a core on the Indian River lagoon

THE IMPACT OF MARINE TECHNOLOGY ON EDUCATION AND TRAINING IN MARINE TRANSPORTATION

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MARITIME INSTITUTE OF TECHNOLOGY & GRADUATE STUDIES

As the raison d'etre of the Marine Technology Society (MTS) is to promote the exchange of information in ocean and marine engineering, science and policy, the precluded assumption is its stewardship of a body of professional knowledge. Frontiers of this body are constantly being broadened by MTS scientific and engineering arms. The marine transportation arm, on the other hand, is one of MTS largest users of the knowledge gleaned. How users is the marine transportation arm implement this knowledge through post-graduate education and training is the theme of this paper. Used to demonstrate this hypotheses is the Maritime Institute for Training and Graduate Studies (MITAGS), Baltimore based and serving professional ship's officers, pilots, MSC, NOAA, the Corps of Army Engineers, and many other professionals in the advancement and enhancement of their seagoing careers after job entry upon academy graduation.

If the question was posed as to which was the least mutually exclusive category among those labelled for paper themes -- Education and Training would be the hands down winner. For, among the myriad professions, businesses, technologies, science, commercial enterprises, arms of government, etal., comprising the marine industry -- none escape the needs, disciplines and exchanges provided through education and training.

Precluded in the Marine Technical Society's (MTS) stated mission to promote the exchange of information in ocean and marine engineering, science and policy, is a vast body of knowledge. Frontiers of this knowledge are constantly being broadened by the MTS scientific and engineering components. Upon these broadened frontiers policies are made and implemented: the industrial users educated and trained. Thus, education and training is the cohesive element that molds and channels fragmented isolated frontier discoveries into a powerful and dynamic data base for industry users to draw from.

Among the heaviest industry users are those involved in marine transportation, commercial fishing and recreational boating. Unfortunately, the greatest emphasis on education and training lies within the marine transportation segment of the industry, the officers and seafarers who man the cargo, tanker, passenger (cruise) and container vessels which trans it the oceans, bays, rivers and sounds of the world. The extent of the education and training required by a flag nation of its officers and crews, measured on a scale from 0 to 10 is dependent upon the flag flied. And, a vessel might fly, other than its national flag, the flag of any one of 20 or more "open registries" as they are called which suit the needs of a particular owner. Quite often, or should I say most often, as is the case, a particular open registry is chosen over another, or, the flag of origin nation, because of monetary considerations alone, which quite often includes the exclusion of education and training standards for the crew. Many shipowners contend that flags of parent nations require too many rules and regulations that build safety and restrictions into a ship. And as most casualties to life, ship and the environment are caused by human error, some would avoid the logical solutions which accept rules and regulations as measures of safety for the crew, ship and the environment -- but this is another subject, unto itself, and is somewhat tangential to the theme.

The point that I am trying to make here has nothing to do with flag waving but one that stresses the need for education and training as it affects the common good of us all. Fifty years ago, well before the formation of MTS, the International Maritime Organization (IMO) the International Convention of the Standards of Training, Certification, and Watchkeeping (STCW), MARPOL, segregated ballast tanks, ocean dumping, ARPA, SATNAV -- to name a few of the policy setters, problems and innovations, little thought was given to the protection -- or should I say problems in the making, to the ocean environment. In the past 20 years knowledge through science and technology has outpaced industry practices to such a degree, we in maritime are still learning to deal with what is happening. It is in these areas that education and training are vital. State of the art education and training in the marine transportation area is best exemplified in Baltimore's own Maritime Institute of Technology and Graduate Studies (MITAGS) the educational arm of the International Organization of Masters, Mates and Pilots, AFL/CIO, the leading deck officer union in the United States.

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MITAGS is world renowned as the foremost maritime training institution of its kind given to an array of courses using marine simulation. And, it is truly a graduate school, being dedicated to the advancement in upgrade and training of those maritime college graduates who have chosen careers at sea. Most of today's young maritime officers entering the seafaring profession as Third Mates are graduates of one of seven maritime colleges, namely: Kings Point, the Federal United States Merchant Marine Academy; Fort Schuyler, the University of the State of New York Maritime College; Massachusetts Maritime College; Maine Maritime Academy; Texas Maritime Academy, a part of Texas A & M; California Maritime Academy, and, Great Lakes Maritime Academy.

To describe the course offerrings would not only be redundant, but a poor substitution for the audio-visual presentation I am about to show you. However, one of the few courses not simulated, Laws and Ships Business, needs a bit more elaboration, illustrating how one facet of MTS impacts upon another.

MITAGS staff, apart from instructing ships captains in the latest Coast Guard directives, comments and advises regularly on various advanced notices of proposed rule making (ANPRNS) published in the Federal Register. Our comments on the recently revamped licensing examinations were included almost totally in the final revisions. Simulation, incidentally, is now an accepted partial substitute for actual sea experience. Currently, pollution is the major concern. ANPRN's on the disposal of liquid hazardous material and the latest scourge to the environment, plastic waste are of top priority for comment and suggestion in classroom seminars. As an advisory source, MITAGS draws from the collective frames of reference and experience of better than 1000 ships Masters, State and Federal Pilots, Panama Canal Pilots, federal employees including members from the Corps of Engineers, NOAA and the Military Sealift Command -- MM&P members all. MITAGS, therefore, not only implements policy, but contributes to it.

The latest ANPRN proposing regulations to implement Pollution Prevention Requirements pertaining to Annex V of MARPOL 73/78 on the disposal of plastic waste touches the summer seashore communities to such a degree that it is front page news in Long Island and the Jersey shore where beaches are closed. Home prices, vacations jobs and the income of a number of other businesses are impacted upon the severest way -- economically, through the pocketbook. MTS scientists and researchers have been warning of problems in waste disposal for years. It has now hit home and I am sure most all MTS components are touched by it in one way or another. MITAGS staff is now poring over this proposal seeking advices from both in house and in the many MM&P field offices on how to contribute positively to the proposal. Ad hoc groups such as SAVE OUR PORT in New York and New Jersey have been seeking solutions to waste problems for years. Subaqueous burrow pits, among other remedies, have been proposed. MM&P pilot members are active in this group.

There are many more examples where types of problems and questions can be given answers through the direct research capability available at MITAGS. This capability centers around two ship simulators which have a 360 degree, high resolution visual scene which can present an enriched twilight through to dawn simulation of a port and any specific area in question. The vessels that will typically be using a port can be accurately modelled or may already be available in our extensive library. Additionally, the staff available for such projects consists of researchers who have experience in a wide range of disciplines including personnel testing, measurement, the experimental design of studies, programming and simulator equipment engineering and designing. Again, of most importance to a marine project is the number of experienced Pilots and Offshore licensed personnel that are available as advisors and subjects for research programs. This is that vast reservoir, the resource reference pool touched upon a few minutes ago.

As automation and the new advances in technology have taught us, quality of crew is not measured in terms of navigation, seamanship and engineering prowess alone. American President Lines didn't think so when it commissioned MITAGS to develop a training program for its officers who were to man the new, state of the art, D 10, PRESIDENT TRUMAN class container vessels. Sea-Land didn't think so either when it held seminars at MITAGS for both officer personnel and shoreside personnel, one week this past June. And, MITAGS doesn't think so as it is ever in the process of changing and revising curriculum. Training tapes are in constant states of either revision or development. The overview tape you are about to see is about three or four years old but has been subject to changes which few are able to pick up. One, for example, involves the Computer Course. The Commodores you will see have been replaced by IBM PC's and Epson printers. The introductory course is two weeks long, 8 hours a day, Monday through Friday. Basic proficiency in operating the DOS and LOTUS programs are course expectancies. PC proficiency is a must for any mate or master with a high powered ompany.

So then, when one speaks to education and training through upgrading of licenses and the advancement of skills of seamen, much more than rote learning is implied. And it should be, when one considers the responsiblity for safe passage of a $100 million ship and the safe delivery of its $100 million cargo. To this end none of the 15,000 or more students who have passed through MITAGS these past 16 years have been involved in a maritime casualty. This is somewhat of a record, and one in which we are most proud.

I hope that many among you have the opportunity to visit with us during this conference period. Should time permit for post-audio commentary, I

shall be glad to answer any questions -- or, at least try to.

RESOLVING THE ENVIRONMENTAL DECISIONMAKING AND RESEARCH DILEMMA

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ABSTRACT

Shortsighted pollutant source controls and fragmented research activities too often result from the typical environmental decisionmaking process that tends to focus very narrowly, sometimes mistakenly, on only the perceived cause(s) of marine ecosystem problems. A two-part resolution of this dilemma is recommended:

1) Environmental managers and researchers need to broaden the context and perspective of their efforts to consider holistic ecosystem processes and responses to stress. Development and validation of quantitative, marine ecosystem risk assessment models are recommended as an appropriate mechanism for cost-effectively and efficiently improving our understanding of how marine ecosystems respond to multiple, manmade and natural stresses. Establishment of quantifiable ecosystem objectives could result from such holistic ecosystem perspectives and modeling capabilities.

2) Environmental managers and researchers need to communicate more effectively so that researchers can input latest, relevant scientific findings effectively into the environmental decisionmaking process, and environmental managers can provide feedback on specific research needs. Such input and feedback will contribute simultaneously to marine ecosystem problem solving and our collective understanding of ecosystem processes. A national workshop is recommended to develop an appropriate mechanism for improving environmental manager-researcher communications.

1. INTRODUCTION

For purposes of this presentation, it is important to understand that these are my own views and recommendations as an experienced environmental manager, not those of the office I represent. Also, please understand that the pattern of activities described below does not follow an established format or decisionmaking structure. Rather, this is the typical pattern of activities currently followed by most environmental managers and researchers and applies to ecosystem problems generally, not just marine and estuarine ecosystem problems.

2. BASIC ENVIRONMENTAL RESEARCH

Basic environmental research is an ongoing activity that normally follows disciplinary lines (areas of expertise and interest). University and research foundation physical scientists, chemists, and biologists conduct research on environmental and ecosystem subject areas that is of interest to the sponsoring institution. Currently, much of what we know today about marine and estuarine ecosystems and their responses to man's activities has been generated by this kind of basic research.

Unfortunately, there is no institution, or mechanism established for the purpose of coordinating the dozens, perhaps hundreds, of basic research programs related to marine and estuarine ecosystem processes. To my knowledge, nobody is routinely reviewing available research results and ongoing and planned research objectives for the purpose of synthesizing research findings and assessing our understanding of marine and estuarine ecosystems and the probable impacts of man's activities on those ecosystems. Lacking this kind of review and assessment, managers and environmental researchers cannot understand or be advised of the most significant gaps and weaknesses in our capability to quantify the probable risks to marine and estuarine ecosystems from man's activities. Consequently, although we know a lot about major elements of marine and estuarine ecosystems, our knowledge is fragmented and, at the present time, we cannot quantify ecosystem risks within acceptable ranges of uncertainty. Furthermore, we are not likely to develop credible ecosystem risk assessment capabilities anytime soon unless we find an effective way of coordinating relevant research activities and improving communication between researchers and governmental agency environmental managers. This is an extremely important issue, and I will talk more about it later.

3. IDENTIFICATION OF ECOSYSTEM PROBLEMS

Identification of ecosystem problems tends to fall into two categories. At one extreme, major fish kills (or dead dolphins on the beaches, as happened last summer along the mid-Atlantic coastline), red tides, and human food poisonings from contaminated seafood are acute, crisis type events that are readily recognizable and usually result in public demand for some kind of immediate regulatory

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reaction, even though we may not know what has specifically caused such visibly evident problems. At the other extreme, problems related to gradual environmental degradation (such as increasing incidence of seasonal hypoxia problems, widespread habitat losses, long term reductions in recreational and commercial fish catches, and accumulations of water column and sediment toxics) tend to be much less visible and, consequently, more difficult for many of us to comprehend as problems caused by man's activities.

In either case, other than public health preventive measures such as oyster bed and swimming beach closures, cost-effective decisionmaking on appropriate regulatory responses to marine and estuarine ecosystem problems can be very difficult. Prerequisite to effective decisionmaking are:

- a statutory framework that authorizes imposition of controls applicable to the evident ecosystem problem(s) and

- hard evidence or credible predictions linking the problem(s) to controllable pollutant sources.

The relationship between these prerequisites is important to understand. We have, for example, explicit and enforceable authorities under the Clean Water Act for imposing national technology-based performance standards on point source discharges to waters of the United States, including coastal waters. However, when technology-based point source controls do not adequately protect water quality, more stringent controls are authorized that will depend on evidence or credible predictions linking achievement of water quality standards to the contributing point sources. The Clean Water Act also provides for limited management controls on nonpoint pollutant sources but, here again, there needs to be a demonstrable link between resolution of identified ecosystem problems and planned levels of nonpoint source controls. Therefore, whenever ecosystem problems are identified for regulatory control purposes, environmental managers need to establish cause and effect linkages between proposed point source and nonpoint source controls and the identified ecosystem problems.

4. REVIEW OF AVAILABLE DATA AND LITERATURE

Once a major ecosystem problem has been identified, the first step normally taken by environmental managers is to review available data and literature to:

- define and understand the scope and nature of the problem. This is extremely important because the "evident" problem, such as reduced fish catches, may be caused by a combination of complex problems, such as overfishing, direct toxic stress, anoxia or hypoxia, particulate smothering of spawning beds, or habitat losses.

- determine the physical, chemical, and biological cause(s) of the problem. Sometimes, an evident problem, such as the dead dolphins example or red tides, may be the consequence of natural causes, not man's activities. In any case, however, "cause" determinations should be documented by available data or persuasively argued from a combination of data and widely accepted biological response theory findings.

- determine the source(s) of the causative factor(s). In a complex environment, determining the source(s) of physical and chemical pollutants that are linked by cause and effect to an evident ecosystem problem can be a major challenge because, more often than not, there are multiple potential sources contributing to the problem.

- determine whether or not the identified source(s) is (are) controllable within the framework of existing regulatory authorities.

Such reviews of available data and literature are usually done informally but may take the form of highly structured, interagency studies, such as for the Great Lakes, Chesapeake Bay, and the several estuaries within EPA's National Estuarine Program. In any case, however, program deadlines and public pressures tend to limit this "study period" to a span of months, one or two years at the most. All too often there is insufficient time for additional field studies or research to accomplish the review objectives. Simply put, environmental agency managers usually must make ecosystem problem response decisions based on limited review and analysis of readily available data and literature.

5. REGULATORY CONTROLS IMPOSED

"Armed" with results from this limited review and analysis, environmental managers normally will impose whatever controls are:

- available within the statutory framework,

- relevant to identified pollutant sources that are linked to the problem, and

- demonstrated to be meaningful and feasible.

In many cases, national technology based performance standards have already been imposed to resolve persistent ecosystem problems. Such additional controls are usually calculated to ensure compliance with State approved water quality standards which, in turn, are based on published EPA, numeric Water Quality Criteria. EPA Criteria are intended to reflect the latest scientific findings. However, there is a necessary time lag of, perhaps, several years between research findings for individual chemicals and organisms and State approval of enforceable water quality standards. Consequently, there is always the possibility that approved standards do not reflect the latest scientific findings.

Also, EPA's Water Quality Criteria are based on toxic dose-response data for individual, selected freshwater and marine species. Although an application factor is incorporated to help ensure protection of biological communities and trophic levels, the Criteria are not literally based on toxic dose-response data for entire ecosystems.

Finally, the interrelationships among toxic stresses, nutrient imbalances, excessive turbidity, high temperatures, etc. as determining factors to ecosystem health are, generally speaking, poorly understood. Consequently, imposing controls on any one of these factors without considering relative and synergistic effects of multiple stresses on the ecosystem may not be an adequate response to evident problems on a case-by-case basis.

Therefore, environmental managers normally provide the research community an opportunity to comment on controls that are proposed before such controls are finalized. And, EPA's Water Quality Criteria and technology-based point source controls are proposed in the Federal Register for public comment before they are promulgated.

Consequently, I feel that, under existing circumstances, environmental managers not only do their best to build state-of-the-art scientific understanding into proposed decisions but also try to provide the research community an opportunity to input last-minute scientific findings into the final decisions.

6. DIRECTED RESEARCH

Imposing national technology-based performance standards on point sources does not require quantifiable relationships to local water quality conditions and the health of affected biological communities for specific water bodies. However, as mentioned above, when experience shows that implementation of technology-based requirements has not achieved water quality standards, more stringent point source controls are authorized. Although more stringent controls must be linked to achievement of water quality standards, such standards themselves tend to represent only fragments of ecosystem health. Hence, there is usually no direct link to biologic or geographic ecosystem objectives.

The resulting pattern of environmental agency responses to water quality and ecosystem problems in the United States, therefore, is not normally the result of a definitive and quantifiable understanding of cause and effect relationships between man's activities and ecosystem problems. With statutory emphasis on technology-based point source controls, State environmental agencies, consistent with EPA guidelines, have focused their energies over the past fifteen years on imposing technology-based controls on municipal and industrial dischargers. (This is the NPDES program under Title IV of the Clean Water Act). By the early 1980's, however, it was becoming evident that, although the average water quality conditions nationally were improving or, at least, not getting any worse, ecosystem conditions in many of the Nation's estuaries and coastal waters were not improving and, in some cases, were in fact getting worse. Simply put, worsening conditions of many of the Nation's estuaries have prompted Congressional legislation of statutory authority and funding support for the National Estuarine Program (NEP). The purpose of NEP is to focus cooperative Federal, State and local attention on identifying and resolving ecosystem problems of selected estuaries. Clearly, successful achievement of NEP objectives will require implementation of improved scientific understanding of cause and effect relationships between man's activities (including both point and nonpoint pollutant sources) and estuarine ecosystem problems of coastal waters such as the New York Bight and Southern California Bight.

And, this leads us to the subject of environmental agency directed research. Very often, when environmental managers (sometimes Congress) feel the need for a better understanding of ecosystem responses to man's activities, we "direct" additional research to specific subject areas of concern. EPA and the National Oceanic and Atmospheric Administration, for example, are cooperating in major, directed research programs on the Great Lakes, estuaries, and coastal waters to better understand the nature and extent of water quality and associated ecosystem problems, also the relationship of pollutant dischargers to those problems. Similarly, EPA and the Corps of Engineers have cooperated extensively years on characterizing particulate resuspension, transport, fate and biological effects from contaminated dredged materials dumped into marine waters. Finally, the Minerals Management Service has committed large sums of money to directed research on pollutant source characterization, transport, fate, and effects of gas and oil exploration, development, and production activities in marine waters of the United States.

Too often, however, directed research programs do not effectively advance our overall understanding of the effects of man's activities on marine and estuarine ecosystems. Directed research programs normally tend to focus on those "bits and pieces" of ecosystem response for individual chemicals, individual organism species, individual pollutant sources, etc. This aspect of many directed research programs is important because it means that scientific advances resulting from marine and estuarine ecosystem related research programs, collectively, cannot be assembled to yield equivalent advances in understanding the broader question of ecosystem responses to man's activities. For example, when conducting research on seasonal hypoxia problems in estuaries, the focus tends to be on phosphorus and nitrogen controls rather than the broader questions on relative and synergistic effects of nutrient fluctuations (including organic and inorganic carbon), turbidity, temperature, alkalinity, and freshwater flow effects on algal productivity and associated hypoxia problems. Similarly, when

conducting research on fishery or habitat losses, the focus tends to be on individual factors, such as direct chemical toxicity, rather than the combined effects of toxicity, turbidity, temperature, salinity changes, overfishing and predation.

There are at least three reasons why directed research may be too narrowly focused or, in some cases, focused on the wrong factor(s). First, environmental managers don't always know the right questions to ask. We have an evident problem we're trying to resolve, but the "obvious cause" of the problem (that we consequently direct research to focus on) may not be the total or, in some cases, even the correct cause. And, second, our available communications with the research community may be inadequate. And, of course, budget and time constraints are a factor. This whole issue of fragmented ecosystem research activities "directed" at visibly evident problems is another aspect of the uncoordinated research issue mentioned at the beginning of this paper. Fragmented and uncoordinated research has very serious implications for resolution of marine and estuarine ecosystem problems.

7. REFINEMENT OF REGULATORY CONTROLS

Over time, environmental managers will normally review directed research results plus field data from monitoring programs to further refine existing controls on point and nonpoint sources. However, environmental managers are not likely to feel entirely comfortable with this decisionmaking framework for three reasons. First, the results from the narrowly focused research programs may not yield adequate controls on all parameters impacting ecosystems of concern. Also, the environmental managers may not be aware of ongoing, basic research results that are relevant to the problems they are trying to resolve. When you think about it, there simply is no effective communications link between the basic research community and environmental agencies on resolution of individual environmental and ecosystem problems. And, finally, field monitoring data will likely lead environmental managers to suspect that, indeed, they are not regulating all of, or the correct sources that are contributing to persistent ecosystem problems.

In summary, then, this gets to be kind of a "catch 22". When faced with ecosystem problems, environmental regulatory agencies normally impose controls on those pollutant sources that are evidently causing the problems, are amenable by statute to control, and which we are authorized by the statute to control. When the results of directed research and monitoring programs indicate the problems are not fully resolved, regulatory controls are likely to be escalated on the same sources. There must be a better way.

8. A BETTER WAY

Yes, there is a better way. Several years ago, a number of researchers and contract consultants began developing quantitative risk assessment models. Typically and very simply put, these models are designed to simulate productivity and natural variations in productivity of interconnected, multitrophic level ecosystems as functions of nutrient (food) availability and environmental variables, such as sunlight and temperature. The models predict productivity changes (usually rates of biomass increases or decreases) of the several trophic levels as a result of induced stresses, such as toxic exposure. The models also attempt to predict the induced stresses as functions of time.

Quantitative ecosystem risk assessment models are intended to express numerically our current understanding of ecosystem responses to a variety of stresses. The levels of uncertainty associated with modeled ecosystem risk predictions depend on:

- modeling error, that is, the extent to which productivity algorithms (in the model) for such processes as photosynthesis, respiration, and food uptake and depuration represent the complete and real thing,

- natural variability of the biological processes, and

- parametric error, that is, uncertainty of data inputs to the model.

In an ideal world, if we completely understood biological processes and responses to environmental stresses, assuming accurate data inputs, we would be able to simulate ecosystem responses to stress accurately.

Clearly, however, we do not understand biological processes very well or biological process responses to environmental stresses. And we do not understand transport and fate of pollutants in the environment very well either. Even if we did, algorithmically representing such processes correctly and completely would be exceedingly difficult. In fact, currently available ecosystem models tend to predict ecosystem (productivity) responses to toxic exposures only within several orders of magnitude.

However, the holistic representation of ecosystem processes and responses to stress by quantitative models is an excellent way to focus research attention on improving our understanding of such processes and responses. Sensitivity analyses, for example, will help tell us which of the model variables are most significant for influencing changes in productivity for individual trophic levels and the ecosystem as a whole. Focusing research attention on the most significant variables will hasten improvement in modeled predictions and our understanding of the processes

involved. This would be an efficient way to address the fragmentary nature of our present knowledge of ecosystem responses to man's activities. Consequently, I urge the research community to do two, related things:

- broaden the design of individual research program perspectives towards a more holistic consideration of ecosystem processes and responses to stress and

- cooperate with each other and environmental management and regulatory agencies in the promotion, development, validation, and use of quantitative ecosystem models.

Similarly, I recommend that we environmental managers begin to think in more holistic ecosystem terms about how pollutant controls, environmental quality, and ecosystem health are related to each other. For example, we need to question whether or not the controls we prepare to impose in response to evident or potential ecosystem problems really do make sense for ecosystems that are impacted by multiple, manmade and natural stresses. Over time, I believe that such holistic thinking and questioning, in combination with credible ecosystem risk modeling capabilities, could result in establishment of quantifiable ecosystem objectives (fishery productivity objectives, for example) that would provide a meaningful context for related environmental standards and pollutant source controls. In the short term, I am confident that trying to think in holistic ecosystem terms will cause environmental managers to see the importance of improved communications with our research colleagues.

Indeed, improved communications and cooperation between environmental managers and researchers is essential, and we environmental managers must shoulder the major burden for improved communications. Simply put, the research community and environmental agencies need to find some way of efficiently communicating research findings and needs. All of us are busy. I have made the point several times above, for example, that environmental managers have limited time available for literature surveys, data collection, and analyses in support of decisionmaking on pollutant source controls that are responsive to evident or potential ecosystem problems. There is no question that we very often miss relevant research findings in our reviews and analyses. This is unfortunate but inescapable under existing circumstances. Therefore, I suggest at least one major, national workshop of representative researchers and environmental managers devoted exclusively to developing an efficient communications link between the research community and environmental agencies, also within the research community and among the environmental agencies. If such a mechanism exists today, I am totally unaware of it.

In closing, I feel that, through effective communications between environmental managers and researchers on issues and problems within a holistic ecosystem context, the environmental program decisionmaking process can, in fact, encourage productive research and adapt effectively to evolving scientific understanding.

A STRATEGY FOR PROGRAM IMPLEMENTATION

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ABSTRACT

The Clean Water Act of 1972 mandated "fishable, swimmable waters" for the United States by 1983, yet our research into just one phase of that original decision indicates that the program implementing the legislation fell short of its goals, resulting in agency and public frustration, misspent resources and wasted regulatory effort. Our paper recommends and discusses the following ideas: look before you legislate, use complete solutions, avoid unilateral approaches to environmental problems and use periodic program evaluation.

1. INTRODUCTION

The Clean Water Act mandated "fishable, swimmable waters" for the United States by 1983. A new computer simulation model, cost and feasibility analysis, legislative and literature review, interviews and surveys were used to evaluate the success of one aspect of the 1972 Federal Water Pollution Control Act. That work focused on requiring Marine Sanitation Devices (MSDs) on recreational vessels 65 feet in length and less with installed toilets. Our research on that phase of the original decision indicates that the program implementing the legislation fell short of its goals, resulting in agency and public frustration, misspent resources and wasted regulatory effort. This paper evolved from our master's thesis completed at the University of Michigan in 1987 which provided valuable input to this study. The thesis was titled "Marine Sanitation Devices, a Mechanism for Achieving the Clean Water Act Goals: An Evaluation of a Decade Old Environmental Management Decision." The magnitude of the problem was assessed by using demographic data from recreational boating statistics provided by the Coast Guard. A stochastic simulation model was used to evaluate the risk of discharging sewage into a waterbody. Field visits to a Marine Sanitation Device (MSD) manufacturer, a Coast Guard approved testing facility for MSDs, and to Canadian government officials also provided valuable input.

From this experience four generic recommendations have been synthesized. Our paper recommends and discusses the following ideas: research before legislation, using complete solutions, avoiding unilateral approaches to environmental problems and using periodic program evaluation. Recommendations such as these have been made before. Our intent here is to highlight how their use may have provided for a more effective regulatory program. Each recommendation is followed by examples from our research of the (MSD) portion of the Clean Water Act.

In order to avoid some of the frustrations experienced in implementing the MSD program we recommend that the following process be considered from start to finish when addressing a problem.

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2. LOOK BEFORE YOU LEGISLATE

The leading edge of legislation often exceeds the leading edge of technology. Efforts to provide immediate technological solutions to complex problems fall short because the path from the drawing board to the public bypasses the bogs of sufficient research and adequate field testing. Legislation may also change before technological innovations can meet the expectations, and demand, of the public. The standards for discharge limits, and the type of equipment that would be allowed, changed during the legislative evolution. The program's original intent for limiting effluent was "no discharge" type equipment; however, it was discovered that there weren't enough pump out stations. The use of "treatment" devices was allowed within restrictions based on municipal sewage treatment standards. During this evolution technology and the boating public were attempting to keep up with the changes in legislation. Technology and the equipment testing process to verify the proper operation of that technology weren't in place. Although the presence of an MSD was verified during a vessel boarding, no attempt was made to test its operation, or in the case of treatment devices, its effluent. This type of equipment had never been used aboard vessels before.

Changes in standards or regulations are often very confusing to the public. In this instance it was made more onerous because the changes in standards required boat owners to expend additional resources and purchase equipment to comply with the regulatory intent. People will reach a point where too many changes divert their attention from the problem the regulatory program was developed to remedy. In the MSD case they focused on the regulatory burden that seemed to change in an irregular way, resulting in a negative cash flow, and wasting their time. The original intent was holding tanks for all vessels. This changed to holding tanks for some vessels, treatment systems for others and a deadline for compliance that was impossible to meet because producers of equipment could not meet demand.

Study the hazards of the problem. One may start by asking some basic questions, "How big is it? Are there patterns?" A close look at the problem or hazard is necessary to develop a picture of it. A 1967 government study examined the problem of wastewater from vessels by concentrating on commercial and public vessels because that data was readily available. Authorities were aware of the hazards of wastewater from recreational vessels but did not study them enough to discover the incidence rate and the probable location of its occurrence. We developed a model for use in determining levels of fecal indicator organisms in a waterbody. The model indicated what everyone had suspected: concentrations of effluent occur in waterbodies with low flows. An unexpected discovery was the relatively small number of vessels necessary to create unsafe levels.

Next, define the problem. Defining the problem often sounds like a silly exercise, but unless you have defined the problem you are not going to know when it has been solved. This is a critical step. All other steps revolve around how the problem is defined. In the MSD case the problem was defined as one that applies for all waters and all vessels; however, this didn't appear to be an accurate assumption. The problem definition, coupled with agency practices, led to a focus on one type of vessel. An organization or agency should not focus on portions of the regulated public unless there is a very defensible reason for doing so. In the MSD case the focus was on larger commercial vessels examined regularly by the U. S. Coast Guard. Smaller commercial and recreational vessels were required to be equipped with MSDs if they had installed toilets, but since they weren't required to be examined as were larger commercial vessels, enforcement did not offer the incentive for compliance that it did with inspected vessels.

The process continues by examining possible problem solution alternatives. Examining alternatives actually involves generating alternatives, developing criteria for selecting alternatives and the actual selection process. The selection process is usually set up so that the most time consuming analysis is left for those final alternatives that have made it through other selection processes.

Some problems could have been foreseen through feasibility analysis. Feasibility analysis is usually the last hoop that an alternative must go through and is the most extensive. It is a framework for examining the proposed "life" of an alternative. The "life" of an alternative includes the normal analysis of costs and benefits but looks at them from an agency standpoint. The analysis examines communication of policy objectives, operational demands, resource availability, agency morale and effects of shared responsibility. There are many methods for conducting this analysis and we make no recommendations other than to use a defined process.

3. USE COMPLETE SOLUTIONS

Once a program is approved it is important to implement all its provisions or the proposed solution may fail. Many programs have been brilliantly written and coordinated, but have failed miserably during implementation because of resistance from within the agency that had responsibility or resistance from the regulated public. In the MSD case, pump out stations were needed for holding tanks. The standards and requirements for pump out stations were never developed though mandated by Congress. The approval of equipment was not well coordinated. Equipment was approved that had not been tested in a marine environment; it met the effluent discharge standards but wasn't suitable for vessel use. Dual problems occur from this: the equipment doesn't work so the problem will not be solved, and people are forced to purchase equipment that is not reliable. They are caught in a "no win" situation.

4. AVOID UNILATERAL SOLUTIONS

Single agent solutions to environmental problems should be avoided. Environmental problems usually cross the jurisdiction of more than one agency or industry and many times cannot be implemented and enforced by one agency. There must be a coordinated effort that utilizes as many agents' strengths as possible.

Coordination leads to cooperation and development of a larger acceptance base. If government officials and private sector people are involved in the decision making process, and ultimately the program itself, they will feel a sense of "program ownership," and be more likely to support its goals.

The Coast Guard was faced with an enforcement burden that they could not accommodate. Cooperation, even between Federal agencies, was not encouraged. An unpopular regulation was enforced by a single agency without the resources necessary to accomplish the task. If states and impacted private sector groups had been encouraged to participate in the planning and execution of the program it would have been easier for all involved and perhaps more effective.

5. USE PERIODIC EVALUATION

Periodic program evaluation can be used to increase effectiveness. It forces reviewers to measure program effectiveness by determining whether the program goals and objectives are being met. In addition, periodic program evaluation assists managers in delineating the direction of a program. It might lead the program manager to major program modifications. In addition, evaluation enables managers to "fine tune" the program. We often

leave programs to run themselves and only return when someone outside the program suggests that a problem exists. Programs should be examined on a periodic basis so that problems can be alleviated while they are still small.

This is done by defining measures of program effectiveness that are observable achievements of the program. The measures of effectiveness should correlate to goals needed to solve the problem. For many environmental problems, this is a difficult task to accomplish. Once completed, however, the program will have direction and changes will be easier.

6. CONCLUSIONS

These generic suggestions are intended to provide a process for program implementation and evaluation.

Generic suggestions don't guarantee success but may decrease the amplitude of problems encountered in implementing a program. These processes, if followed when the MSD program was first initiated, might have produced different and more beneficial results for both the Coast Guard, boat owners and others who enjoy our nation's waters.

The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the opinions of the Commandant of the Coast Guard, the Chief Counsel of the Coast Guard, or the Coast Guard at large.

UPDATING THE STRATTON COMMISSION: A PROPOSAL FOR THE U. S. COAST GUARD OCEAN SURVEY CORPS

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ABSTRACT

Twenty years after the Stratton Commission Report recommended consolidation of the nation's many ocean programs, federal agencies with marine responsibilities are as fragmented as ever, and the U.S. government still lacks an effective policy system to coordinate and manage multiple ocean resources. Although the creation of NOAA was a major step towards unification of this effort, the exclusion of the Coast Guard has hampered NOAA's effectiveness and diminished the sea-going efficiency of federal ocean scientists and engineers. Today, in separate departments, the USCG continues to maintain the nation's aids to navigation, but NOAA provides the hydrographic survey information and the charts, and each agency is tossed about yearly by stormy budgetary seas. Changing conditions over the years have once again set the stage for functional reorganizations. This paper proposes that parts of NOAA's National Ocean Service and the NOAA ships and officers be integrated into the Coast Guard, forming the nucleus of an Ocean Survey Corps (OSC), similar to the Army's Corps of Engineers. The OSC fleet- CG icebreakers, buoy tenders, and NOAA ships- should be manned as research vessels by dedicated CG/OSC personnel, performing the NOS survey and ocean science functions, while also policing the EEZ.

INTRODUCTION

One of the objectives of the Commission on Marine Science, Engineering and Resources when it issued its comprehensive 1969 report "*Our Nation and the Sea - A Plan for National Action*" was to streamline the jumbled federal ocean bureaucracy by consolidating most of those agencies into one major organization responsible for the nation's ocean effort. This single agency became the National Oceanic and Atmospheric Administration. The Commission, named for Chairman Julius Stratton, was a product of the heady days of the 1960's, when President John F. Kennedy, followed by Vice President Hubert H. Humphrey, spearheaded a drive to put men in the deep sea along with men on the moon. Their efforts helped catapult oceanography to the forefront of scientific interest and funding at that time. There was an idealistic feeling then that from the oceans would come the food, minerals and other resources necessary to meet the world's needs for the rest of the century and beyond. But the intervening years have shown that the boom on the ocean frontier erroneously envisioned to begin in the 1970's never occurred, and, except for those who study marine affairs, the Stratton Commission Report has been largely forgotten since its issuance with modest fanfare only a few days before President Lyndon B. Johnson left office. But, even after 20 years, it still stands as a landmark document whose wisdom was far ahead of its time.

Before the advent of the Stratton Commission, federal marine activities had grown over the years largely without any plans to meet specific situations and problems and were scattered throughout the government. In 1969, some 38 federal agencies had programs with marine responsibilities, and there existed significant duplication and overlap. The vision of the Stratton Commission was to create a single, large civilian agency to be the principal instrument within the federal government for administration of the nation's civil marine and atmospheric programs {1}. But the Commission was thwarted on two of its primary goals; first, to make NOAA, like NASA before it, an independent agency reporting directly to the President; and second, to include the Coast Guard. The objective of this plan was to create one major organization with a "critical mass" large enough to compete successfully for attention and funds within the federal bureaucracy. Untethered to the policies of any particular cabinet department, NOAA could thus adequately represent diverse ocean interests and encourage ocean development. The Coast Guard, together with the U.S. Coast and Geodetic Survey, was to have provided the ships and operational capabilities needed for going to sea by the ocean and atmospheric bureaus coming together under the NOAA umbrella {2}.

But the fish don't vote, most people in this country paid little attention, and politics, as usual, triumphed. After having chased smugglers for every Secretary of the Treasury since Alexander Hamilton in 1790, the USCG had just been moved by President Johnson into his newly created Transportation Department in 1967. Even before he received the Stratton Commission Report on his way back to Texas, LBJ was in no mood to move the Coast Guard again, and this view continued to persist after he left office. So in the summer of 1970, when Richard Nixon signed Executive Reorganization Plan No. 4, NOAA was created without what was supposed to be its major component of critical mass. Instead of an independent agency of nearly 55,000 people, the new organization included only about 15,000 employees. As early as 1972 it had already started to become obvious that because the Commission's recommendations were not fully implemented, NOAA was never going to be the strong leader in the ocean arena that its creators had envisioned {3}. Thus today, 54 federal agencies have marine activities, and two of the most politically feeble, NOAA, placed by President Nixon in the Department of Commerce, and the Coast Guard, in DOT, are tossed about yearly by stormy budgetary seas. The Coast & Geodetic Surveyors, a commissioned corps of less than 400 sea-going officers created in 1917, has become the NOAA Corps, which, along with the Public Health Service, form the sixth and seventh of the uniformed services.

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The purpose of this paper is to briefly review the relationship between the Coast Guard and NOAA since the Stratton Commission, focusing on smaller scale suggestions for future improvement of the operational performance of ocean science and engineering by these agencies at the field level, rather than on "big picture" decisions about ocean policy and the organization of the entire government. However, a quick review of the many reorganization proposals put forth since the Stratton Commission is useful.

FEDERAL ORGANIZATION FOR MARINE AFFAIRS

Reorganizing the federal government's ocean effort has been a consistently recurring theme over the past twenty years. Just as there were many wars following the 1914-18 "Great War to end all wars", many reorganization proposals have followed the great blueprint for ocean development that was supposed to finally put the nation's ocean policy house in order for the long haul, the Stratton Commission. Since 1969 there have been at least five major reorganization proposals: (1) the Ash council "Department of Natural Resources" proposal (1971); (2) the Norton "Independent NOAA" proposal (1976); (3) Senator Hollings' "Department of Environment and Oceans" proposal (1976); (4) President Carter's Reorganization Project/Department of Natural Resources report (1978); and (5) the National Advisory Committee on Oceans and Atmosphere (NACOA) "Department of NOAA & NASA" proposal (1979) {4}. During the time the Reagan Administration has been in Washington however, any reports of proposals which saw the light of day seem to have been confined to academic journals, such as Gail and Miller's "U.S. Ocean Resources Service" Proposal (1986) {5}. But the sheer number of reorganization plans put forth hammers home the general perception in the ocean community of the inadequacy of the present federal structure. The lack of an administrative focal point with direct access to the President as an oceans advocate, jurisdictional overlap, and duplication of effort are common themes. So is the call for a cabinet-level agency to coordinate federal ocean activities {6}. Most reorganization advocates feel that a "Secretary of the Oceans" would provide the needed focus on the marine environment that has been missing for so long.

THE ROLE OF THE COAST GUARD

The Stratton Commission also reported that the most difficult question faced by its members in over two years of study and hearings was whether or not to recommend the transfer of the Coast Guard into NOAA. As the nation's oldest continuous sea-going service, the USCG is a multi-mission maritime police force which has grown and evolved in response to the needs of the country since its inception. The many missions of the service have been acquired through the absorption of different federal agencies as those bureaus with marine responsibilities grew to be overlapping and interdependent through the years. Alexander Hamilton's original Revenue Cutter Service merged with the Lifesaving Service in 1915 and became the Coast Guard. During the World War II period, the Coast Guard took in the Lighthouse Service, and the Bureau of Navigation and Steamboat Inspection. Congress additionally tasked this amalgamated agency with icebreaking, port security, and marine environmental protection duties, and, as the fifth armed force, the Coast Guard has served as a branch of the U.S. Navy in almost every war since 1790 {7}. Ultimately it was this breadth of experience, along with the USCG's impressive physical resources- it ranks as the world's 12th largest naval fleet, with a complement of over 6,000 officers, 31,000 enlisted and 5,000 civilians, along with hundreds of ships, aircraft and stations all over the globe- which led the Commission to recommend that NOAA include the Coast Guard.

Interestingly, at the same time many in the ocean community have begun a renewed call for an independent NOAA, other supporters of the Coast Guard have begun a loud drumbeat to move the service out of the Transportation Department. They use an argument similar to that of ocean advocates, citing a lack of strong federal coordination of the Drug War. A recent poll found that over 90% of CG personnel, weary of budget cuts, now support a move to greener pastures, but it is not a new idea. Even before the Stratton Commission and subsequent proposals, between 1790 and 1967 Congress had talked about moving all or part of the Coast Guard to another federal agency at least 15 times {8}. Don Walsh has written that most of the recent list of reorganization proposals put forth by ocean policy study groups remind him of an ice cream sundae- the obligatory whipped cream and cherry popped on top is always the Coast Guard- they rarely get left out of any centralized ocean organizational plans! {9}

The United States Coast Guard is truly a singular organization in the world. Great Britain's Coastguard is largely a volunteer maritime safety organization much like the USCG Auxiliary here, and Canada's few Coast Guard ships and icebreakers are manned by federal civil servants. In Ecuador and in Chile, on the other hand, the Coast Guard operates small patrol boats and does hydrographic surveying as a division of the Navy at all times, and the navies of most small and developing countries are really coast guards in the strict sense. But the global responsibilities of the United States Navy create for the USCG a niche unique amongst the naval forces of the world. Yet this unique spot poses the same problem faced by NOAA- where should each one fit into the organization of the Executive Branch as a whole? The ocean community has coveted the Coast Guard since 1967, when the service was transferred to fill out LBJ's new Department of Transportation as the federal maritime component to the Aviation, Highway and Railroad Administrations. But now the organizational debate has gone beyond ocean interests and been taken up by a broad spectrum of public and Congressional USCG supporters, as many charge that the legacy of twenty years in DOT has moved the Coast Guard more towards a regulatory bureaucracy than an operational military service, causing it to fall behind in the War on Drug Smuggling. These people now believe the Coast Guard rightly belongs in the Defense Department, Justice Department, or elsewhere. Their arguments usually proclaim primacy of a particular CG mission, like maritime law enforcement, as reason to move to another department, such as DOJ. They argue that in DOT the service has been underfunded and ill-equipped to meet the increased demands of the many new statutory duties which have expanded throughout the last two decades. Indeed, just since 1970 the original base of Coast Guard authority in federal law has been expanded greatly by passage of at least 12 major acts, giving the service new duties in marine fisheries and pollution protection, coastal defense, and drug law enforcement. The CG regulatory shift was accelerated for a time by the country's anti-military "Vietnam Syndrome", which caused the service to publicly emphasize its non-military "good guy" roles as maritime lifesavers and defenders of the environment, at the expense of other duties. Strangely, during the Reagan era, even though CG funding has gone down, morale and retention have generally gone up. Still, in the last few years the many

missions of the Coast Guard have produced spirited budget battles between competing programs within the service, causing both internal and external parochial interests to suggest that the CG should give some of its "other" missions away to federal, state, or private agencies. This dissension generates an omnipresent and uneasy coexistence between those members committed to duties like law enforcement and military readiness operations, and those who joined the service strictly to "save lives- not take them".

Fueling the argument of those who would like to see the Coast Guard in another department is the fact that during the 1980's the phrase "Ronald Reagan's defense buildup" has basically meant "Department of Defense buildup". Like NOAA, the Coast Guard has actually experienced declining real budgets since the 1970's, and the service's shrinking number of large cutters have an older average life in service than the aging NOAA and University (UNOLS) federal oceanographic fleets. Concurrently, the naval warfare capability of these cutters is also mired in the 1960's. Since 1966, the number of CG high endurance cutters (250' or longer) has declined by two thirds, from 36 to 13, and more than half of the nation's former fleet of 8 polar icebreakers has been cut as well, with only 2 replacement icebreakers on the drawing board for the 1990's. The Coast Guard does continue to maintain an inventory of about 2000 utility and rescue boats under 65 feet long. Although this figure and the number of CG personnel has declined only slightly from those reported by the Stratton Commission, the total number of vessels over 65 feet- those, like icebeakers, capable of performing ocean science and engineering jobs- has dropped from 343 ships and patrol craft in 1966 to 242 today {10}.

THE 200 MILE EXCLUSIVE ECONOMIC AND MARITIME DEFENSE ZONE

If the USCG's pre-eminent roles in the 1970's were search and rescue (SAR), marine safety, and environmental protection, the service's new dominant duties in the 1980's have been law enforcement and naval defense operations. These two activities have jumped from less than a 20% slice of the Coast Guard budget pie as reported by the Stratton Commission to a 42% share today. As recently as 1982, law enforcement and defense operations still constituted just 25.9% of USCG funding. It can almost go without saying that our nation's vigorous and increasingly vocal War on Drugs is the obvious reason for the significantly bigger Coast Guard outlays on law enforcement, but the driving force behind the recent larger naval defense expenditures has its own story. The Stratton Commission stated that "the Coast Guard is indeed the Nation's guardian against the hazards of marine operations...it's multi-purpose vessels do almost everything in the broad and often dangerous reaches of the sea but guard the coast in the military sense". At the time that statement was written in 1968, most CG cutters and facilities had served in World War II, and in the post war period only perfunctory naval defense exercises were conducted as other Coast Guard duties expanded. Historically, the USCG has never had specific naval tasking, and has performed different "jack of all trades" functions for the Navy when called upon in every conflict through Vietnam. But even before the Reagan Administration took office, the Coast Guard and Navy had recognized how far behind the CG had fallen behind in the expensive technology necessary for most cutters to be of use to the Navy fleet in fighting a modern, high threat electronic missile war. As a result, the services undertook joint planning to look for a more realistic Coast Guard role in U.S. sea power strategy, including specific warfare tasking for the USCG as a naval force. So, in March 1984, a year after President Reagan proclaimed full U.S. jurisdiction over the 200 mile Exclusive Economic Zone (EEZ), Secretary of the Navy John Lehmann and Secretary of Transportation Elizabeth Dole implemented the Maritime Defense Zone (MDZ) concept, giving the Coast Guard, in its wartime role as part of the Navy, the principal responsibility for defense of this nation's coastal zone out to 200 nautical miles. Planning and exercises in the EEZ/MDZ area for mine countermeasures, antisubmarine and inshore undersea warfare, port security, and antiterrorist activities now fall to the Coast Guard Atlantic and Pacific Area Commanders. These two admirals now have a joint service staff and CG and Navy units assigned to them in the event of a mobilization, and they are directly responsible to the Naval Commander-in-Chiefs of the Atlantic and Pacific Fleets for coastal defense {11}. So, as the service approaches its 200th birthday, the U.S. Coast Guard can finally say that it truly does, indeed, guard the coast.

The flip side of this trend toward law enforcement and military readiness is that the money to support it comes out of other Coast Guard missions, because the budget pie has actually been shrinking when adjusted for inflation since the Carter Administration. The Stratton Commission reported that 13 percent of the Coast Guard budget then went to oceanography, meteorology, icebreaking, and other marine sciences; and 28% to provide for the nation's aids to navigation system. In the 1988 budget, all icebreaking and marine science operations make up a meager 4 percent, and aids to navigation is down to a 21% slice of the pie. Probably the most startling budget priority change, however, is in search and rescue, which has dropped from 35% of the total twenty years ago to just 18.7% in the current fiscal year.

THE NOAA-COAST GUARD RELATIONSHIP

Throughout their histories, NOAA and its predecessor agencies have had an especially close relationship with the Coast Guard. Information provided by the Coast Guard's aids to navigation teams and buoy tending cutters has been a regular part of U.S. Coast & Geodetic Survey and now National Ocean Service charts and Coast Pilot books since the early part of the century. During the 1950's and 60's, the Coast Guard's largest cutters were placed for month-long periods at fixed points in the North Atlantic and Pacific Oceans to provide observations to the National Weather Service, collect oceanographic data, and to serve as navigational way points and potential rescuers for trans-oceanic airplane flights. This program lasted until 1978, when NOAA satellites finally made the last of once numerous CG "Ocean Stations" obsolete. CG-NOAA close cooperation probably reached its zenith, however, in the middle 1970's, when much new federal environmental, fisheries, and marine mammal protection legislation had large segments of NOAA and the Coast Guard working side by side to implement commercial fish management plans and environmental baseline studies. The centerpiece of their relationship was Washington Senator Warren Magnuson 's Fisheries Conservation and Management Act (MFCMA) of 1976, which established the 200 mile Fisheries Conservation Zone (FCZ), giving the USCG and National Marine Fisheries Service responsibility for patrolling and regulating some 10 percent of the world's fisheries resources over a 2.2 million square mile area.

Coast Guard participation in marine environmental science goes back at least to the sinking of the *Titantic* in

1912. Since then the Coast Guard has been the operating agency of the International Ice Patrol, tracking iceberg movements into North Atlantic shipping lanes. The Coast Guard's most famous ocean scientist, Admiral "Iceberg" Eddie Smith, later headed the Woods Hole Oceanographic Institution. In 1961, Senator Magnuson pushed through legislation expanding the Coast Guard's authority to engage in oceanographic research, thus providing better data collection utilization for cutters on ocean station. The service's role in oceanography then expanded throughout the 1960's, and reached fever pitch when the CG got wind of the Stratton Commission's intention to recommend their inclusion in the new NOAA. All of the sleek, destroyer-type *Hamilton* class 378-foot high endurance cutters under construction at that time were built with features similar to the large Class I NOAA ships, such as an oceanographic lab, wire winch, and weather balloon shelter. The service even remodeled several of its WW II vintage tugs and buoy tenders and designated them as oceanographic cutters, used for studying surface currents and towing big NOAA data buoys. Three marine pollution "Strike Teams", including divers, were created, stationed on each coast. These Strike Teams and their equipment could fly by C-130 to a location at a moment's notice in the event of a major accident or spill. The U.S. Coast Guard Academy in New London, Connecticut, established an undergraduate major in Marine Science to train future officers, and the service also cross-trained its enlisted weathermen ("Aerographer's Mates"), converting them into all purpose, sea-going Marine Science Technicians. To top all this off, page 45 of the Stratton Commission Report even shows a picture of a Coast Guard planned helicopter-carrying "High Endurance Oceanographic Cutter", saying it was scheduled to be built by 1972.

All this effort ultimately went for naught when Executive Reorganization Plan Number 4 went into effect in 1970, creating NOAA in the Commerce Department and leaving the Coast Guard behind in DOT. Throughout the decade CG oceanography basically ran on the momentum generated at the time of the Stratton Commission Report, but by 1973 it had become obvious that oceanography in the Coast Guard was doomed by shifting budget priorities never to be a major program. That same year, the Coast Guard made its very first seizure of a vessel trying to smuggle several tons of marijuana into the United States.

By the early 1980's, the NOAA-Coast Guard honeymoon, following their brief marriage in the church of fisheries enforcement, was over. The MFCMA was working very well, but CG and NOAA people had no time to rejoice, because since then they've been too occupied hunkering down every year or two to duck salvo after budgetary salvo from the Administration and the Congress. The CG leadership has been forced at times to tell the troops, "we've suffered another budget cut - but we're not going out of business!" NOAA has been in even worse shape, with a total budget decrease of 27 percent just from Fiscal Year 1985 to FY 88. Overall, the NOAA budget is difficult to analyze, because expenditures for atmospheric and satellite activities have actually increased by 25% in the last year, while the deepest cuts have fallen on the agency's ocean and research programs, with recent decreases of over 50 percent {12}. If these budget cuts threaten to remove the "O" from NOAA, however, the "O" in the Coast Guard is already gone. Only a handful of physical oceanographers in the International Ice Patrol remain. The service-wide program coordinator, the USCG Oceanographic Unit in Washington, D.C., was disestablished a few years ago. Laboratories, wire winches, and Marine Science Technicians have been removed from all but the 2 *Polar* class icebeakers, and the oceanographic cutters have been redesignated as drug patrol vessels. A consolidated Strike Team now does not have a single diver. Marine Science is no longer a major at the Coast Guard Academy, ending with the Class of '85, and rare is the CG officer these days who receives a graduate degree in Oceanography or Ocean Engineering. And several hundred enlisted MSTs are now on their way toward an official role change to Marine Safety Technicians. Besides continuing joint fisheries enforcement, mostly in Alaska, and doing some data buoy work in Bay St. Louis, Mississippi, it is hard to find anything much going on today between NOAA and the Coast Guard but the traditional exchange of hydrographic survey and navigational data.

THE ROLE OF NOAA

After six years of regulating the Fisheries Conservation Zone, in 1983 President Reagan expanded the U.S. offshore claim from just the fisheries to include all the resources on and under the sea bed in the 200 mile zone. This area encompasses some 3 billion acres off the coasts of the United States and its territories. The EEZ has given NOAA ships the large task of using today's advanced electronic surveying methods to produce detailed bathymetric maps of the huge area of continental shelf and slope over which the U.S. has now claimed exclusive economic rights. We have to know what is out there, and maps, charts and resource assessment surveys will certainly be needed if the area is ever to be utilized. But recently the National Ocean Service has been particularly hard hit by budget cuts. NOAA has had numerous internal reorganizations in the eighteen years since its inception, and NOS is now composed of five offices: (1) Charting and Geodetic Services, (2) Ocean and Coastal Resource Management, (3) Oceanography and Marine Assessments, (4) Marine Operations, and (5) Ocean Services. The National Marine Pollution Program Office is also assigned to NOS. The Office of Charting and Geodetic Services provides charts and related information for the safe navigation of marine and air traffic, maintains the National geodetic networks, and conducts supporting research and development. The Office of Marine Operations is in charge of operating the NOAA Fleet, consisting of 23 ships, ranging in size from Class I (275' or more) to Class VI (65 ft.) research vessels {12}. These ships support all NOAA missions and are operated by the 400 commissioned officers of the NOAA Corps. The officer-scientists who serve in NOAA hold naval ranks from Ensign to Rear Admiral and comprise the nation's Seventh, and smallest, uniformed service. The Corps, renamed in 1970, was created in 1917 to provide engineers qualified for ship command who could conduct coastal hydrographic and geodetic surveys. These officers supervise crews of civil servant merchant seamen when assigned to NOAA ships and perform research or administration duties when assigned to NOAA facilities ashore. A few pilots among them also run the Office of Aviation Operations, which flys and maintains NOAA's small fleet of P-3 and C-130 research aircraft.

In almost every fiscal year in this decade, at least one of these research ships or aircraft has had to be laid up due to funding constraints. With budget problems paralleling those of the Coast Guard, NOAA has also seemed to lack direction, and a NACOA study group has recommended that "NOAA accelerate efforts to clearly define its long term role in the nation's ocean research effort." {12} Recently retired Rear Admiral J. Brad Mooney, former Chief of Naval Research and Oceanographer of the Navy, has stated that "if

NOAA is to continue to exist, NOAA needs a charter. Until then, there will be territorial disputes among several federal agencies that do work in the ocean" {13}.

As an ocean agency in the Department of Commerce, NOAA has the same problems getting attention as the Coast Guard does as a sea-going armed service in the Department of Transportation. Both agencies' constituencies are not big or loud enough to channel even emergency funding away from politically powerful bureaucratic competition like the International Trade or Federal Aviation Administrations. NOAA makes up 38% of the Commerce Department work force, and the Coast Guard is definitely the majority component of DOT. The DOT Secretary travels in CG aircraft and enjoys the services of a Coast Guard aide, as does the Commerce Secretary, who is assisted by a NOAA officer. Yet last year, the Coast Guard received only 9.2% of the total Transportation Department budget, a category known as Function 400. During the Reagan years, privatization advocates have claimed that many USCG duties, such as aids to navigation; and NOAA services, such as hydrographic surveying and chart production, should be turned over to the private sector. For its part, the Coast Guard has responded that only the military can perform these vital functions during wartime, which is the reason the USCG got into the merchant marine inspection business in the first place during World War II. Ironically however, the marine safety program also forms the basis for the service's home in DOT. But, as politicians continue to argue public versus private sector ideology, budget cuts slash both agencies to the bone. The Administration blames Congress, Congress blames the Administration, and in the meantime NOAA ships and Coast Guard cutters sit at the dock, laid up or out of money for fuel, as EEZ ocean research goes undone and drug smugglers have free passage to our shores.

THE USCG OCEAN SURVEY CORPS

In the midst of all this, and with the federal budget deficit and the current need for greater government efficiency firmly in mind, it seems that the time has come, as it did in 1915, during World War II, and in 1969, for a reorganization of the federal marine agencies, and that a politically plausible approach is necessary. The Coast Guard maintains the nation's aids to navigation, but NOAA provides the hydrographic information and the charts. The EEZ and MDZ have set the stage for the 38,000 members of the Coast Guard to absorb a portion of the 15,000 employees of NOAA to form a Coast Guard counterpart to the Army's Corps of Engineers. The USACOE operates in support of both the nation's civil works and construction needs and the Army's combat engineering readiness. With this model, the National Ocean Service's Offices of Charting and Geodesy, Marine Operations, Aviation Operations and the NOAA Corps would remain basically intact and be integrated into the Coast Guard, forming the nucleus of an Ocean Survey Corps (OSC) within the service, probably under the USCG Office of Navigation. Over 100 Coast Guard buoy tenders and icebreakers, together with the 23 NOAA ships, would become part of the OSC. These vessels, all of which have virtually no capabilities to fight a modern naval war, would basically be considered support or auxiliary ships, a separate component from the main Coast Guard fleet. They would be crewed entirely by OSC military personnel, mostly Marine Science Technicians, at the minimum manning levels necessary to accomplish only the peacetime jobs. The crews could then be augmented by CG Law Enforcement Detachments (LEDETs) and CG or Navy reservists, if necessary, for special deployments.

This reorganization would accomplish several things. It would consolidate the services of nearly 45,000 people and provide more of the critical mass envisioned by the Stratton Commission and certainly needed in the era of Gramm-Rudman-Hollings. It would bring together the organizations charged with providing the nation's hydrographic and navigation information, and do away with the "union shop" frustration faced by NOAA Corps officers, who currently must stop surveying at 4 pm every day at sea or pay overtime to the unionized federal merchant seamen who crew their ships. It would reduce the oversize crews of Coast Guard polar icebreakers, which have become essentially polar research vessels, to give more room and make them more responsive to the research scientists they serve; as well as reducing the crew complement of CG buoy tenders, helping to silence those who scream for privatization. The Ocean Survey Corps would provide a more complete and diverse career ladder for those NOAA Corps officers who complain that they get too many tours at sea, as well as those Coast Guard personnel in marine safety or aids to navigation who don't get enough sea duty. The OSC organization immediately puts more Coast Guard hulls at sea for drug smugglers to have to avoid, and the reduced crews, supplemented by LEDETS and reserves, frees up other Coast Guard people for law enforcement and military readiness duties in the regular white hull fleet. This will allow for higher, naval ship-size manning levels on both current and future patrol cutters, which will be needed for policing and defending the EEZ/MDZ. In the multi-mission CG-OSC, NOAA ships without employment wouldn't have to be laid up; the crew could simply be augmented and the vessel sent out on patrol until other ocean projects come along. Conversely, an OSC ship engaged in research or survey would simply radio the position of any spotted smuggling suspects to CG aircraft or other patrol vessels for them to track and make the interdiction. The concept of an Ocean Survey Corps fleet provides a more stable and efficient operating environment for CG red hull (icebreakers) and black hull (buoy tender) sailors, NOS personnel, and those members of the Coast Guard to whom the growing missions of law enforcement and military readiness hold no appeal. It also retains the basic multi-mission character of the service, while simultaneously providing a broadened and better sense of direction for the NOAA Corps, and a degree of specialization for CG officers. For example, OSC officers could retain the distinctive NOAA Corps insignia, just as USPHS medical personnel do while wearing the Coast Guard blue uniform. The OSC allows CG officers more career opportunities in ocean science and engineering, while giving more NOAA Corps people opportunities for responsibilities in administration. With a Vice Admiral as Chief of the OSC, the organization would not have to change much from what is currently found in the USCG Office of Navigation and the National Ocean Service. Taking the NOAA Corps just by itself, it does seem ludicrous for this country to continue to maintain a quasi-military group of less than 400 commissioned officers, all chiefs with no real indians, adrift in the middle of a civilian agency.

Exploration of new frontiers under military auspices is a tradition as old as mankind. Virtually all of history's great explorations of discovery, including space exploration, have been supported by military personnel. The problem is in adapting the military organization to meet the needs of exploring the EEZ. As NOAA ships and Coast Guard polar icebreaker crews are presently organized, however, this kind of scientific efficiency is simply not possible. Neither

unionized seaman nor oversized wartime complements of military men can efficiently perform marine science at sea. A streamlined and dedicated group of scientists and MSTs can accomplish much more. Another function which has been conspicuously lacking in strength in NOAA which had been recommended by the Stratton Commission is the vigorous development of new marine technologies. This is the muscle that has long been essential in moving toward new maritime goals. After lagging for awhile, however, the marine technology situation is quickly improving, as evidenced by the recent highly publicized use of Remotely Operated Vehicles (ROV's) for the exploration of the *Titanic*, as well as in the search for the remains of the space shuttle *Challenger*. A large number of other innovative technologies for exploring the last frontier on planet earth are currently under development. The proposed Ocean Survey Corps would also facilitate better coordination and funding for this kind of R&D by the two military sea services, Coast Guard and Navy, who are already drawing closer on the MDZ front, to focus their efforts on the strategic implications of ocean development in the EEZ. Currently, the EEZ is nothing but a geographic boundary, but long term development will eventually require a vigorous maritime police force, with many new and more capable patrol and research vessels above and below the waves.

CONCLUSION

There is not space here to discuss all the ramifications of this organizational change. Many Senators and Congressmen with ocean and maritime interests, however, are already taking action on the subject. Several related bills were introduced in 1987 and are currently pending in committee. One Senate bill would make NOAA an independent agency, fully establishing it as the principle civilian ocean agency in the federal government. Clearly, NOAA would be better off concentrating on policy and coordinating ocean science research and technology, while leaving operations to the UNOLS fleet, the OSC and private charter vessels. NOAA should become the strong, independent agency originally envisioned by the Stratton Commission, especially if the Commerce Department continues to move toward becoming the Department of International Trade and Industry (DITI) as has also been proposed. At the same time it seems that certain NOAA service operations could be more efficiently accomplished from within the Coast Guard.

Finally, in the larger scheme of things, if NOAA and the Coast Guard are to be moved, where should they go? I tend to agree with Don Walsh, who believes the Stratton Commission' s "centralized" plan of reorganization was too politically radical to succeed, and instead prefers a "functionalized" scheme, similar to the current cabinet departments, which requires a minimum of political wrangling with Congress. In this framework only two new organizational elements would be created, and both NOAA and the USCG would each become independent agencies. The Coast Guard, in a separate USCG Administration, would include the NOAA Corps and ships; while NOAA, NASA, and the National Science Foundation would form an independent but closely allied National Science and Technology Administration (NSTA).

In the current climate, I believe this plan could succeed, especially if the USCG Administrator was also appointed the overall coordinator, or "czar" of the drug war; and if some of the "lost sheep" marine programs in other agencies eventually joined the new NOAA down the road a few years. But, above all, Walsh argues, any new plan must be politically "do-able", or it is no plan at all. What is obvious from twenty years of hindsight is that the Stratton Commission's Report had miserable political timing. The lesson to be learned is that any national ocean policy "window of opportunity" which opens in the early 1990's should not be squandered again {14}.

ACKNOWLEDGEMENTS

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NATIONAL RESPONSE MECHANISM

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ABSTRACT

The United States has developed a national oil and hazardous substance spill response system as required under the Federal Water Pollution Control Act (FWPCA) of 1972, as amended, and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980. The National Contingency Plan (NCP) establishes the National Response Team (NRT), Regional Response Teams (RRTs), and the National Response Center (NRC). It also defines the role of the On-Scene Coordinator (OSC). The system relies on the maintenance of comprehensive contingency plans and functions through an intricate network of interagency relationships. The four critical aspects of this system are the statutory authorities, the regulatory structure, the agency response organizations and the composition of the local response community. Each of these aspects is examined individually, and then presented as an integrated spill response system. This paper focuses on the U.S. Coast Guard role in the response system and the Coast Guard's spill capabilities in the coastal zone.

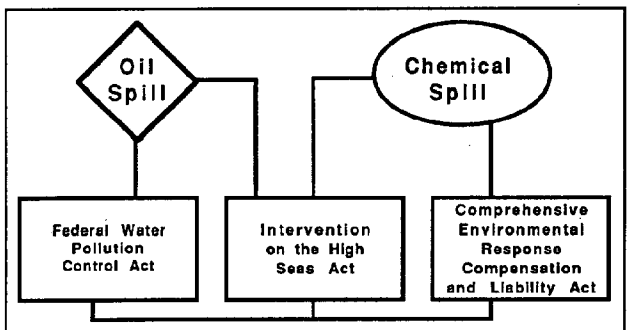

Figure 1

1. INTRODUCTION

The federal response mechanism is a national oil and hazardous substance spill response system. It is based on statute and regulation, relies on the maintenance of comprehensive contingency plans and functions through an intricate network of interagency relationships. The system can be best explained by breaking it into four sections, examining each section individually and then reviewing the integrated system. The four sections to be examined are: The statutory authorities, the regulatory structure, the agency response organizations and the composition of the local response community. This paper concentrates on the U.S. Coast Guard role in the response system but also represents the general Environmental Protection Agency (EPA) role in the same system.

2. FEDERAL RESPONSE STATUTES

The first section to be examined is the statutory authorities. There are three federal statutes that provide the basis for Coast Guard authority to respond (Figure 1). Each statute has specific intent and equally specific limitations.

(a) The Federal Water Pollution Act (FWPCA, 1972, as amended) in section 311 (k) created the $35 million Pollution Fund. This fund, administered by the USCG, but equally available to the EPA, may by used to finance the response to and removal of a pollutant if:

(1) The spilled material is either oil or one of 297 specified chemicals,

(2) the spill has entered navigable/tributary waters or threatens same, and

(3) the spiller is unwilling to undertake cleanup or the identity is unknown.

The Pollution Fund is an appropriated resource requiring periodic Congressional action for continuation. Monies collected through the reimbursement processes are returned to the fund.

(b) The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) OF 1980 established the original Superfund. The Superfund Amendments Reauthorization Act (SARA) of 1986 reauthorized

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the original Superfund at $9.0 billion. This fund, administered by the EPA, but also available to the USCG, may be used to finance an immediate and/or remedial response to either an actual or potential chemical release which threatens the environment. Oil is an excluded substance, and chemicals are identified by characteristic rather than by name to avoid possible oversight. Superfund monies are accumulated from tax revenues related to chemical production.

(c) A third statute which is related to both the FWPCA and CERCLA is the Intervention on the High Seas Act (IHSA, 1974). The IHSA authorizes the Commandant of the U.S. Coast Guard, following a series of consultations/notifications among State Department, EPA, and the International Maritime Organization (IMO) to assume physical control of any (non-military) vessel on the high seas, regardless of flag, which poses a substantial environmental threat to specific United States' resources. Both the FWPCA Pollution Fund and the CERCLA Superfund may be used in conjunction with high seas intervention activities.

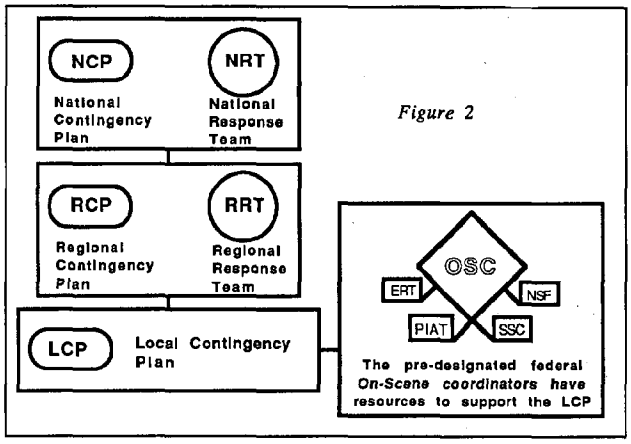

Figure 2

3. FEDERAL REGULATORY STRUCTURE

The second section to be examined is the regulatory structure (Figure 2). Both the FWPCA and SARA require the development of a National Contingency Plan (NCP) to establish the federal framework for oil and hazardous material spill contingency planning and response organization. The NCP has been codified and appears as federal regulation in Title 40 of the Code of Federal Regulation (CFR) Part 300. The NCP establishes the National Response Team (NRT). The NRT is primarily a national planning, policy and coordinating body that does not respond

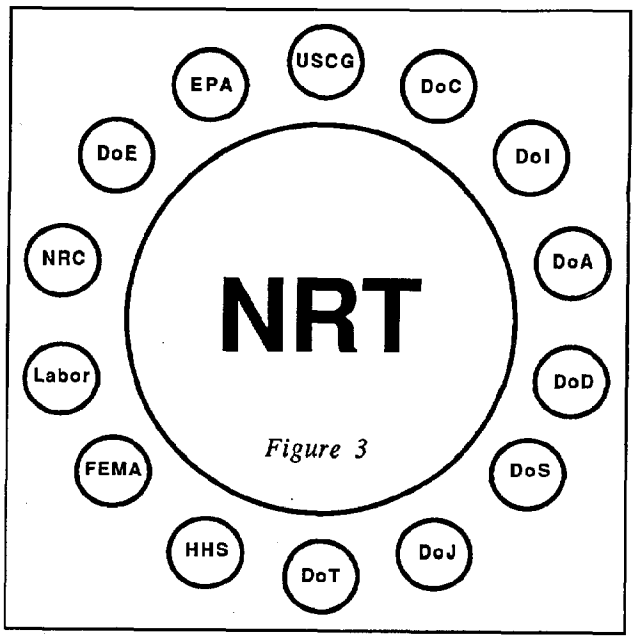

Figure 3

directly to incidents but provides guidance prior to an incident and assistance as requested during an incident. Its membership includes representatives from those fourteen federal agencies having environmental responsibilities (Figure 3). The NRT is chaired by the EPA and vice-chaired by the USCG. Meetings are held in Washington, DC once a month. The NCP also established the National Response Center (NRC) as a 24 hour report processing and response coordinating center. The NRC is supported by the members of the NRT and staffed by USCG personnel.

The NCP created a second organizational level through the establishment of Regional Response Teams (RRTs). Like the NRT, RRTs are planning policy and coordinating bodies and do not respond directly to incidents. There are 13 RRTs, one for each of the ten federal regions plus one each for Alaska, the Caribbean, and the Pacific Basin. RRT membership is basically the same as the NRT but also includes a representative from each state in its respective region. Each RRT is co-chaired by the USCG and EPA. RRTs meet semi-annually, more often if necessary, to maintain their Regional Contingency Plans (RCPs) and to provide local resource support.

The third organizational level created by the NCP is at the local level. The Local Contingency Plan (LCP) is a specific document which identifies environmentally sensitive areas and resources at risk, contains a response equipment guide and response procedures, and

identifies operational contacts throughout the local response network. The LCP is developed as an "immediate response" document. As with most operational planning documents, a significant benefit is derived during the development and annual updating of the LCP.

The most important element in regulatory structure is the role defined for the On-Scene Coordinator (OSC). The OSC is the predesignated federal official responsible for ensuring proper pollution response and enforcement. The OSC: coordinates all federal containment, removal and disposal efforts and resources during an incident; authorized to control and finance pollution cleanup operations; serves as point of contact for the coordination of federal efforts with those of the local response community; and is a source of valuable support and information to the local response community.

The USCG provides OSCs for the coastal zone and the EPA provides OSCs for the inland zone. The boundary between the coastal zone and inland zone is determined by an agreement between the USCG and the EPA for each of the 13 regions and is found in the respective RCPs.

4. USCG/EPA RESPONSE STRUCTURES

The organization of the response agencies is the third section to be examined. Figure 4 illustrates that the national structure allows for the designation of essentially parallel agencies (USCG and EPA) to resolve inland and coastal zone spill situations using the same planning, logistics, and funding strategies.

The USCG, an agency in the Department of Transportation, is headed by the Commandant (G-C), to whom the Secretary of Transportation has redelegated the various authorities for the FWPCA, CERCLA, and IHSA. The Commandant's representative serves as vice-chair of the NRT. The USCG is divided into ten districts which don't coincide with the ten federal regions. Each district is headed by a District Commander (d), to whom most of the statutory authorities have been transferred (except IHSA). Assisting the District Commander in a staff capacity is the Chief, Marine Safety Division (m) and the Chief, Marine Environmental Protection Branch (mep). The Chief, Marine Safety Division serves as co-chair of the RRT. The Chief, Marine Environmental Protection Branch generally manages each district's allocation from the Pollution Fund. Close coordination among USCG districts and associated staffs is required since

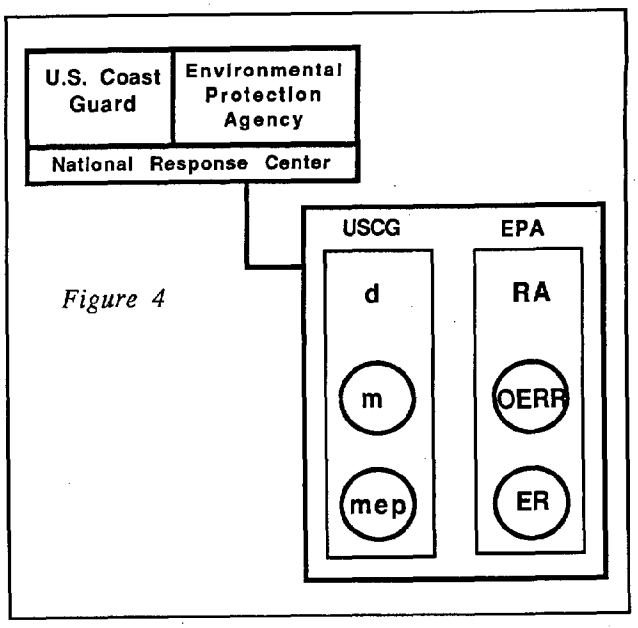

Figure 4

district boundaries and federal regions don't align.

Next in the actual line of authority after the District Commander is the Captain of the Port (COTP) (Figure 5). The COTP is normally the Commanding Officer of the local Marine Safety Office (MSO). This individual serves as the USCG OSC when an incident occurs. There are currently 48 MSOs in the Coast Guard.

The EPA organization parallels that of the USCG to a large degree. The EPA has an Administrator (A) (instead of G-C) and the Administrator's representative serves as chair of

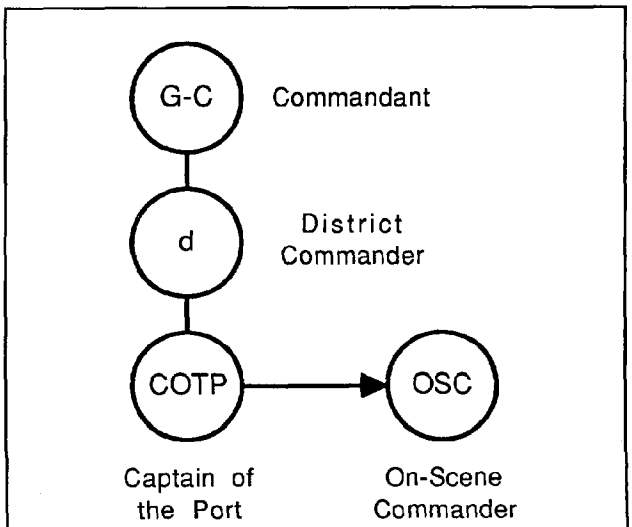

Figure 5

the NRT. There are ten Regional Administrators (RA) (instead of d), and each region has an Office of Emergency and Remedial Responses (OERR), or equivalent (instead of m). The regional Chief, OERR generally serves as co-chair of the RRT. The similarity ends with Emergency Response Branch (ER) (equivalent to mep). Unlike the USCG which has a three-level organization (national, district, and local), EPA has a two-level organization (national and regional). Since there is no local-level EPA structure, the pre-designated OSCs come from a group in the regional offices.

5. LOCAL RESPONSE COMMUNITY

The fourth and final section to be examined is the composition of the local response community. The focal point of activity for all major response episodes involving the use

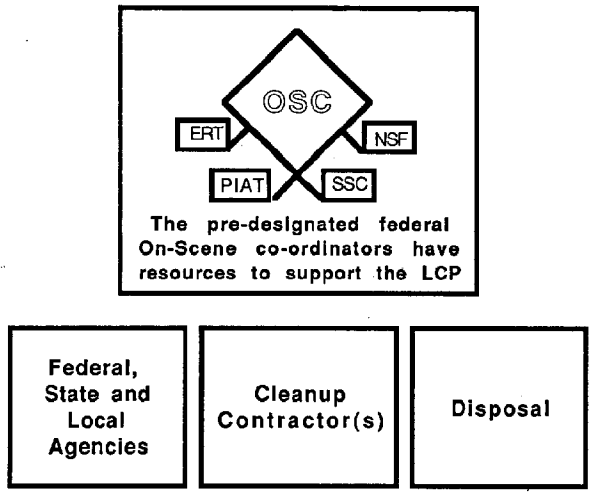

Figure 6

of federal funds is the OSC, (Figure 6). Most cleanup activities are accomplished through prenegotiated agreements with private sector contractors. In addition to the cooperative assistance of various federal, state, and local agencies, and contracted services, the OSC (either USCG or EPA) has Special Forces to call upon. The Special Forces are four unique resources:

(a) The National Strike Force (NSF) consists of two strategically located strike teams on the Pacific coast and the Gulf coast. These units are composed of a corps of extensively trained USCG personnel who have a large pollution response equipment inventory. Strike Team capabilities are especially suited to large-scale, immediate-response oil spills and chemical releases in the marine environment, but also include site assessment; safety and action plan development; and documentation for both inland and coastal zone incidents.

(b) The Scientific Support Coordinator (SSC) is a scientific and technical advisor funded by the National Oceanic and Atmospheric Administration (NOAA) and assigned one to each USCG district. The SSC assists OSCs in the evaluation of available technical data and serves as the principal point of contact for members of the scientific community. The SSC network involves detailed and frequent exchanges of information to support one another. Their capabilities include: Surface/subsurface trajectory forecasting/hindcasting, resources at risk analysis, technical hazard data, contingency planning, and general communications.

(c) The Public Information Assist Team (PIAT) is a highly skilled unit of Public Affairs Specialists funded by the USCG and based in Washington, DC. At the request of an OSC, PIAT is prepared to either complement the existing or provide additional public information capability for an OSC to properly address the role of the media during an immediate response. PIAT maintains and coordinates the flow of timely and factual information from the OSC to the public through frequent and direct contact with the news media.

(d) The Environmental Response Team (ERT) is a group of highly-trained scientists and engineers funded by the EPA and based in Edison, NJ and Cincinnati, OH. The capabilities of the ERT include multimedia sampling and analysis, hazard evaluation, contamination monitoring, cleanup techniques and overall technical support to the OSCs.

6. CONCLUSION

The purpose of this paper has been identify and examine the four parts of the national spill response system. The dynamic integration of the components (Figure 7) during an actual incident enables an On-Scene Coordinator to assemble a multi-disciplinary support group which is otherwise unavailable during an emergency time frame.

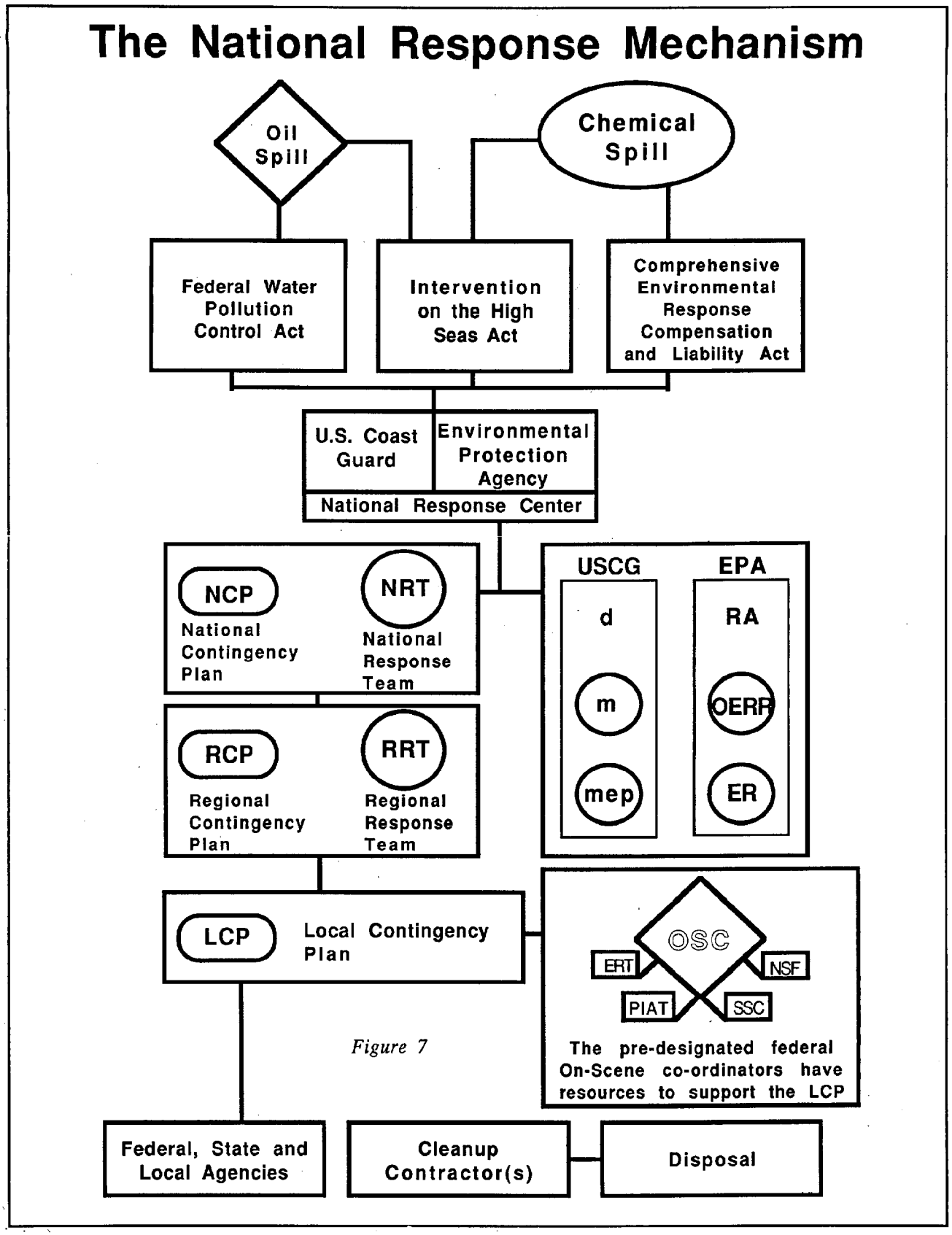
The National Response Mechanism
Oil Spill
Chemical Spill
Federal Water Pollution Control Act
Intervention on the High Seas Act
Comprehensive Environmental Response Compensation and Liability Act
U.S. Coast Guard
Environmental Protection Agency
National Response Center
NCP
National Contingency Plan
NRT
National Response Team
USCG
EPA
d
RA
m
OERR
mep
ER
RCP
Regional Contingency Plan
RRT
Regional Response Team
LCP
Local Contingency Plan
OSC
ERT
NSF
PIAT
SSC
The pre-designated federal On-Scene co-ordinators have resources to support the LCP
Federal, State and Local Agencies
Cleanup Contractor(s)
Disposal

Figure 7

SATELLITE OCEAN MONITORING AT TEN YEARS: PERCEPTIONS AND REALITIES

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ABSTRACT

Satellite remote sensing of the ocean is important to the maritime industry, fishing, and environmental research, but has real limitations. The capabilities and limitations of remote sensing should be better understood by policy and decision makers, as well as nonremote-sensing oceanographers.

Satellites are perceived as being the solution to many nagging ocean surveillance problems, like pollution monitoring. While satellites hold the promise to do more in the future, and are critical elements of various maritime programs today, the applicability of space-based remote sensing should not be oversold.

This year is the tenth anniversary of the TIROS-N series of polar-orbiting spacecraft. It is time to reexamine what the nation's only operational remote sensing satellites have contributed to oceanography and commerce. When planned, these satellites were not expected to be beneficial as they now are or can be.

INTRODUCTION

Faced with increasing coastal pollution and erosion problems, and, following a series of maritime mysteries like dolphin deaths, mid-latitude red tide blooms, and Caribbean coral bleachings, scientists and politicians are looking to the skies for answers. Earthbound efforts have yet to yield many definite conclusions. Satellites, we are led to believe, are exactly the high-tech ocean watchdogs that we need. They can see everything over the entire globe. They help find hurricanes where no ship-board weather observers exist. Surely they can find plumes of pollution where no EPA or Coast Guard observers are sailing.

Unfortunately, too many policy and decision makers are victims of false perceptions about satellite capabilities that circulate in the media, in the Congress, even among some scientists on the periphery of ocean studies.

Misconceptions about satellite capabilities in general, and remote sensing from space in particular, are not limited to national tabloids. Here are some examples of things NOAA satellites can not do that were legitimate requests from our constituents:

- Identify earthquakes
- See the mid-air explosion of an Irish jetliner
- Identify the vessel which cast off a lifeboat of refugees near Newfoundland in 1986
- Witness illegal refuse dumping
- See the Statue of Liberty unveiling fireworks display
- See Halley's Comet
- See Skylab reenter the atmosphere
- Identify fields of marijuana

The tenth anniversary of the current series of NOAA operational polar-orbiting satellites, TIROS-N, is a good time to re-examine satellite remote sensing for ocean applications and to set the record straight about satellite capabilities.

SATELLITE-DERIVED SEA SURFACE TEMPERATURES

Origins. The reason for attempting oceanography from space in the first place was to improve weather forecasting. Several patriarchs of numerical weather forecasting had long pointed out that the modelling of air-sea interaction was essential for good numerical weather prediction. [7] The conventional ship and buoy network was hopelessly inadequate in depicting the thermal properties of the earth's enormous ocean surface. [10]

In the late 1960s, thoughts in weather forecasting circles turned to satellites as potential sea surface temperature (SST) observers. [5,8] Polar-orbiting spacecraft were perfect in that they provided global coverage of the global ocean. (Figure 1)

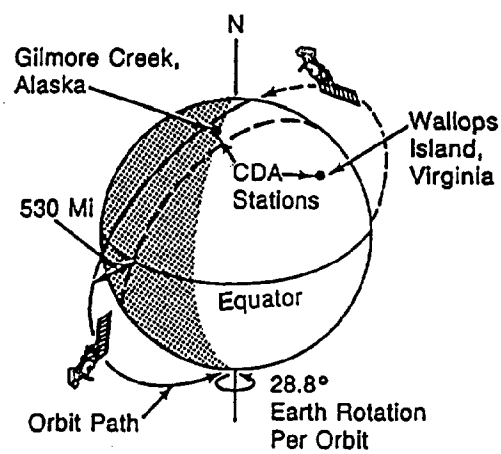

Figure 1. Configuration of sun-synchronous polar-orbit used by NOAA's TIROS-N series of environmental satellites.

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Planners for the 1968 Carribbean-Atlantic atmospheric research experiment, BOMEX, speculated that satellites "may prove almost as useful as ships for the synoptic data needed for environmental predictions." [5]

Other scientists were quick to point out that the utility of satellite-derived SSTs would extend to the maritime industry, particularly to fishing. [6]

The First Practical Applications. The distance between a weather satellite in orbit and the surface of the sea or the deck of a fishing boat loaded with albecore has decreased over the past two decades, figuratively speaking. In 1966, when some NASA researchers first looked at crude SST fields derived from their Nimbus II spacecraft, the captain of a Starkist Tuna boat or an Exxon tanker would have dismissed remote-sensing satellites as toys for white-collared, slide-rule-toting physicists hunkered over light tables in some back-East research lab. (Figure 2)

However, in 1975, a fleet of eleven Exxon tankers was used to prove the benefit of using satellite current analyses for navigation. Five of the ships received satellite-derived maps of the Gulf Stream and were told to use them for routing from the Gulf of Mexico to the Northeast. The other six did not receive them and navigated by customary means. The savings were significant: Exxon estimated that 31,500 barrels of fuel oil per year could be saved by its fleet of 15 tankers using satellite data to find the stream northbound and avoid it southbound. [3]

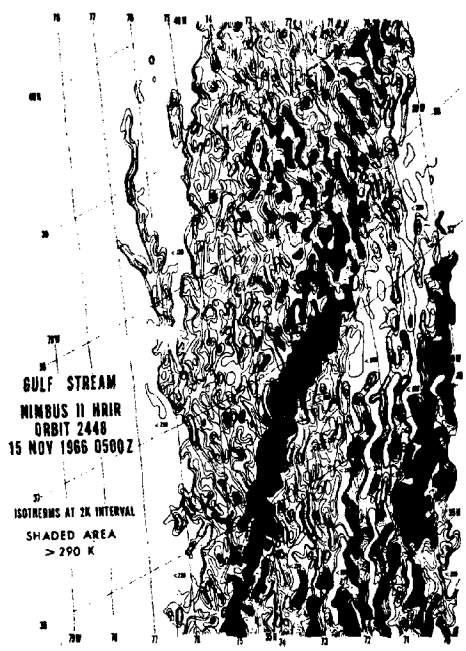

Figure 2. Earliest satellite-derived SST fields, like this one along the East Coast from NIMBUS II data, were of little operational use; the views were distorted and lacked adequate cloud and atmospheric moisture corrections. (From Rao, 1968 [7])

As for the fisherman, the success stories are many. Entire fleets now rely on satellite-derived ocean thermal boundary charts, radioed from the National Weather Service or private consultants, to save fuel and increase catches by identifying the most likely areas of high fish concentration. Satellite-derived sea ice charts, used primarily by the Navy, are also being received by fishermen in Arctic regions.

Although NOAA had been producing satellite and ship-based ocean current analyses for the National Weather Service operationally since 1973, it was with the 1978 launch of the improved "third generation" polar-orbiting satellite, TIROS-N, that satellite oceanography came of age. The sensors were higher resolution and less noisy. The spectral response and calibration were better, allowing for more accurate retrievals that accounted for atmospheric effects. Computer power had increased substantially, too, allowing for more timely fields on finer (as low as 14 kilometers) grids in numerous regions globally. Global distribution of analyzed satellite SST maps burgeoned, and a greater variety of users, commercial and government, research and operational, began receiving them on a subscription basis. By 1981, the National Weather Service Forecast Office at Redwood City, California, had added locally-derived satellite-based thermal boundaries to their twice-weekly Pacific sea-surface analysis. [3] In 1983, further improvements in accuracy were wrought by a new multi-channel SST algorithm using all infrared bands of the newest version of NOAA's Advanced Very High Resolution Radiometer flying on NOAA-8.

OPERATIONS VS. DEMONSTRATIONS

By early 1983, some five years into the TIROS-N program, and hundreds of millions of SSTs, thousands of upwelling boundary charts, current analyses, and sea ice maps later, the following uses of satellite observations for operational purposes were well established:

- SSTs globally for input to weather modelling
- SSTs for local weather forecasts
- Ocean thermal boundary analyses for fishing, ship routing, search and rescue missions, sailing races, offshore oil and mineral production
- Ice boundary analyses over oceans and the Great Lakes for the Navy and commercial shipping

For experimental purposes, these other applications had been at least demonstrated:

- Wetland habitat change monitoring
- Oil spill tracking
- Sedimentation of river deltas, estuaries, sounds
- Marine-mammal habitat surveillance
- Pollution plume surveillance

Clearly the most significant contribution of oceanography from space had been and continues to be radiometric thermal analysis. [9] The highly publicized, ongoing NOAA investigation of the 1987 Carolina Red Tide event uses a satellite-based SST analysis as a focus for forwarding the idea of operationally monitoring for such events in the future; it was not direct space-based observations of Red Tide, but observations of extraordinarily warm filaments of water breaking away from the Gulf Stream near Cape Hatteras that propelled this investigation.

But, what put the brakes on furthering other demonstrated applications, like those listed above, and kept us from

developing them into operational programs?

The Oil Pollution Example. We have looked at pollution from space. Point source and non point source pollution has been identified from TIROS-N series and Landsat satellites. Two general criteria must be met to identify ocean pollutants from these spacecraft: 1) the pollutant must cover a large enough area -- more than the 1.1 kilometer square pixel in the case of the TIROS-N sensors, and 2) the pollutant must be of a different reflectivity or have significantly different thermal or spectral properties than the surrounding water mass. (A third criteria, frequent repeat viewing, must be met for successful source identification of point-source pollution.)

Plumes of turbid water are relatively easy to discern. But, identifying slicks of floating plastics in well-mixed water is virtually impossible. Landsat has seen acid iron waste plumes from vessel dumpings because of their spectral difference from sea water. Oil spills have been seen on many occasions because they alter the reflectivity of the surface. [4]

Oil spill detection and tracking from space, however, have been limited in an operational sense. The world's largest oil spill, originating from a blown-out platform in the Gulf of Campeche in 1979, offered the chance to use multiple space platforms to track an oil slick with mixed success. While a post-analysis of nearly six months of Landsat imagery left no doubt that oil washing ashore in Texas was indeed from Campeche, sensor resolution, sun-angle variations, and cloud cover limited the usefulness of imagery from NOAA satellites for accurate tracking. [4]

THE REAL LIMITATIONS

Orbital Problems -- Repeat Views. Satellites in polar orbit can see the entire globe. The benefit of making these orbits sun-synchronous means a constant sun angle for image comparisons. The frequency of repeat viewing is dependent upon the width of the swath over the the ground viewed by the sensors, as well as the altitude and inclination and procession of the orbit. In general, higher resolution means a narrower swath which means a less frequent repeat view for a given point on the ground. Lower resolution means a larger swath can be sampled and the repeat view is more frequent. (Figure 3)

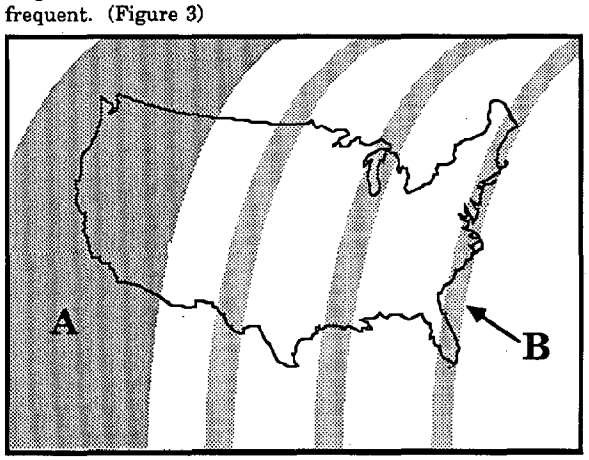

Figure 3. Narrow orbital coverage swaths (A) of most high-resolution satellite sensors in polar orbit yield less frequent repeat views. Wider swaths (B) of the NOAA TIROS-N series afford repeat viewing of any point twice daily at a lower resolution (1.1 km).

For example, the NOAA TIROS-N series repeats a view twice each day--once in darkness, once in daylight--and has a resolution of 1.1 kilometers. Landsat, with a much better resolution of thirty meters, repeats a view only every sixteen days.

An orbit inclined to, for instance, 40 degrees to the equator will offer a more frequent view and could be set up to afford a high resolution view, but would not be sun-synchronous. In addition, its repeat cycle would be an irregular pattern.

Cloud Climatology - A Hard Reality. One problem too frequently overlooked is that most weather instruments on satellites were designed to look at clouds, not through them, and the Earth is a cloudy planet. Passive microwave sensors can detect surface properties where there are clouds, but the resolution of current microwave instruments is far too coarse for many detailed oceanic applications, except for ice determination. For visible and infrared surveillance considerations, U.S. satellite users must contend with a rather cloudy EEZ. During a relatively clear month, climatology shows that, over New York Bight for instance, skies are less than one-fourth cloud covered only about 40% of the time; clear skies account for only about 15% of all observations. [12] Some 200 miles off San Francisco, the odds decrease to 29% and 9%. [12] In the famous "Doughnut Hole" of the Bering Sea, the numbers drop to a dismal 6% and 2%. [2] (Figures 4,5,6)

OTHER SATELLITE SYSTEMS AND SENSORS

Landsat. The Landsat system, originally a NASA research program, was turned over to NOAA for operations in the early 1980s. With a thematic mapper sensor resolution of 30 meters, and a multispectral scanner resolution of 80 meters, it held the promise of sea-surface and coastal scrutiny from space. If NOAA weather birds and NASA research spacecraft were sentinels in the guard tower, Landsat would be the spy, it was thought. But, though many ocean-related investigations utilized high-resolution, multispectral imagery from Landsat, too few of them demonstrated the applicability for an operational program. The reasons are painfully simple: Landsat has a sixteen day repeat cycle versus twice-daily for the NOAA polar orbiters. Even the addition of a second Landsat would reduce the repeat view to only eight days. In addition, the higher resolution of Landsat data means a smaller areal coverage, and a much greater data processing volume and cost for viewing a TIROS-N-sized swath portion. Processing time for Landsat is much longer, too, with a twenty-four hour turnaround about the best possible (compared with an hour or so for the TIROS-N series).

Ocean Color. Coincident with the advent of TIROS-N was the NASA research mission satellite, NIMBUS VII. Onboard was the first coastal zone color scanner (CZCS) -- an instrument designed to reveal biological activity near the ocean surface. CZCS showed color variations linked to seasonal blooms of algae, and nutrient variations on upwelling boundaries in the open ocean, sounds, and estuaries. Researchers had a field day intercomparing CZCS fields and satellite temperature data from TIROS-N. In the remarkable 1982-1983 El Nino, CZCS data showed biological changes in areas of unusual surface warming along the Pacific Coast.

A new ocean color instrument called SeaWiFS (Sea Wide Field Sensor) is scheduled to fly on the Landsat 6 satellite, slated for a 1991 launch.

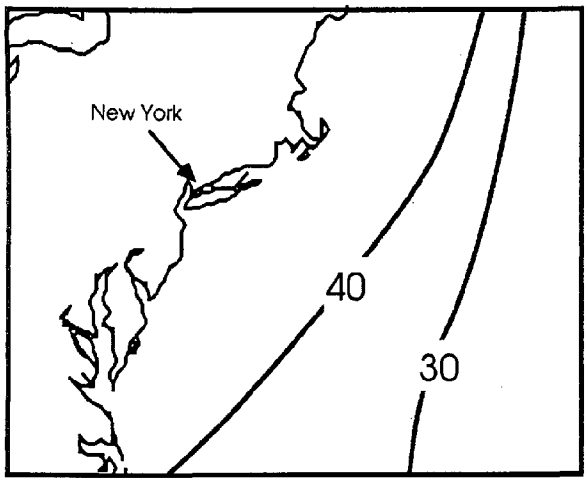

Figure 4. Clouds hamper routine monitoring of small scale ocean events from space. Contours show percent of time sky is less than one-quarter cloud covered -- October ("clear" month) -- New York Bight.

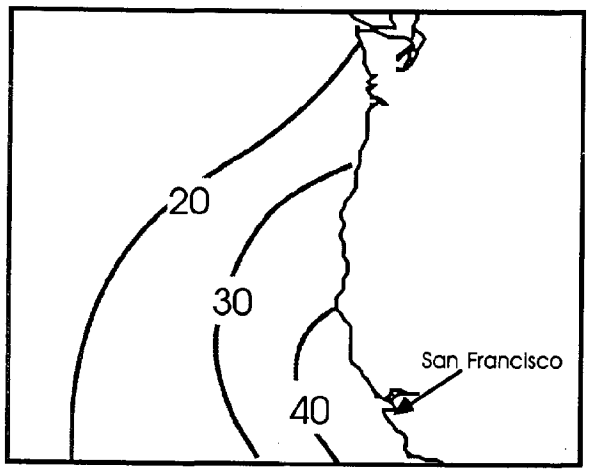

Figure 5. Same as Figure 4 for West Coast.

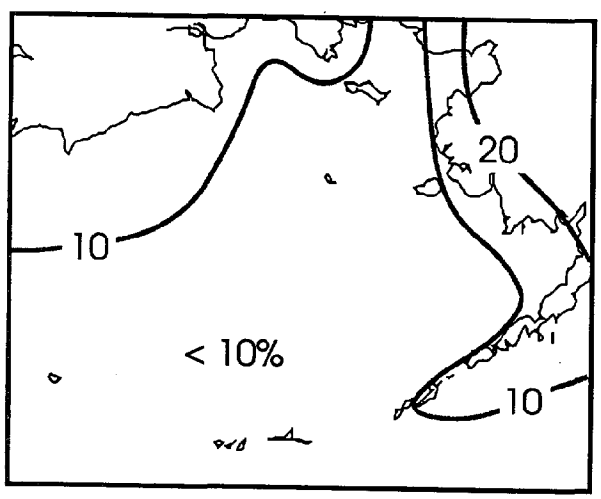

Figure 6. Same as Fig. 4 for Bering Sea & "Doughnut Hole."

Radar. Besides passive microwave, the limitations of which have already been described, what satellite-borne sensor could aid in piercing clouds? The only unclassified answer to date is radar -- specifically, synthetic aperture radar (SAR). SAR, with a resolution of as little as 25 meters, has been shown to be able to detect ships and ship movements. The ships themselves appear only as quasirectangular blips on the SAR image. The data processing volume of SAR data, a research version of which flew on SEASAT in 1978, is enormous. Turning the raw data into a product in time to be useful for enforcement or surveillance purposes is unlikely, and has yet to be demonstrated. Moreover, SAR instruments are big and expensive. A NASA SAR will probably fly on the polar platform of the late 1990s. The European Space Agency's ERS-1, slated for a 1990 launch, will carry a SAR. NOAA will process limited ERS-1 SAR data through a direct readout station in Alaska.

SAR, as well as similar radar instruments like the space shuttle's SIR (Shuttle Imaging Radar), do provide exciting new ocean-surface observations which have yet to be thoroughly exploited. Space-based radar holds the promise to bear plenty of ocean-dynamics-research "fruit" in the next decade.

Other space-borne instruments, like scatterometer and the radar altimeter (both on SEASAT) will be flying on the polar platform, and will add much to ocean flux studies and other research experiments geared toward identifying global change processes.

SUMMARY

Remote sensing from space is not the solution to numerous nagging ocean-related problems, specifically in certain programs of surveillance and enforcement. Future systems for ocean color and radar imaging, experimental versions of which have already flown on research spacecraft, will spur more investigations aimed at developing programs to monitor and protect the oceans and coasts. But, today's real limitations related to orbital cycles, cloud climatology, and data processing will not go away.

Remote-sensing satellite capabilities should be better understood by policy and decision makers, and others on the periphery of ocean sciences. Applications of satellite oceanography, which came of age ten years ago with the advent of the TIROS-N series of satellites, are critical elements of various marine programs today.

Exploiting the existing systems, recognizing the limitations, and developing plans to use proposed sensors are the keys to realistic satellite ocean programs in the future.

ACKNOWLEDGEMENTS

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MONITORING THE ESTUARY

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ABSTRACT

The importance of estuaries cannot be over stressed because of their tremendous biological productivity and proximity to centers of commerce and population. Most of the shellfish and much of the finfish consumed by man are harvested from bays. Definitive monitoring is crucial to restore the national resources. Enhanced monitoring will allow for sufficient data to make valid management decisions.

1. INTRODUCTION

The environmental quality of major U.S. estuaries today when compared with historical accounts of 2-3 hundred years ago leaves something to be desired. Today, the greatest population densities are located in the estuarine environments. The large magnitudes of people have resulted in intensive uses of the estuaries. Agriculture has been the backbone of bay area economies. Poor farming techniques have caused water pollution through erosion, siltation, and chemical runoffs. Industry took a back seat to agriculture for decades, but now it rivals. Industrial water use contributes to bay pollution; waste water from treatment plants and effluents from power plants are getting increased attention as sources of trouble for bay life. Sedimentation in the estuaries - the process of deposit of material from the land into the bays by the tributaries - has been increased by the activity of man: e.g., sprawling housing complexes, massive highway networks, large industrial parks, and shopping centers. All of this denuding of natural vegetation and laying bare of the soil surface has created greater runoff. In terms of volume, sedimentation ranks above domestic sewage, industrial wastes, and chemicals as a major cause of water pollution. These and other disconsonant uses have resulted in degraded environmental quality and consequently there has been substantial reductions in living marine resources. Capt. John Smith, in 1608, wrote about the Chesapeake Bay, "a country that may have the prerogative over most places known, for large and pleasant navigable rivers, heaven and earth never agreed better to frame a

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place for man's habitation." Smith and the early settlers praised the clarity of estuarine waters as well as the bounty of the living resources found.

The estuaries after more than 10,000 years of developing into major and generous resources, and after neglected and taken for granted for the last 200-350 years without proper management, are finally getting the attention of some. "Save the Bay" organizations around the country are poised to clean up the estuaries. A vast range of citizens, farmers, educators, researchers, resource managers, legislators, and governors will use monitoring information to answer questions and solve problems about the estuaries.

2. CHESAPEAKE BAY PROGRAM

The Chesapeake Bay Program (CBP) may serve as a benchmark program for other estuaries. The achievements and experiences of the CBP may be emulated by other regional estuarine programs. In 1976, Congress directed the U.S. Environmental Protection Agency (EPA) to conduct a 5-year, $25 million study of the Chesapeake Bay. The CBP established a Chesapeake Bay Monitoring Plan.

The monitoring program/plan was designed to provide, initially, a sound "base-line" or characterization of the health of the Bay, which can then be used to document the response (hopefully improvement) of the system to the many abatement actions planned by State and Federal governments. This documentation process has been the principal emphasis of the program. Both the initial establishment of base-lines and the ongoing monitoring program are predicated upon a long-term commitment that will ensure consistent data covering many years. Emphasis has been placed on obtaining high quality data that can serve reliably to document changes in the system over time, taking into account natural year-to-year variations. Estuaries typically show seasonal and annual differences which reflect meteorological and hydrological patterns as well as cyclic phenomena which may cover a number of years. This kind of information is essential to provide a clear record of the impact that Federal and State governments' remedial programs, both current and future, have on the Bay. (CBP Monitoring Subcommittee, 1985).

The CBP Study, which was directed in 1976, was completed in 1983. The study identified 10 primary water quality problems of the Bay, and chose three critical areas from the ten to receive intensive investigation: nutrient enrichment, toxic substances, and the decline of submerged aquatic vegetation. The major findings of the Bay Program

were:

o SUBMERGED AQUATIC VEGETATION (SAV) HAS DECLINED THROUGHOUT THE BAY. The loss of submerged aquatic vegetation appears to be most severe in the northern Bay and western shore tributaries.

o OYSTER SPAT SET HAS DECLINED SIGNIFICANTLY IN THE PAST 10 YEARS, particularly in the upper Bay, western tributaries, and some Eastern Shore areas such as the Chester River. Trends in oyster harvest show a similar pattern.

o LANDINGS OF FRESHWATER-SPAWNING FISH, SUCH AS SHAD, ALEWIFE, AND STRIPED BASS HAVE DECREASED IN RECENT YEARS. Spawning success of these and other semi-anadromous or anadromous species has also been fair to poor in most areas sampled. Harvests of marine-spawning fish, such as menhaden, have generally remained stable, or increased.

o LEVELS OF NUTRIENTS (PRIMARILY NITROGEN AND PHOSPHORUS) ARE INCREASING IN MANY AREAS OF THE BAY, LEADING TO DECLINING WATER QUALITY. Nutrient enrichment is most severe in the northern and middle Bay, and upper reaches of tributaries and large algal blooms have been observed. Only parts of the Potomac and James River, and some smaller areas currently exhibit improving water quality with regard to nutrients.

o THE AMOUNT OF BAY WATER SHOWING LOW (OR NO) DISSOLVED OXYGEN IN THE SUMMER IS ESTIMATED TO HAVE INCREASED 15-FOLD IN THE LAST 30 YEARS. Currently, much of the water deeper than 40 ft., plus or minus, is anoxic from early mid-May through September in an area reaching from the Bay Bridge to the Rappahannock River.

o ELEVATED LEVELS OF HEAVY METALS AND TOXIC ORGANIC COMPOUNDS ARE FOUND IN BAY WATER AND SEDIMENTS. Highest concentrations occur near urban or industrialized areas, and in the upper Bay. Some of the toxicants are being bioconcentrated by plankton, shellfish, and finfish. (EPA, 1983).

These findings strengthened the recognition that because of the historical decline in the living resources of the Chesapeake Bay, a cooperative approach was needed. The Chesapeake Bay Agreement of 1983 was signed in 1983, by the EPA Administrator, Governors of the States of Maryland, Pennsylvania, and Virginia, and the Mayor of the District of Columbia, to fully address the extent, complexity, and sources of pollutants entering the Bay. In addition, Memorandums of Understanding (MOUs) were established between EPA and the U.S. Army Corps of Engineers, the U.S. Geological Survey, the Soil Conservation Service, and the National Oceanic and Atmospheric Administration (NOAA). These MOUs established the participation of these

Federal Organizations in the management of the Chesapeake Bay Program. Under this institutional framework, the 1985 Restoration and Protection Plan was developed to "Improve and protect the water quality and living resources of the Chesapeake Bay's ecological integrity, productivity, and beneficial uses and to protect public health" (CBP Executive Council, 1985). This plan has been implemented through the commitment of Federal, State, and Local governments, public and private entities, and citizens. The plan was structured to address the following goals:

o Nutrients:

Reduce point and non-point source nutrient loading to attain nutrient and dissolved oxygen concentrations necessary to support the living resources of the Bay.

o Toxics:

Reduce or control point and non-point sources of toxic materials to attain or maintain levels of toxicants not harmful to humans or living resources of the Bay.

o Living Resources:

Provide for the restoration of living resources, their habitats, and ecological relationships.

o Related Matters:

Develop and manage related environmental programs with a concern for their impact on the Bay.

o Institutional Management:

Support and enhance a cooperative approach toward Bay management at all levels of government.

Each year since the Agreement of 1983 was placed into effect,the CBP Executive Council has reviewed the progress toward achievement of the set goals. CB research, assessment, management, and of course, monitoring, were examined for successes. These initiatives clearly indicated the complexity of the Bay's ecosystem and the parallel difficulty in attempts to understand it. Nevertheless, in-depth monitoring interpretations and correlations enabled the linkages between problems and their causes to become increasingly clearer during the course of the CBP study: (1) Pollution activities occur throughout the drainage basin affecting water quality in the tributaries and the Bay; (2) Degradation of the Bay's water and sediment quality, in turn, has affected the living resources; and (3) Declines in living resources have been paralleled by changes in water quality which include increases in nutrient concentrations, chlorophyll a, turbidity, and toxic chemicals/metals, and decreases in dissolved oxygen.

The adoption of these findings resulted in enhancement of programs to reduce and control nutrient loadings to the system. Further, regulation of toxic contaminant loadings were enforced more rigidly. Stormwater management and the installation

of best management practices for agricultural and urban lands reduced the flow of toxic substances and nutrients. Improved monitoring has increased the understanding of the fate and effects of toxic materials and ability to determine the levels which are not harmful to humans and the living resource. Continuation of enhanced monitoring programs is necessary to provide answers to the remaining research and management questions.

A few hopeful signs should be noted. Submerged aquatic vegetation (SAV) beds are coming back strongly. SAV are important habitat for fisheries and waterfowl; this could lead to increased living resources in the future. Ospreys and eagles are rebounding. The "rockfish" appears to be benefiting from recent protective regulations, and there is optimism about the hatchery release program. Although the shad, river herring, yellow perch, and oyster remain at all-time lows, the blue crab is still abundant. The upper Potomac estuary has recovered partially and is attributed to the control of point sources, particularly at the regional wastewater treatment plants, e.g., Blue Plains.

In December 1987, a new Chesapeake Bay Agreement was signed which committed the signers to a detailed set of goals and objectives including a timetable for the development of specific Bay-wide management plans. The centerpiece of the Agreement is the commitment to achieve a 40% reduction in total nitrogen and total phosphorus inputs to the Bay by the year 2000, an ambitious target by any standard. Emphasis is now being placed on living resources' needs in the Bay ecosystem. Previously, the highest priority was restoring water quality. This Agreement calls for emphasizing improvements in living resource habitats, of which the water column is a key component.

3. WHY MONITOR?

Monitoring by itself will not solve the estuarine problems but it can provide data that will answer or contribute to answering some key questions:

o Is the anoxic region increasing over the long-term?

o Are submerged grasses recovering or continuing to decline?

o Are stocks of anadromous (river spawning) fish decreasing or increasing?

o How are oyster and other shellfish stocks changing?

o Are nuisance algal blooms worsening or improving? Are they occurring near sources of nutrient loading?

o Are bay waters becoming turbid, or clearer over time?

o What are the levels of specific toxic compounds in the estuary and in bottom-dwelling organisms? What is happening to

these compounds?

o Are pollutant load reduction programs improving the quality of receiving waters? Locally? In the tributaries? Bay-wide? What is the response time?

A monitoring program must accumulate a number of year's data before statistically supportable interpretations can be made on water quality and living resource trends. At the same time, we may also gain short-term insights into how water quality responds to local intensive cleanup activities, and improve our ability to interpret the effects of short-term phenomena such as storms and drought. It is important that we learn how to interpret long-term trends against the background of short-term interference.

4. OBJECTIVES FOR A MONITORING PROGRAM

An analysis of existing estuarine data and its availability for most troubled estuaries reveal numerous problems: (1) Because of gaps in the historical data bases, trends (temporal and spatial) are difficult to detect; (2) Water quality and living resource data surveys were not planned in concert which make correlations hard to achieve; (3) Often, monitoring sites were not planned with the total estuary as a concern, e.g., only a tributary might be surveyed for a particular reason; (4) The integration of monitoring programs and research programs was nebulous; (5) Data quality assurance and uniformity of sampling and analysis procedures are lacking which result in error uncertainties; and (6) Coordination and communication among the agencies, scientists, and managers were absent which indicated no commitment toward regional comprehensive data management.

These problems will be solved greatly if strong objectives are accomplished:

o <u>Describe and track long-term trends:</u>

Monitoring should be done in an uninterrupted fashion for at least 15-20 years, for the value lies in longevity.

o <u>Characterize the estuary</u>:

If longevity is maintained, the long-term trends will be detected on a seasonal basis. Calculation of means and estimation of variability may be associated which will enable the determination of how a bay may respond to new stresses or the remedial action to take place. Accurate assessments are fundamental.

o <u>Assure a bay-wide perspective:</u>

The estuary should be dealt with in an holistic fashion because it is a singular ecosystem associated with inter-connected subsystems ranging from the fresh water ongoing and future scientific studies. Data should support research and modeling which will enable hindsight and predictability.

o <u>Establish a monitoring network</u>:

Mechanisms should be developed to assure the development of a data base that cuts across all disciplines. The holistic

perspective should be maintained. The scientific community and estuarine users should have rapid access to monitoring data. All should be committed to an integrated approach which allows the synthesis of comprehensive and confident interpretation of biological, physical, and chemical data.

5. CONCLUSION

The continuing and often disconsonant uses of the estuary cause modification in environmental quality which affect natural resources, human health, and/or the quality of life. Development of monitoring strategies that lead to improved use of the Nation's bays requires a body of useful and reliable information about ambient conditions in these environments. This information, in turn, must be based upon systematic monitoring if trends in environmental quality are to be detected. Comprehensive long-term observations are necessary for promulgation of effective estuarine restoration, protection, and preservation initiatives.

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CLIMATE, WEATHER, AND COASTAL RECREATIONAL GROWTH IN THE SOUTHEAST U.S. IN 1986

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ABSTRACT

Along the Southeast Atlantic coast of the U.S., attractiveness of climate and an ocean setting highlighted by a string of barrier islands and sandy beaches have drawn large numbers of people not only to visit but also to become permanent residents of the coastal zone. This expansion has been part of the increasing demand for outdoor recreation, the national movement toward the coasts, and other economic factors including overall growth in the Southeast. However, weather in any one year may stimulate or curtail recreational activities and, as in the case of destructive hurricanes, interrupt short-term recreational and residential development in a specific locality. This paper analyzes the relationship between climate and long-term recreational development along the Southeast coast. Then, using 1986 as the study year, the paper assesses short-term weather impacts on recreational usage and related development in the Southeast coast zone.

Introduction

The four Atlantic coastal states of the Southeast U.S. are enjoying population growth rates above the national average. In the period 1980-86 Florida population grew by 19.8 percent, Georgia by 11.7 percent, South Carolina by 8.2 percent, and North Carolina by 7.6 percent. The average U.S. percent change was 6.4 percent. While a variety of economic factors have stimulated growth in the Southeast, a benign climate which supports both business activities and recreational lifestyles is frequently cited one of the strongest factors in the expansion.(1) The growth of the Southeast is predicted to continue into the 21st century.(2)

Coastal areas, including the recreational areas around estuaries, have become popular vacation spots and are a particular source of climate-related growth in the Southeast. Beaches and an ocean setting draw people to the coasts. Beaches have been cited by Florida visitors as the number one reason they travel to the state.(3) Coastal recreational parks with beaches typically draw more visitors in a given period than those without them (see below, National parks and State parks). A climate that supports recreation or being outdoors most of the year is particularly sought by people investing in second residences and by retirees seeking homes that allow them the maximum opportunity for leisure living. The significance of an aging population with retirement security to this type of recreational/residential development has been pointed out by students of population dynamics and recreational demand.(4)

Recreational Climate of the Southeast

The temperature regime of the south Atlantic coast varies from temperate in the northern part of the area to subtropical in the southern part to tropical in the Florida Keys.(5) The gradation of temperatures from north to south is regular, increasing with decreasing latitude. Another interesting variation is the general modification of the ocean and coastal temperatures on each other. Along the coast the sheltered land weather stations typically record warmer summer temperatures and cooler winter temperatures than do stations located on exposed points.(6)

Figure 1 presents normal monthly mean air

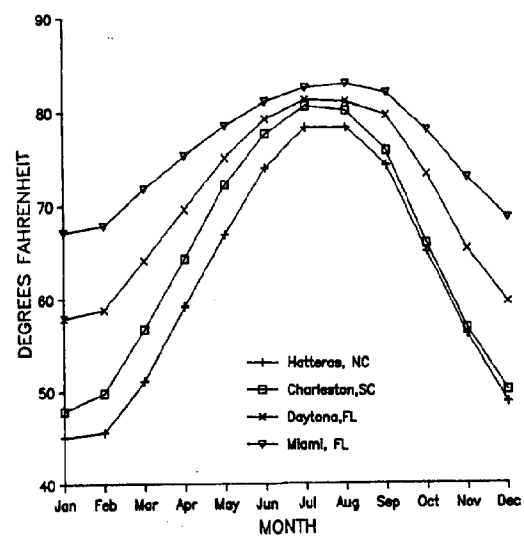

Figure 1. Normal monthly air temperatures (°F), 1951-80, selected Southeastern coastal stations. Data from National Climatic Data Center, NOAA.

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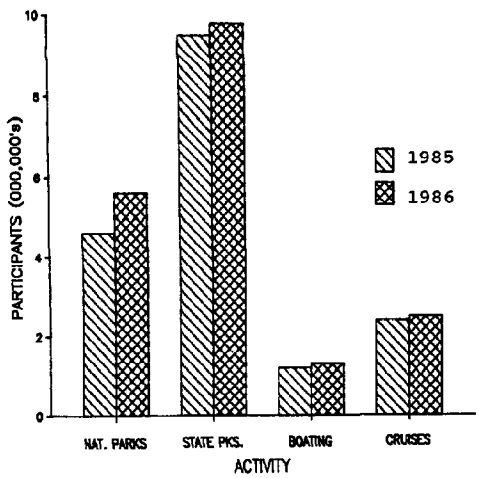

Figure 3. Leading recreational indicators, Southeastern coastal area, 1985 and 1986. Data from National Park Service; NC, SC, GA, and FL Parks Departments; U.S. Coast Guard; and Port of Miami, FL.

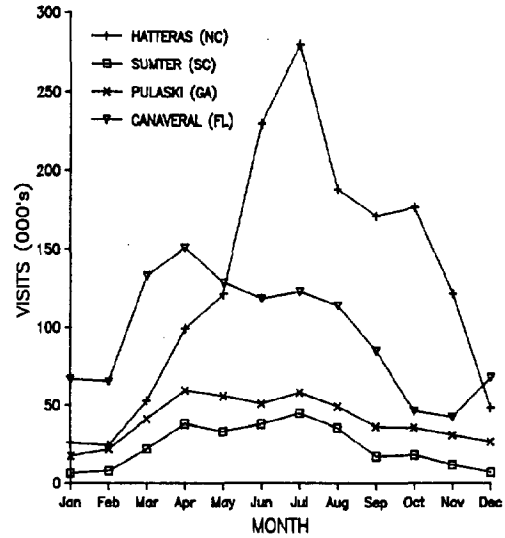

Figure 4. Monthly attendance at selected national parks along the Southeastern coast, 1986. Data from National Park Service.

was 5.4 million visitors compared with 4.6 million visitors in 1985. The strong rise over 1985 in visitor attendance at coastal national parks sampled for this study was led by Wright Brothers National Memorial (41 percent increase), which is located near Cape Hatteras National Seashore (25 percent increase), and Canaveral National Seashore (22 percent).

Four national parks in the Southeastern region were selected to examine seasonal patterns of attendance at various locations the coast. In general, these seasonal patterns are the same from year to year, although weather or important events in any location may alter them somewhat. At three of the four selected locations in 1986 these patterns were maintained. Cape Hatteras National Seashore, the northernmost of the parks selected, experienced modestly rising attendance in March and April which accelerated to a peak in July. By October attendance had dropped back by a third before dropping sharply in the winter months. Canaveral National Seashore, located midway on the Atlantic coast of Florida, had some of its lowest attendance of the year in the cooler months of January and February. Visits to the seashore rose sharply in March and reached a peak in April, the height of the Easter vacation season. Attendance then dropped slightly in May and remained at about the same level over the summer months until dropping over the fall and winter months. This pattern was somewhat different from other years when high attendance was achieved in the summer rather than the spring. This change of pattern may be attributed to increased attendance at the Kennedy Space Center, which is near Canaveral Seashore, due to expanded interest in the space program following the Challenger space shuttle disaster of January. Fort Sumter near Charleston, SC, and Fort Pulaski in Georgia, both of which are located in the mid-temperature range of the Southeast coast, experienced high attendance months from April through August (Figure 4).

State parks. The slightly warmer, drier weather in coastal areas in 1986 had a positive effect on state park visits in three of the four Southeastern states (Table 1). Florida's Atlantic

Table 1. Annual visits, selected Southeastern coastal state parks, 1985 and 1986. Data from NC, SC, GA, and FL Parks Departments.

State	Attendance 1985	Attendance 1986
North Carolina	1,609,694	1,748,151
South Carolina	3,336,616	2,804,724
Georgia	330,311	370,502
Florida	4,258,173	4,838,738
Total	9,534,794	9,762,115

coast parks experienced a 14 percent rise in visits in 1986 over those in 1985. The increase in Georgia in state park attendance was 12 percent and in North Carolina it was 9 percent. Only in South Carolina, where the adverse effects of the drought that began in early spring and lasted through the fall were felt strongly, did state park visits actually decline. Here the drop in 1986 visits from 1985 was 16 percent. Myrtle Beach State Park, which is by far the South Carolina state park with the largest volume of annual attendance, also had the largest decline from 1985--23 percent. Park officials believe that the decrease in state park attendance was due not only to drought conditions in the state but also to publicity about the event. Media stories about the drought carried to other areas from which the Myrtle Beach area draws tourists. Worries about the availability of water

temperatures for four selected coastal stations in the Southeast. The range of air temperatures suggests that even in the area of the northernmost station of Cape Hatteras, NC, outdoor recreational activity is possible from March on and certainly on the warmer days in January and February. The strong relation between the moderate climate of the Southeast coastal zone and recreational usage has been pointed out in climatologies of the four states.(7)

Water temperatures of about 65°F can support some recreational swimming activity for brief periods while temperatures of 70°F will be found more comfortable by most swimmers.(8) Figure 2

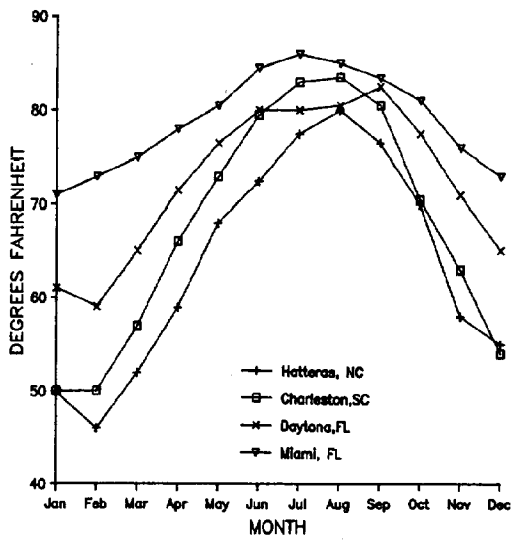

Figure 2. Monthly surface water temperatures (°F), 1974-81, selected Southeastern coastal stations. Data from National Oceanographic Data Center, NOAA.

depicts monthly surface water temperature profiles for four beach locations in the Southeast, the same areas used in the air temperature profiles. The surface water temperatures south of Cape Hatteras are directly dependent upon seasonal air temperatures as is indicated in the correspondence of the two sets of profiles. During winter surface water temperatures decrease from the relatively warm Gulf Stream toward the shelf. In spring the gradient weakens until summer when it largely disappears.(9) Because of the influence of the Gulf Stream, beaches along much of Florida's Atlantic coast are suitable for recreational swimming most of the year. But at any location along the Southeast coast, when the water is not warm enough for short swims, a walk along the beach or a visit to a beachside park may utilize the ocean setting.

Population Growth in Coastal Counties

Population growth in coastal counties continued in 1986 and an analysis of this growth is an indicator of the significance of recreation in the development picture. In North Carolina population growth in Carteret and Brunswick Counties between April 1, 1980 and July 1, 1986 was up 23.8 and 32.6 percent, respectively, far exceeding the state average population growth of 7.7 percent for the period. Both of these counties are popular beach and fishing areas. In South Carolina the figures for coastal-county growth in the same period show a similar increase. The coastal counties of Beaufort, Berkely, Dorchester, and Horry experienced 27.1, 30.6, 28.1, and 28.8 percent growth rates, respectively, while the average state growth rate was 8.2 percent. Beaufort County is the location of Hilton Head Island, a vast leisure-retirement-recreational complex, and Horry is the location of the popular Myrtle Beach recreation area. Horry and Beaufort Counties were among the three top gainers in population in the state, each with an increase of 29,000 persons for the period. Florida continued to have strong growth along the coasts and in the interior. The state's growth even in the interior is strongly tied to climate and recreational development along the coasts. In 1986 Palm Beach County on the Atlantic coast had the largest numerical gain in population in the state, 178,000 persons, and a growth rate of 31 percent compared to a state rate of 19.4 percent.(10)

Weather Impacts on Recreation in 1986

Impacts on Participation

In 1986 the Southeast experienced the worst drought since precipitation records began in 1876.(11) The drought started in December 1985 and intensified through the first five months of 1986. Overall, the Southeastern states had a warmer-than-normal year, although for Florida the increase was not as great as that for other states. Air temperatures during 1986 averaged from less than 1°F above normal at several stations in coastal Florida to nearly 3°F above normal in Charleston, SC, and Savannah, GA. Coastal areas did not experience drought to the same degree as inland areas. Negative rainfall departures from normal were significantly greater for longer periods of time for inland weather stations than for those along the coast.(12)

Leading recreational indicators for the Southeast region (Figure 3) show expansion in recreational activities in 1986 despite the drought. Indeed the warm, dry weather may have been a factor in the this expansion. The only measured negative impacts on coastal recreation noted related to the drought were in South Carolina. National park visits rose by about 20 percent for the region from 1985 to 1986. State park visits rose throughout the region by 2 percent despite a large decline in South Carolina attributable to the drought conditions beginning in the spring. A January freeze in northern Florida had minor impacts on recreational usage. Boating registration rose a strong 9 percent. Number of cruise passengers carried from/to Port of Miami rose 6 percent.

National parks. At ten Atlantic coast national parks in the Southeast attendance in 1986

might have been a concern of potential tourists. The 1986 decline in South Carolina park attendance marks a departure from a long period of strong growth in their use.

Boating. A long boating season brought about by the moderate coastal temperatures, relatively calm seas much of the year south of Cape Hatteras, and the lure of good fishing enhance the attractiveness of this recreation in the region. The weather of 1986 was no impediment to this growth since there were few coastal storms during the boating season in any Southeastern coastal state. The growth of boating in the Southeast for the period 1976 to 1986 was 44 percent, or 1.5 times the national growth rate of 29 percent. Population growth and recreational development in the coastal zone contribute to this increase. Florida, one of the fastest-growing boating states in the nation, has almost half the registered boats in the Southeast coastal region. In 1986 boating registration in the region grew 9 percent over that of 1985. This was three times the national rate, but Florida boat registration grew 14 percent.

Recreational cruising. Recreational cruising involves the enjoyment of the marine environment aboard ships that might be called floating resorts. Miami, FL is the number one cruise port in the world. Miami's location near the Caribbean and the Gulf of Mexico, its year-round warm climate, and its proximity to other recreational areas have made it an attractive port for vacationers. The number of cruise passengers carried in 1986 was over 2.5 million (a round-trip passenger is counted once at embarkation and once at debarkation), which was an increase of about 6 percent over the number 1985 passengers. Port Everglades and Port Canaveral also have substantial cruise businesses. Over a half million passengers passed through each port in 1986. Cruising from Southeastern ports is an all-year recreation with the peak interest during the spring and summer. The fall months of September and October, which traditionally have the highest incidence of tropical storms in the region, are the months of lowest interest in cruising. In 1986 tropical cyclone activity which might affect these cruises did not develop.

Impacts on Beaches and Property

Coastal storms. Beach erosion is one of the most critical environmental problems along the Southeast coast. Erosion threatens the foundations of both residential and commercial property and wipes out beach areas for recreation. Coastal storms and hurricanes add significantly to this erosion problem. Tides, storm surge, and waves combine their effects when a large storm moves ashore, the elevated water levels permitting the waves to dissipate their energies high on shore. Along the Southeast coast winter storms can be very damaging.

At the end of 1986 an alignment of the sun, moon, and earth occurred at that time which is termed a "syzygy." The syzygy was predicted to result in higher-than-normal tides and the possibility of flooding of low-lying areas, particularly if a storm were to develop in this situation. A storm did develop in the Gulf of Mexico late on December 31 and subsequently moved up the Southeast coast bringing heavy destruction to beach property in South Carolina, particularly near Myrtle Beach, and moving farther north into Pender, Onslow, and Brunswick Counties in North Carolina. The estimated losses from this storm to beachfront property in South Carolina were about $13 million, not considering the erosion itself. This storm followed by only a month a December 1 coastal storm whose damage to structures and bulkheads in the Myrtle Beach area was estimated at about $3 million. This storm also moved on to North Carolina doing additional damage. Newspapers reported that in some areas of Myrtle Beach homes after these two storms were left 50 feet closer to the water than they had been in November.(13) No other storms affecting the coast during 1986 were regarded as having had significant erosion effect.

Hurricanes. Hurricanes can have devastating effects on beach areas and on residential and commercial building. Sometimes rebuilding and restoration from such damage may take several years. Such was the case with the impacts of Hurricane Hazel in 1954 which leveled Myrtle Beach, SC.

In 1986 the tropical storm season passed quietly in the Southeast. Hurricane Charley made landfall in mid-August. It had minimal strength and was the only tropical storm to be classified as a hurricane during the season. The storm crossed the Outer Banks of North Carolina on August 17. While Charley carried beneficial rains to some areas, wind damage and flooding resulted in property and crop loss damage of about $15 million and the storm was responsible for five deaths. Some of this damage was inland rather than in coastal areas. Recreational usage and property along the coast were only slightly impacted by Charley.

Conclusions

1. The trend toward expansion of recreational usage and development in the coastal zone of the Southeast is climate related and is likely to continue since population growth in the Southeast region is predicted to continue and the demand for outdoor recreation is expanding.

2. The drought, which was the major weather event of 1986 in the Southeast, did not significantly impact recreational activity along the coast. This was because the drought was not as severe in the coastal zone and because the warm, dry weather may have supported increased outdoor recreation.

3. Where impacts on recreational usage from the drought were felt in the coastal zone, mainly in South Carolina, they came, according to officials, from a secondary cause, media accounts about the event. This suggests that recreational usage is sensitive to publicity about environmental events. This conclusion is significant in

understanding the impacts pollution may have on recreational usage along the coasts.

4. A one-year study of the impact of weather on recreational usage along the Southeast coast is not sufficient to draw reliable conclusions about the significance of weather events that may span several years. This is true of the drought of 1986 since drought in the Southeast has occurred in the two succeeding years. Therefore, a useful future study would be to investigate the entire period from 1986 through 1988 to see whether repeated incidences of drought have had major impacts, either positive or negative, for recreational expansion in the coastal zone of the Southeast.

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AN INNOVATIVE APPROACH FOR THE SYNTHESIS OF LARGE OCEANOGRAPHIC DATA SETS WITH PRE-PROCESSING AND POST-PROCESSING OF AN ECOSYSTEM MODEL OF THE NEW YORK BIGHT

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ABSTRACT

Using an unambigous coordinate description of a data record in time, space and depth and the concept of simulation model output as "high frequency, synoptic" data sets , an innovative approach for the reduction of large data sets generated with simulation models has been designed for the verification of a coupled hydrodynamic and ecosystem model of the New York Bight. A synthesis of observed data from a large oceanographic data base with model data from the New York Bight ecosystem model is applied to an analysis of the large-scale 1976 anoxic event in the New York Bight.

1.0 INTRODUCTION

The increasing scientific complexity and cost implications of marine resource management issues related to waste disposal practices in estuarine and coastal ecosystems requires the use of large data sets and sophisticated methods for credible scientific evaluations of public policy options. The recent Governor's Agreement that established 40% reduction of nutrient inputs to Chesapeake Bay as a goal for the year 2000, for example, is based, in part, on the results of a complex hydrodynamic and eutrophication model and an extensive analysis of the historical data base (1). With funding from EPA, NOAA, USGS, the US Army Corps of Engineers and State agencies, large estuarine and marine environmental data sets are becoming available from a number of platforms including conventional shipboard water column sampling; *in situ* biological and hydrographic instrumentation; CZCS satellite imagery; and simulation models of hydrodynamic and ecological processes.

Although the spatial and temporal frequency of observations of such diverse data sources can be quite different, there is a common need for data base management software that can be applied for data compilation, reduction and generation of data products that are typically organized by criteria of time, space and depth ranges. A number of generic commercial (e.g. System 1032, Software House, Cambridge, MA; System Analysis Software, SAS Institute, Cary, NC) and proprietary (e.g. "CHESSIE", EPA Chesapeake Bay Program, Annapolis, MD; "ODES",EPA 301(h) Program, Washington, DC) data base management systems have been applied to generate data products for a variety of marine and estuarine monitoring programs over the past decade.

In contrast to data sets generated from monitoring programs, data sets generated with simulation models are typically not organized for post-processing with the same data base management system and data file structure used to reduce the observed historical data base for model calibration and verification (2). Reduction of model output for calibration, verification and interpretation of the model then becomes a significant task requiring separate post-processing software since the model output files are usually organized with an arbitrary coordinate system (e.g. segment number, depth layer) that is different than the unambiguous coordinates used for the observed data base (e.g. river kilometer, latitude, longitude, sample and bottom depth).

Using an unambiguous description of data record coordinates in time, space and depth as a common link between observed data sets and the output of simulation models, an innovative approach has been developed for a coupled hydrodynamic and ecosystem model of the New York Bight. Published and unpublished data from analyses of eutrophication and anoxia (3,4) is presented to document the application of this methodology for pre-processing, model development and post-processing of the New York Bight ecosystem model. The method is illustrated with: (1) observed distributions of pycnocline depth and vertical stratification; (2) observed and simulated distributions of dissolved oxygen and chlorophyll; and (3) model distributions of the sources and sinks of oxygen and chlorophyll.

2.0 BACKGROUND

Over the past 10-20 years, a number of water quality and aquatic ecosystem models have been developed for streams and rivers (5), lakes and impoundments (6), estuaries (7,8) and coastal environments (9). These models range from relatively simple steady-state, one-dimensional analyses (e.g. BOD-oxygen in a river) to complex, two and three dimensional, time dependent hydrodynamic, eutrophication and toxic chemical analyses in large lakes, estuaries and coastal oceans (2,10,11).

The typical approach in the development of a water quality model is to average one or more dimensions in space or time to simplify the analysis of contaminant fate and transport (e.g. steady-state, laterally averaged, depth averaged etc.). Although there are many differences in the choice of state variables and the dimensionality of the model used to represent the prototype and the specific water quality problem, every water quality model is based on the reduction of the inherent variability of a natural system by averaging over incremental ranges of the spatial,

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temporal or depth domains. Historical data is aggregated and averaged to develop parameter values, model functions, initial conditions, boundary conditions and forcing functions for model input data. For calibration and verification, model output should also be averaged over the same time, space and depth domains as the observed data.

A significant (and often underestimated) component of the level-of-effort required for the development of complex simulation models of aquatic ecosystems is the compilation and reduction of large data sets for: (1) pre-processing of model input data to describe exogenous forcing functions (e.g. temperature), initial conditions and boundary conditions; and (2) post-processing of model output for comparision to observed data sets for calibration, verification and interpretation of the model (i.e. hypothesis testing). Model development, in fact, is typically not a linear, but rather an iterative process between pre-processing and post-processing with any particular set of summary statistics of observed and model data more dependent on the "learning curve" of the research team (12) than on the proposed approach for verification of a simulation model.

Although observed data sets and model data sets are intended to represent the same physical prototype, data sets generated with a model are often viewed as inherently "different" from observed data in relation to the task of post-processing model output for verification and interpretation of a model. Simulation data sets can, however, be thought of as "high frequency, synoptic sampling" where the source of the data is a numerical model rather than an oceanographic monitoring platform.

The development of any water quality model then can be based on the same data management process for both observed data and data sets generated with a simulation model. Since there is such a wide diversity of spatial and temporal dimensionalities used in water quality models, there remains a need for computer techniques designed to standardize the synthesis of observed data sets with model output during the pre-processing and post-processing stages of model development.

Commercial or proprietary data base management packages are often used for the aggregation and averaging of model input data files related to the observed data base. By contrast, model output files are frequently designed for post-processing according to an arbitrary coordinate system of relative time, spatial segment and depth layer numbering where the coordinate system is meaningful only for the internal model computations. The output files of many water quality models, for example, are typically designed for the dimensionality of the specific model (e.g. c(x); one-dimensional, steady state) rather than the more general dimensionality of the observed data from the prototype (e.g. c(x,y,z,t); space, depth and time). Separate computer programs, usually requiring substantial effort to develop and apply, are then needed for each individual water quality model to aggregate and average model output for comparison to observed data.

The inherent iterative nature of the model development process requires flexibility in the approaches used for structuring the broad range of problems investigated by a water quality analyst over a period of years. Such flexibility is not readily available with models that are "hard-wired" for the specific dimensionality of the simulation problem being investigated with arbitrary model coordinate systems of segment and layer indexes and relative time.

Long-term flexibility in the model development process can be achieved with an approach based on the consideration of numerical models as "high frequency, synoptic data sets" where the model results are transformed to unambiguous coordinates of space, depth and time consistent with the coordinates of the observed data base. Commercial or proprietary software developed for the aggregation and averaging of an observed data base (i.e. pre-processing) can thus be readily used for the post-processing tasks required to reduce the large data sets generated with simulation models.

3.0 METHODS

All water quality data obtained from either monitoring programs or simulation models can be uniquely described in a data file with coordinates of time (date and 24 hr clock time), space (latitude, longitude, river kilometer) and depth (sample and bottom depth). A consistent framework for the pre-processing and post-processing tasks of the model development process is the use of data base management software designed for a standard data file structure based on unambiguous coordinates of time, space and depth. A key concept in this approach is that a single software package, designed for the retrieval, aggregation and calculation of summary statistics according to time, space and depth increment criteria, operates identically on both an observed data base and output files generated with a water quality model.

Since historical water quality data bases are generally compiled from a large number of different data formats into a consistent file structure prior to aggregation and averaging with commercial or proprietary software systems, the primary task required to achieve flexibility in the model development process is the revision of model computer code so that the model output files are written with a data record structure consistent with the observed data base. Using this innovative approach, a single, well-designed data base management system can be used for all stages of the model development process including:

- reduction of historical data to define forcing functions, initial and boundary conditions for model input;
- reduction of historical data for model calibration and verification;
- reduction of the often enormous amounts of model output for model calibration and verification;
- reduction of computed statistical test scores for skill assessment of the model

Figure 1 illustrates a conceptual flow diagram of the data management approach used for the verification of an ecosystem model of the New York Bight (3). In the development of the New York Bight model, an extensive historical data base was compiled (4) with key data record descriptors of: data source, cruise and station identification, date, time, latitude, longitude, bottom and sample depth. Model state variables, computed variables and mass flux components of the model state equations were written to multiple output files designed with the

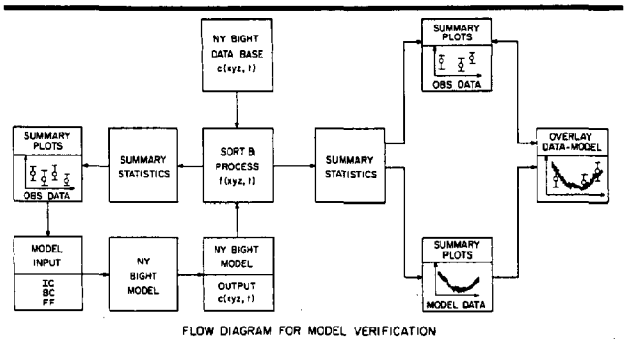

Figure 1 - Conceptual flow diagram of data management for pre-processing and post-processing of the New York Bight ecosystem model.

same data record coordinate system as the observed data base. The internal model coordinates of time and segment number were transformed to unambiguous coordinates of date and 24 hr clock time, latitude, longitude, and bottom depth of the model "station". The center of the model depth layer was transformed to depth of the model "sample". Model segment number was defined as the "station" for the data file and model run identifiers were defined as "data source" and "cruise" labels for the model data set.

Data product options available in the New York Bight data base management system are presented in Table 1.

Table 1
Data Products of the New York Bight Data Base Management System

Notation	Data Product	Averaging Increment
c(t)	time series	(x,y,z)
c(z)	vertical profile	(x,y,t)
c(x,y)	contour distribution	(z,t)
c(x)	depth averaged transect	(y,z,t)
c(x,z)	depth dependent transect	(y,t)
c (z,t)	time series at a point	(x,y)
c1 vs c2	phase plane plots	(x,y,z,t)

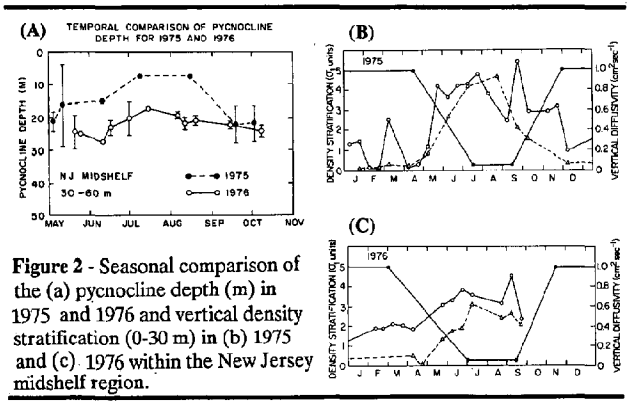

Figure 2 - Seasonal comparison of the (a) pycnocline depth (m) in 1975 and 1976 and vertical density stratification (0-30 m) in (b) 1975 and (c) 1976 within the New Jersey midshelf region.

In specifying a data product, increments of time(t), space (x,y) and depth (z) can be defined as uniform or non-uniform intervals with summary statistics calculated as either arithmetic or geometric statistics. The data file is searched in space according to one, or more, station identifiers or latitude and longitude ranges. In retrieving records based on sample date, time can be defined as within year or cross-year for either calendar date or julian day. Pycnocline depth can be calculated from density data and data records can be selected for a discrete interval above the bottom (e.g. 5 m above bottom). Vertical averaging can be based on depth integration or averaging within a depth layer. (e.g. 10-20 m).

4.0 APPLICATIONS

The New York Bight data base management system has been applied to evaluations of nutrient enrichment and phytoplankton production (13,14) and oxygen depletion (3,4,15). In this paper, I present summary analyses generated with the New York Bight data base management system related to pre-processing of model input; development of model functions and parameter values; and post-processing of model results and observed data sets for verification and interpretation of the model. A detailed description of the theory, data sources and results of the New York Bight model is presented in (3).

4.1 Interannual Variation of Pycnocline Depth and Vertical Mixing: 1975-1976

The pycnocline field, an input parameter to the diagnostic model of shelf circulation, is also a forcing function for the analysis of oxygen depletion in the New York Bight. With a pycnocline depth of about 30 m in 1976 in contrast to a much shallower depth of about 12-15 m in 1975, interannual variation in the depth of the pycnocline was a significant factor in the onset of the 1976 anoxic event (18) (Figure 2a).

Stratification of the water column is parameterized with a linear representation of the seasonal variation in the density gradient from the surface to 30 m. The data base of density observations for the New Jersey midshelf, used to determine the dates of onset and erosion of the seasonal pycnocline for 1975 and 1976, was applied to the development of a model function for calculation of the time varying vertical mixing coefficient. As is evident from the density data, stratification of the water column was initiated about one month earlier in 1976 (Figure 2c) than in 1975 (Figure 2b).

4.2 Seasonal Distribution of Chlorophyll and Dissolved Oxygen: 1976

The dramatic increase of calculated sub-pycnocline netplankton chlorophyll over the New Jersey midshelf during June-July, 1976 (Figure 3a) results from the dominant lateral advective and diffusive mass fluxes coupled with *Ceratium* sinking out of the water column (Figure 3b). The model results for *Ceratium*, clearly demonstrating the influence of the flow field reversal on the accumulation of particulates (including *Ceratium*), are consistent with the hypothesis of subsurface onshore

transport as a mechanism accounting for the anomalously high abundance of this large dinoflagellate in June 1976 (17).

The most striking feature in the computation of *Ceratium* dynamics is that respiratory losses exceeded the overall growth rate with maximum losses occurring from mid-June through mid-July when maximum abundances were observed off the New Jersey coast. The substantial increase in *Ceratium* abundance resulted from accumulation from physical transport from the large scale reversal (upcoast, NE) of typical circulation patterns of the New York Bight (downcoast, SW). Concurrent with accumulation by transport processes, physiological processes contributed to the decline of *Ceratium* in the model (Figure 3b). The agreement between the sparse observed data and the model calculations for *Ceratium* is good, particularly with respect to the observed decline of *Ceratium* and a shift to nanoplankton as the dominant phytoplankton group by September 1976 (Figure 3a).

The *Ceratium* bloom resulted in a ten-fold increase of particulate organic carbon (POC) from ca. 10 g C m^{-2} (1969-1980) to ca. 80-130 g C m^{-2} during June 1976 (4). Using an initial condition of 4-5 m*l* l^{-1} for the May oxygen concentration and 25-100 g C m^{-2} for the May-June POC content below the pycnocline, decay of the anomalous POC pool in the water column ($K = 0.013\ d^{-1}$, 10 C) during the summer (75 days) of 1976 accounted for the observed rate of oxygen consumption (1614 m*l* $m^{-2}d$) and bottom oxygen levels ranging from 0-3 m*l* l^{-1} within the New Jersey midshelf (Figure 4a, 5b). Analysis of the model oxygen budget for the New Jersey midshelf (Figure 4b) demonstrated that, although sewage loading contributed to localized nearshore oxygen consumption, respiration and decay of the *Ceratium* bloom was the key factor in the onset and persistence of anoxic conditions during 1976.

4.3 Bottom Hypoxia in the Middle Atlantic Bight: 1976 - 1985

Evaluations of a number of data sets have clearly indicated systematic differences in summer bottom water oxygen depletion between the New Jersey shelf and the Long Island shelf that appear to be related to shelf width and the volume of sub-pycnocline water as well as organic loading of the New Jersey shelf from the Hudson-Raritan estuary (18). Historical data sets describing winds, circulation processes, phytoplankton production and oxygen depletion were applied to retrospective analyses of eutrophicaton and oxygen depletion as part of an investigation of the "Green Tide" blooms of 1984-1985 off the southern coast of New Jersy (19).

Hydrographic data sets for the New York Bight were compiled (20) to generate composite bottom 5 m oxygen distributions averaged over July-September from 1977-1985 (Figure 5a). The distribution of the minimum values of bottom oxygen clearly documents recurrent hypoxic conditions within the nearshore New Jersey coast. Hypoxic areas are associated with the Hudson plume and the area of the 1984-1985 "Green Tide" blooms from Cape May to Atlantic City, New Jersey. The similarity in the distributions of nearshore hypoxia and the "Green Tide" blooms, as well as the documented high rates of primary production within the nearshore New Jersey coast (14), strongly suggests common physical processes as a mechanism accounting for these observed features.

Periodic reversals of the circulation field off New Jersey (i.e. upcoast, NE) of varying magnitude and duration, shown to result from relatively persistent southwesterly wind forcing (16, 21), would be characterized by variable flushing times over the nearshore New Jersey coast. The onset of water quality problems such as algal blooms and intermittent hypoxic events are related to urban carbon and nitrogen loading and the respective time scales for biological and chemical reaction rates in relation to the flushing rate of the nearshore region.

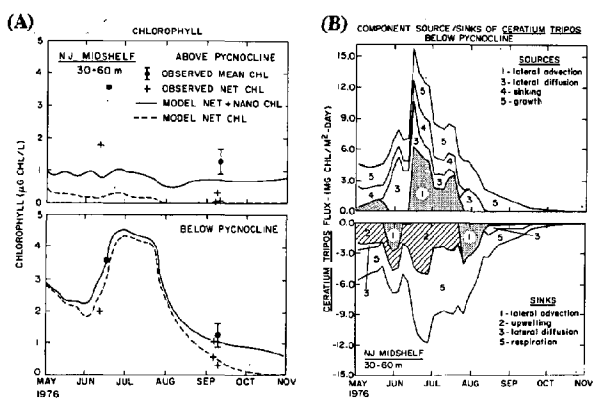

Figure 3 - Seasonal comparison of model results to observed data (mean ± 2SE) for (a) chlorophyll (µg l^{-1}) in New Jersey midshelf (30-60 m) region, May-November, 1976 and (b) seasonal variation of chlorophyll mass flux components (mg ch*l* m^{-2}-d^{-1}) of the model in New Jersey midshelf (30-60 m) region.

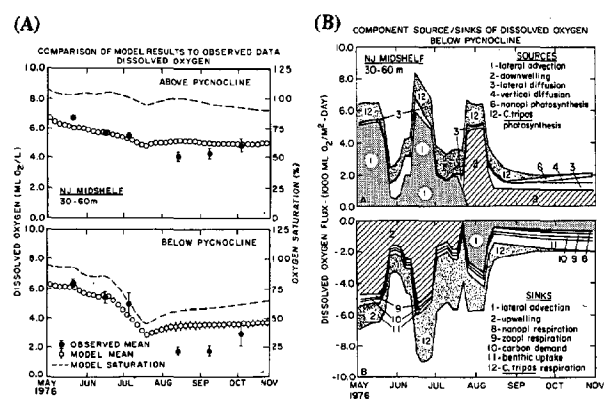

Figure 4 - Seasonal comparison of model results to observed data (mean ± 2SE) for (a) dissolved oxygen (m*l* l^{-1}) in New Jersey midshelf (30-60 m) region, May-November, 1976 and (b) seasonal variation of oxygen mass flux components (m*l* O_2 m^{-2} d^{-1}) of the model in New Jersey midshelf (30-60 m) region.

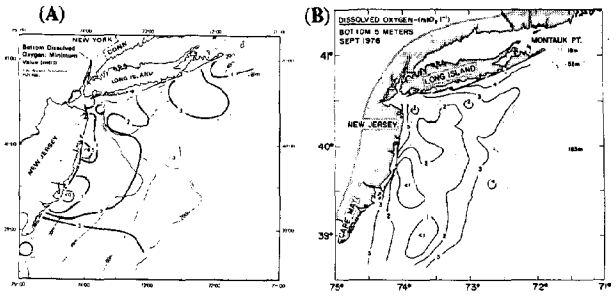

Figure 5 - Spatial distribution of (a) minimum bottom 5 m dissolved oxygen (m$l\ l^{-1}$), July-September, 1977-1985 and (b) mean bottom 5 m dissolved oxygen (m$l\ l^{-1}$), September, 1976.

The remarkable similarity in the spatial extent of hypoxia demonstrated with the composite 1977-1985 data set with the distribution of anoxia during the 1976 fishkill event (Figure 5b) strongly suggests that wind forcing, shelf circulation processes and shelf bathymetry are critical factors reflected in the interannual variability of the duration and extent of bottom water hypoxic episodes within the nearshore New Jersey coast.. The interaction of natural and anthropogenic carbon and nitrogen loading with variable physical flushing of the nearshore shelf results in intermittent episodes of bottom hypoxia and phytoplankton blooms that appear to persist over time scales related to the variability in summer wind forcing.

5.0 SUMMARY

Using the pre-processing and post-processing approach based on a single data base management system described herein to provide a common link between monitoring data and simulation results, retrospective data analyses can provide valuable insight for the assessment of public policy issues related to waste disposal options. Application of this technique to the New York Bight has demonstrated the utility of the approach with an ecosystems analysis that integrated a historical data base with output from a complex simulation model. The approach can be readily applied to the analysis of similar large-scale coupled hydrodynamic and water quality models being developed as part of the EPA National Estuary Program for Long Island Sound, the New York Bight, Pamlico/Albemarle Sound and Chesapeake Bay.

6.0 ACKNOWLEDGEMENTS

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BIOLOGICAL CONTROL OF WATER QUALITY IN ESTUARIES: REMOVAL OF PARTICULATE MATTER BY FILTER FEEDERS

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ABSTRACT

Benthic filter feeders remove substantial numbers of particles from the water column, and it has been proposed that they can clear the entire water column of an estuary in a short time, improving water quality. We developed a simple probabilistic model of filter feeding by bivalves to predict the fraction of a body of water filtered by the benthos. Inputs to the model include vertical and horizontal dispersion coefficients, weight-specific filtering rates, and abundance and size of bivalves. In summer, Chesapeake Bay bivalves can clear 80-100% of the water column of littoral areas (< 9-m depth) per day, but filter feeding below a pycnocline is negligible. Daily clearance of the total volume of the estuary and its tributaries is 28% of the main stem Chesapeake Bay, 43-44% of the Patuxent and Potomac rivers, and 97% of the shallow upper Bay.

INTRODUCTION

Benthic filter feeders are abundant in estuaries, and their aggregate filtering capacity has led to suggestions that they are responsible for substantial transport of material and energy from pelagic to benthic systems (1, 2) and that they may improve the clarity of the water column by filtering and removing particulate material (2, 3, 4). Several estimates of the aggregate filtering capacity of benthic suspension feeders have been made, but filtering capacity alone does not estimate the fraction of an esutarine water column actually filtered by the benthos. Shallow, well-mixed estuaries can be completely filtered by benthic filter feeders (3), but benthic filtration may be limited in deeper estuaries. In this paper, we develop a probabilistic model to predict the expected fraction of an estuarine water column that will be filtered by an assemblage of benthic filter feeders. The model is applied to the Chesapeake Bay and several of its tributaries to assess whether benthic filter feeders can have an effect on water quality in these estuaries.

DESCRIPTION OF MODEL

The rationale of the model is to predict the entrainment of water by filter feeders with cumulative probabilities of encounter and capture of water. Parcels of water move about randomly in the water column, occasionally coming into contact with the bottom and occasionally being swept out of the estuary. These processes can be described by Poisson probabilities, and are quantified by the vertical dispersion coefficient, the horizontal dispersion coefficient, and the residence time of the water in the estuary. The vertical mixing coefficient varies throughout the water column, being high in the surface mixed layer (SML), near zero at a pycnocline, and low below a pycnocline. Entrainment and capture of water parcels by feeding currents of the benthos is also a random Poisson process, with the water available for filtration being that fraction of the water column in contact with the bottom during an appropriate time interval (e.g., 1 day).

Assumptions of the model are as follows: all transport processes are from random, turbulent mixing, both vertical and horizontal, including tidal currents. Mixing across an established pycnocline is negligible. Horizontal mixing has longitudinal and lateral components; in drowned river valleys such as the Chesapeake Bay and its tributaries, the longitudinal component can be ignored because it parallels depth contours and does not transport water to shallow regions. The model is normalized to daily rates, because phytoplankton production is tied to diurnal cycles. The model does not consider sedimentation or resuspension of sediments, but effects of these can easily be incorporated into the filter feeding model.

Residence time of water in the estuary is given by t_r (days); renewal rate is then $1/t_r$ (day^{-1}). The probability of a parcel of water remaining in the system (i.e., the probability of not being renewed) is then

$$P_r = \exp(-1/t_r) .$$

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In general, if the probability of retention, P_r, is greater than 95% ($t_r > 20$ days), then the effect is considered negligible. For the Chesapeake Bay and its tributaries, $t_r > 20$ days. Thus, retention will not be considered further here.

The vertical and horizontal dispersion coefficients, K, are entirely analogous to a diffusion coefficient. The mean time for a random parcel of water to come into contact with the bottom is given by

$$t_v = z^2/3K_v ,$$

where z is the depth from the surface or from the pycnocline to the bottom and K_v is the vertical dispersion coefficient (5). K_v is typically expressed in cm^2/s, and must be multiplied by 8.64 to obtain m^2/d. The vertical mixing rate is then $1/t_v$ (day^{-1}), and the probability of a parcel of water being at the bottom at least once during a day is

$$P_v = 1 - \exp(-1/t_v) ,$$

where P_v is equivalent to the fraction of the water column at the bottom, which is therefore available for filtration.

For the model, an estuary is divided into three compartments (Figure 1): a littoral zone of water depths shallower than the formation of typical pycnoclines, a pelagic surface mixed layer zone, and a profundal zone below the SML. During summer stratification, mixing across the pycnocline is negligible, but horizontal mixing between the pelagic SML and the littoral zone may be significant. Mean time to mixing into the littoral zone for water in the pelagic SML is

$$t_H = w^2/12K_H ,$$

where w is the width of the pelagic SML and K_H is the lateral dispersion coefficient (5). The probability of pelagic SML water mixing into the littoral zone per day is then

$$P_H = 1 - \exp(-1/t_H) .$$

P_H is also the expected fraction of SML water mixing into the littoral zone.

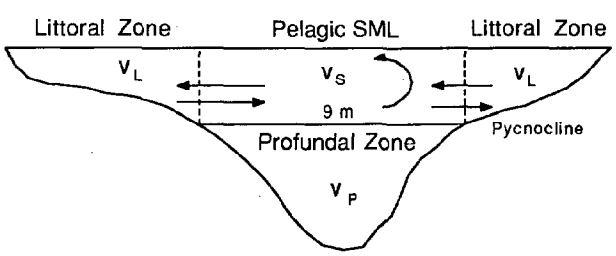

Figure 1. Compartments of the benthic filter feeding model. The littoral zone is treated as a single compartment in the calculations.

Mixing is continuous and net flow is 0, so an equal volume of the littoral water mixes into the pelagic SML. In one day, the "new" water from the pelagic SML that approaches the bottom of the littoral zone is given by

$$P_{Hv} = P_H \left(1 - \int_0^1 \exp(-T/t_v)dT\right)$$
$$= P_H \left(1 - t_v(1 - \exp(-1/t_v))\right) .$$

An equal volume of littoral water flows to the pelagic SML and has an equal probability of approaching the bottom before it leaves the littoral zone. The total volume approaching the littoral bottom is now given by

$$V_b = V_S P_H (2P_{Hv} - P_v) + V_L P_v ,$$

where V_s is the volume of the pelagic SML and V_L is the volume of the littoral zone. We assume here that the new water is distributed throughout the littoral zone. Due to mixing and influx, the total volume available for filtering during a day may be greater than the resident volume.

Benthic filter feeders process a volume of water given by their aggregate filtering capacity (see below). The water volume available for filtration may be more or less than the filtering capacity, and individual parcels of water may be processed more than once in the random Poisson process of capture. Given that it is on the bottom, the probability that a parcel of water will be filtered at least once is

$$P_F = 1 - \exp(-C/V_b) ,$$

where C is the aggregate filtering capacity of the benthos and V_b is the total volume approaching the bottom. The volume filtered by the benthos is now $P_F V_b$.

Clearance rates have been most widely measured in economically important bivalves such as edible clams, oysters, and mussels (3, 6), but little has been done with other taxa that may be ecologically more important in the benthos. Forunately, there is remarkable unity of allometric regressions of physiological rates within major groupings of animals, such as poikilothermic metazoans (7). We have chosen an equation of $C = 120\ W^{0.75}$ to be representative of published regressions for bivalves (2, 3, 8, 9, 10), where C is the clearance rate (L/animal · day) and W is dry body mass (g). For this model, we assume that all filter feeding bivalves fall on the same regression line, but we recognize that future work may refine the regressions for different groups.

Filtering capacity was calculated from the allometric clearance equation using the mean individual dry weight of each taxon within each depth interval, multiplied by the mean density of animals/m^2 and summed for all taxa found in a habitat. The model was iterated from 0-25 m at

0.1-m intervals, and the probability of water in the water column being filtered was calculated for each depth interval. Probability of filtration is also the expected proportion of the water column that is filtered at least once, and the expected volume of the Bay filtered per day was then estimated from the total water volume in each bottom depth interval.

We have restricted this model application to bivalves, as most other benthic filter feeding organisms are passive or facultative filter feeders. Densities and biomass of bivalves were obtained from Holland et al. (11) for the year July 1985-June 1986 in the Maryland portion of Chesapeake Bay. Taxa included and their mean summer densities and body weight are shown in Table 1. Mixing coefficients, K, were obtained from the hydrodynamic model of the Chesapeake Bay by Hydroqual (12). Depth, volume, and area estimates were from Cronin (13) and Cronin and Pritchard (14). Calculations were carried out for the Maryland portion of the Bay (Potomac to Patapsco rivers -- miles 60 to 135) (14) and for three tributaries: the Upper Bay (Patapsco to Susquehanna Rivers -- miles 135 to 155), the Patuxent River, and the Potomac River (Figure 1).

Table 1. Densities and dry weights of Chesapeake Bay bivalves (11)

Species	Density[a] (no./m^2)	Individual dry wt (mg)
Rangia cuneata	4783	3.0
Mulinia lateralis	2393	0.72
Macoma balthica	1337	10.5
Gemma gemma	442	0.19
Mya arenaria	423	20.7
Corbicula fluminea	255	135
Macoma mitchelli	190	4.9
Ensis directus	67	200
Tellina agilis	45	5.0
Lyonsia hyalina	30	0.2
Parvilucina multilineata	13	0.2
Tagelus plebeius	12	205
Crassostrea virginica[b]	0.15	3000

[a]Mean summer density and dry weights in habitats with highest densities.
[b]From (15); mean density in 0-9 m.

RESULTS AND DISCUSSION

Filtration by benthos is dependent on the filtering capacity of the constituent organisms, modified by ambient temperature, and the water supply to the bottom due to mixing. Figure 2 shows benthic filtration due to bivalves in the Upper Bay. Mixing generally extends to the bottom of this shallow arm of the Bay, which has an abundant population of Rangia acuneata. In summer, benthic bivalves can filter most of the water column each day, but in winter only a small fraction of the water column is filtered due to low activity rates at low winter temperatures. Filter feeding in winter is negligible, and for the rest of this discussion we will consider only summer activity.

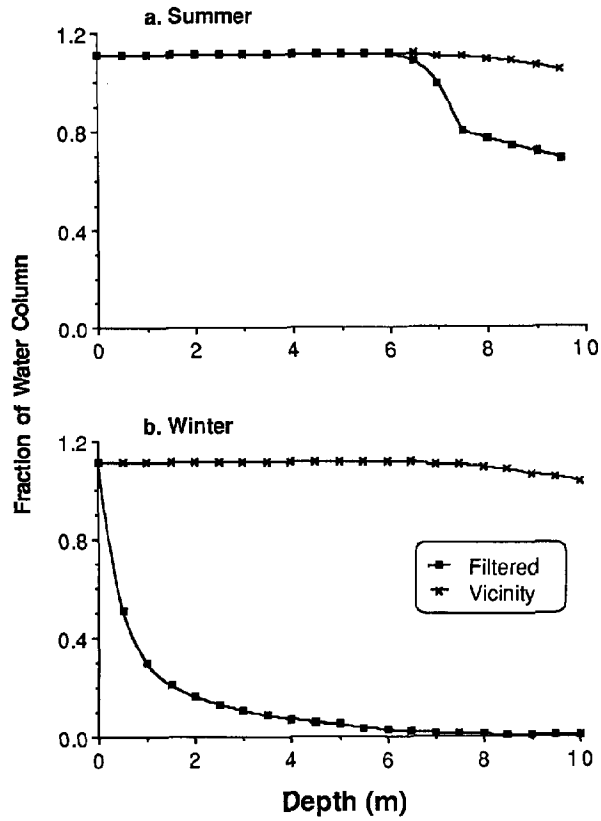

Figure 2. Benthic filtration in the upper Chesapeake Bay. "Vicinity" (crosses) is the fraction of the water encountered on the bottom; "Filtered" (squares) is the fraction processed by benthic bivalves. The fraction filtered may be greater than 1 due to mixing with pelagic water.

The main stem of the Bay has lower densities of bivalves than the upper Bay, but has enough bivalves to filter up to 80% of the littoral water column each day (Figure 3). Due to summer stratification, benthic filtration below 10 m is negligible. The increase in filtration from 2-7 m is due to higher benthic abundance in that range. It has been suggested that historic oyster densities (Crassostrea virginica) could have been responsible for substantial filtration of the entire Bay (4). We ran a simulation using Newell's (4) estimated oyster densities for 1870, which were approximately 120.5 x 10^9 kg dry weight in the Maryland Bay. This results in an

average biomass of 38 g/m^2, or 12.5 oysters of 3 g body weight/m^2. The oysters of 1870 would have increased the amount of water filtered by benthos, but not substantially, assuming that densities of other bivalves were similar to those of today (Figure 4).

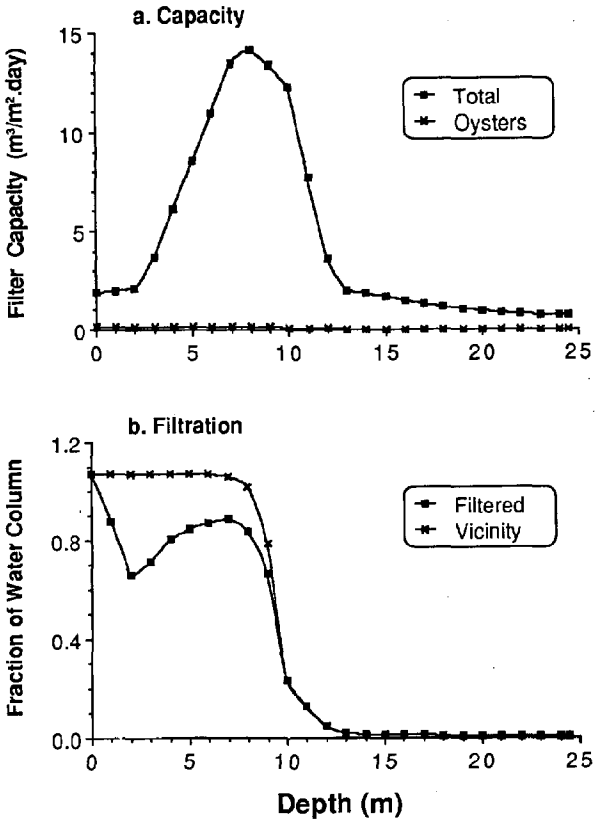

Figure 3. Benthic filtration in the main stem of Chesapeake Bay (Potomac to Patapsco rivers). a. Filtering capacity (m^3 filtered/m^2 of bottom) of oysters and total bivalves. b. Fraction of water column filtered, as in Figure 2.

Filter feeders are concentrated in the littoral zones (as defined by this model, i.e., water depth < 9 m) of these estuaries, and have the greatest impact on the water in the littoral zones. Particle removal from the entire SML and the total water volume of the estuary are fractions of removal from the littoral zone (Figure 4). In the tributaries, filter feeders may filter 90-100% of the littoral zone, but only 43-44% of the total volume of the Patuxent and Potomac rivers. Up to 82% of the littoral volume of the main Bay, but only 28% of the total volume of the Bay, is filtered per day (Figure 4). Addition of the 1870 oysters to the main Bay increases filtration to 92% of the littoral volume and 32% of the total volume.

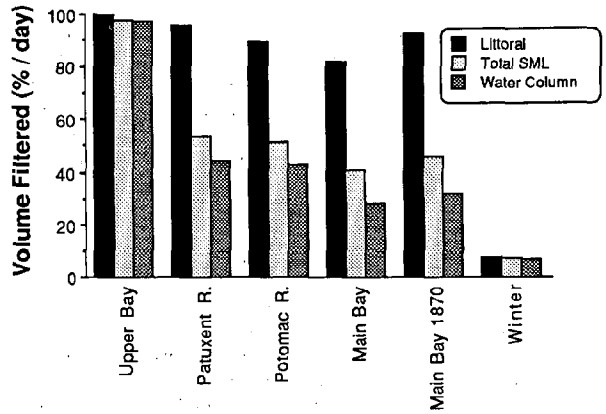

Figure 4. Filtration of Chesapeake Bay and its tributaries by bivalves. Winter refers to upper Bay only; all others are summer filtration.

Each of the three modeled tributaries is dominated by one or two filter feeding bivalves (11) which results in filtration of substantial fractions of the tributaries: Rangia cuneata in the Upper Bay; Macoma balthica (a facultative filter filter feeder (15)) in the Patuxent River; and Macoma, Rangia, and Corbicula fluminea in the Potomac River. These result in high filtering capacities in the littoral zones of the tributaries, and large fractions of the water column being filtered during summer (Figures 2 and 4).

These results reinforce the observation that benthic filter feeding can be effective at controlling particulate matter in shallow, well-mixed estuaries (2, 3). In deeper waters, benthic filter feeding is less effective due to limited mixing to the bottom, resulting in reduced encounter of the benthos with food, and due to limited capacity of benthic organisms to filter a substantial fraction of the water column.

Filtration is severely limited below a pycnocline because mixing does not bring food particles to the benthos. Instead, food supply is limited by the settling rates of organic particles. In the Chesapeake Bay, abundances of most benthic animals are reduced below 9-10 m during summer stratification, and these reductions are usually ascribed to anoxia. However, anoxia does not extend up to the pycnocline, and food limitation may therefore be responsible for low benthic abundances below the pycnocline but above the anoxic zone.

Due to the random nature of entrainment by filter feeders in a mixed water column, water that has already been filtered can be reprocessed and filtered repeatedly within the relevant time scale of one day. For instance, if 60% of the water column is filtered per day, then approximately 20% is filtered 2 or more times. At 90% filtration, approximately 65% is filtered repeatedly. Therefore, food limitation may

occur when a large fraction (> 60%) of the water column is filtered per day.

The three tributaries modeled here currently support high densities of filter feeders that can filter a large fraction of the total volume per day in summer. During spring and summer bloom conditions, phytoplankton doubling times are on the order of 1 day; therefore, filtration in excess of 50% of the water column per day could result in food limitation. Benthic densities for the model were averaged over the whole tributary; highest densities and benthic secondary production occur at the upper ends of the tributaries which receive freshwater input. The dense filter feeding communities at the upper ends of the tributaries thus may be supported by freshwater inputs of organic matter in addition to in situ primary production, since the high filtration rates could deplete phytoplankton faster than its growth rate.

The main stem of the Chesapeake Bay is less affected by benthic filter feeders due to its larger volume, to the restriction of abundant filter feeders within the littoral zone, and to limited water exchange between the pelagic SML and the littoral zone (approximately 17%/day). The main stem of the Bay does not appear able to support oyster densities of the 19th century (4) in addition to present-day filter feeders. Benthic filter feeders in the Chesapeake Bay may have replaced historic oyster populations in function and density, filtering Bay waters to as full an extent as was done by historic oyster populations.

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FACTORS CONTRIBUTING TO WETLAND LOSS IN THE COASTAL CENTRAL GULF OF MEXICO

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ABSTRACT

In response to the dramatic alteration of coastal wetland habitats in Louisiana, Texas, and Mississippi, the Minerals Management Service has initiated a number of environmental studies addressing this problem. The first of this series was a 2-year comprehensive study of factors contributing to wetlands loss. Investigators looked at the direct impacts of canals and pipelines on wetlands as well as the balance between saltwater and freshwater in maintaining a healthy marsh. The role of sedimentation in balancing subsidence and accretion was also investigated. Landscape patterns were studied using remotely sensed data to conduct computer analyses of landloss patterns. This study was completed in early 1988 and has proved effective in describing the complex processes at work in the coastal wetlands.

Another investigation was initiated to look at the impacts of selected Outer Continental Shelf (OCS) activities on sensitive coastal habitats such as barrier islands and barrier beaches with their associated wetlands and to predict the effects of future impacts in the region. An important aspect of the project was a reconnaissance-level assessment of the impacts of OCS-produced water discharges in coastal wetlands. The study has recently been completed with final report distribution scheduled for October 1988.

Recently a cooperative investigation with the Louisiana Department of Natural Resources has been initiated to determine the most efficient marsh management techniques in light of a wide array of environmental conditions that may exist at a given site. A study of the overall coastal marsh environment in Louisiana and an examination of specific sites in a variety of physiographic settings will be carried out over a 2-year period. This analysis of wetland mitigation is an effort to better understand how marsh management is used to reduce the loss of wetlands, to preserve existing productive marsh, and to improve prospects for future marsh growth.

INTRODUCTION

The impacts of Federal Outer Continental Shelf (OCS) oil and gas activities related to onshore alterations in the coastal central Gulf of Mexico have been a concern of the Minerals Management Service (MMS) for a number of years. In the light of a declining economy from oil- and gas-related activities and accelerated wetlands loss affecting the habitat of valuable biological resources, many unsubstantiated claims were being made on who was responsible for the loss and who should be addressing the problem. In this emotional atmosphere, study planning was initiated in 1984 to investigate what factors contribute to wetlands loss and specifically what percentage of this loss is due to OCS pipelines, navigation canals, and support facilities located in wetland areas.

In September 1985, MMS contracted with the Center for Wetland Resources of Louisiana State University (LSU) to conduct a comprehensive study entitled "OCS Development and Potential Coastal Habitat Alteration." This study was completed in early 1988 and has gone a long way toward describing the complex processes and interactions at work in the wetlands. Definitive partitioning of causes of wetland losses was effectively accomplished and a groundwork laid for further testing hypotheses and facing the problem of accelerated wetlands loss.

In October 1986, MMS contracted with Coastal Environments, Inc., to conduct a two-part study to determine the impacts of selected OCS activities on sensitive coastal habitats. The first part of this study was designed to research the impacts of Federal OCS pipelines and associated facilities and navigation channels on barrier beaches and barrier islands along the Gulf of Mexico from Cameron County, Texas, to Bay County, Florida, and on coastal wetlands within this region, except those areas addressed in the aforementioned wetlands loss study. The study was formulated to generate information for predicting impacts of future OCS activities in the region and for documenting measures that have been successful in mitigating impacts to specific habitats and under particular environmental conditions. The second part of the study was a reconnaissance-level assessment of the impacts of OCS-produced water discharges in coastal wetlands, primarily Louisiana wetlands. This aspect of the study carried out by the Louisiana Universities Marine Consortium (LUMCON) and LSU Institute for Environmental Studies was designed to extend, update, and improve the existing record inventory and to provide a field assessment of existing

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conditions at OCS-produced water discharge sites. This study is nearing completion with distribution of a final report scheduled for October 1988.

A third study recently initiated by MMS to address the concern of wetlands loss has been "A Study of Wetlands Mitigation: Marsh Management." The primary focus of this study, being carried out by cooperative agreement with the Louisiana Department of Natural Resources, is to determine the most efficient marsh management techniques in light of a wide array of environmental conditions that may exist at a given site. This determination will be accomplished by a study of the overall coastal marsh environment in Louisiana and an examination of specific sites in a variety of physiographic settings within the study area. The study effort will extend for two years with completion scheduled for April 1990.

BACKGROUND

As early as 1970, estimates of wetland loss indicated that valuable Gulf coastal wetlands were being converted to open water at a rate of 16.5 square miles per year (Gagliano and Van Beek, 1970). More recently, in a study sponsored by MMS (or what was then the Bureau of Land Management (BLM) Outer Continental Shelf office) and carried out through the U.S. Fish and Wildlife Service, this landloss rate between 1955 and 1978 in the Mississippi Deltaic Plain was calculated to be 39 square miles per year (Wicker, 1980) and in the Chenier Plain to be 11 square miles per year (Gosselink, Cordes, and Parsons, 1979). More recent total landloss rate estimates have been as high as 60 square miles per year.

The issue of wetland loss is a crisis of dramatic proportions. Wetland loss directly affects the environmental, economic, social, and geopolitical values of coastal states and the Nation. The wetlands of Louisiana alone, consisting of 2.6 million hectares (ha) (6.5 million acres), constitute over 40 percent of all United States coastal wetlands (Gosselink, 1980).

The bountiful harvest of renewable resources from Louisiana wetlands is estimated to exceed $1 billion annually. Over 40 percent of the Nation's fur harvest and 30 percent of its commercial fisheries harvest are dependent upon these wetlands. Shrimp, oysters, crab, and menhaden worth hundreds of millions of dollars annually use the coastal marshes for nursery grounds.

The waterfowl that crowd Gulf coast marshes during the winter create a hunter's paradise. Migratory waterfowl readily use this important habitat. It is estimated that four million ducks overwinter there annually.

In addition there are the socioeconomic implications of wetlands loss. The marshes are a natural defense against hurricane-induced storm surge. They also provide substrate for the multibillion dollar infrastructure associated with the petroleum industry. Wetlands enhance water quality and provide a living for over a million people in the Gulf coastal area. The unique lifestyles could obviously be altered or lost resulting in the demise of centuries-old traditions (Davis, 1982). The cultural heritage of the region will be diluted and the economic resources devastated.

This vast area of wetlands is not homogeneous, but zoned into transitional areas dominated by characteristic plant species. Their distributions are determined by their tolerance to salinity, soil types, drainage characteristics, and elevation (Chabreck, Joanen, and Palmisano, 1968). Figure 1 illustrates the distribution of these vegetation types.

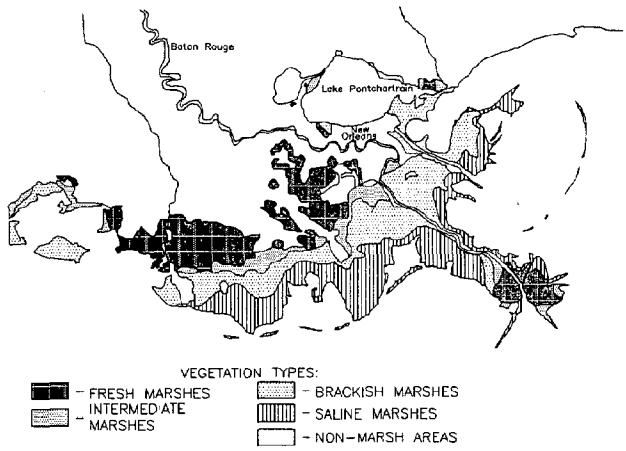

Figure 1. Vegetation zones in the Mississippi River Delta marshes (Chabreck and Linscombe, 1978).

At the upland extent of coastal wetlands are swamp forests dominated by bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*). These trees are very intolerant to saltwater intrusion.

Adjacent to these swamps are freshwater marshes generally forming the northernmost extent of the coastal marsh. It is estimated that there are 1.2 million acres of fresh marsh in Louisiana (Chabreck, 1972). Freshwater marshes are dominated by such plants as maidencane (*Panicum hemitomon*), bull tongue (*Sagittaria* spp.), common reed (*Phragmites communis*), and alligator weed (*Alternanthera philoxeroides*).

As freshwater outflow mingles with marine tidal influences, more salt-tolerant plants such as saltmeadow cordgrass (*Spartina patens*), bull tongue (*Sagittaria* spp.), and sawgrass (*Cladium jamaicense*) are encountered. This intermediate marsh is a little saltier than the freshwater marsh, generally ranging from 0.5 to 5.0 ppt (Cowardin *et al.*, 1979). The intermediate marsh is often defined as a transitional zone between brackish and fresh marsh.

The brackish marsh provides a buffer zone between the saline marsh and the intermediate marsh. The major plants are saltmeadow cordgrass (*Spartina patens*), threecorner grass (*Scirpus olneyi*), and saltmarsh bulrush (*Scirpus robustus*).

The brackish marsh provides habitat for such wildlife as muskrat and geese and is of particular value to the larval forms of such estuarine organsisms as shrimp, crabs, and menhaden. Studies show that brackish marshes are deteriorating faster than any of the other wetland habitats (Adams *et al.*, 1976; Gagliano and Van Beek, 1970).

The saline marsh is adjacent to the Gulf and is usually subject to tidal activity. Plants in this area are tolerant to high salinities and are dominated by saltmarsh cordgrass (*Spartina alterniflora*), black rush (*Juncus roemerianus*), saltgrass (*Distichlis spicata*), and glasswort (*Salicornia* sp.). The saline marsh is important as a nursery ground for numerous marine and estuarine organisms. A conceptual diagram of these delta marshes and their relations to other ecosystems is illustrated in figure 2.

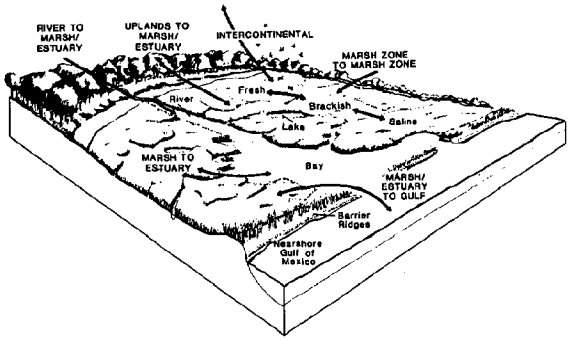

Figure 2. Conceptual diagram depicting the coupling of marshes to other ecosystems (Gosselink, 1984).

These marshes in Louisiana are further divided from east to west into the Mississippi Deltaic Plain and the Chenier Plain. The Deltaic Plain lies east of Vermilion Bay and covers two-thirds of the coastal marsh. It has resulted from cyclical delta growth and decline and the resulting environmental succession. These processes have generated this extensive coastal lowland characterized by a skeleton of natural levee ridges along active and abandoned distributaries, an outer fringe of sandy barrier islands and Gulf beaches, and vast areas of interdistributary swamps, marshes, lakes, and bays (Gagliano *et al.*, 1981).

The Chenier Plain lies west of Vermilion Bay and generally has firmer marshland. It was formed from the deposition of silts and clays swept westward from the Mississippi River by Gulf currents. This area has not been affected by subsidence as much as the Deltaic Plain, but it has been reworked extensively by wave action. This reworking has resulted in separate shore-parallel to shore-oblique ridges of shell and sand separated by progradational mud flats or mud flats that are now open water.

OCS DEVELOPMENT AND POTENTIAL COASTAL HABITAT ALTERATION

The basic problem of wetland loss lies with the engine driving the geological processes of the region--the Mississippi River. For 10,000 years the river has carried hundreds of millions of tons of sediment and fresh nutrients annually into southern wetlands creating huge deltaic lobes. Approximately every 1,000 years the main river course would switch to another route as the gradient became increasingly inefficient. As the new lobe began to grow, the abandoned lobe would begin to subside. This process continued with a net annual growth of a few square miles.

It is difficult to determine why the marsh-building processes began to decline, but somewhere around the turn of the century, the net annual growth converted to landloss. It is not difficult to determine that the activities of man have more recently greatly exacerbated the problem. First, the taming of the river for flood control and navigation has limited its ability to drive marsh-building processes and has literally starved the wetlands of sediments, allowing for increased saltwater intrusion. Second, the coastal zone has become laced with numerous navigation channels and thousands of miles of oil and gas production access canals and pipeline canals. This network has caused the direct loss of wetlands to spoil banks and open water, as well as promoted saltwater intrusion and wave wash. Coupled with these factors is the ominous threat of sea level rise brought on by increasing levels of carbon dioxide. Estimates of a rise in sea level as high as one meter in the next century would obviously be devastating to the maintenance of marshes.

The MMS study entitled "OCS Development and Potential Coastal Habitat Alteration" was begun in 1985 to quantitatively partition the causes of wetland loss and specifically to understand the contribution due to the onshore impacts of offshore oil and gas operations. A multidisciplinary team of scientists was assembled to research and reach a consensus on what were the dominant factors contributing to this growing problem. This 2-year study was completed in December 1988 and a final technical report entitled *Causes of Wetland Loss in the Coastal Central Gulf of Mexico* released.

The geographic focus of the study area was from East Bay, Texas, to Waveland, Mississippi (figure 3). Realizing the different geologic nature of the Louisiana wetlands, the study region was investigated in three areas: 1) the Lafourche study area located to the east of Bayou Lafourche, a water course abandoned by the Mississippi River about 400 years ago; 2) the Terrebonne study area adjacent to the Atchafalaya River, the most recent Mississippi River water course that today captures 30 percent of the system's flow; and 3) the Cameron study area located in the western part of the state outside the major influence of the Mississippi River.

The project was divided into two broad analyses: direct impacts and indirect impacts. Direct impacts were defined as those cultural activities directly linked to the physical conversion of one habitat to another. The major human activities involved in creating direct impacts are land drainage and dredge-and-fill. The major onshore dredge-and-fill activities associated with OCS development are the construction of pipelines and related support facilities and the construction or enlargement of navigation channels.

Total direct impacts accounted for an estimated 25.6 percent of the total net wetland loss within the Louisiana study area from 1956 to 1978. Direct impacts from OCS activities accounted for 4.0 to 4.7 percent of the total Louisiana wetland loss. An important finding was that direct impacts from OCS pipelines averaged 2.49 ha/km and totaled 12,012 ha. Direct impacts are variable and are related to construction technique, geologic region, habitat type, age and diameter of pipeline, and other factors that were not examined in this study.

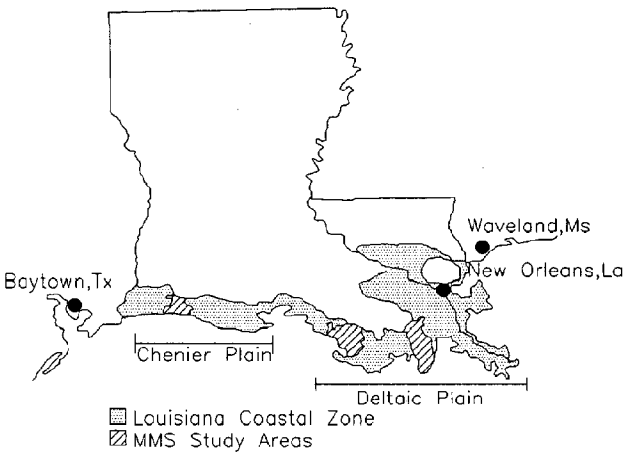

Figure 3. Study area for the investigation of wetlands loss in the coastal central Gulf of Mexico. The three shaded areas were primary study sites for field work (Turner and Cahoon, 1987).

Navigation channels accounted for a minimum of 16,902 ha of habitat change. Of this total change, 13,615 ha resulted from the loss of wetland and beach habitat. It appears that OCS traffic comprises a relatively small percentage of the total commercial traffic using navigation channels; thus, the allocation of navigation channel impacts due to OCS activities is small. Direct impacts per unit length of navigation channel averaged 20 times greater than pipelines.

Indirect impacts were assessed by investigating how oil- and gas-related activities affect the natural processes controlling wetland loss and by quantifying wetland loss that is indirectly the result of these activities. These impacts were more difficult to quantify. Wetlands are a robust habitat so that not all changes or impacts occur coincidentally in time or space. For example, the effects of a spoil bank may take months to years to interact with the hydrology of an area, whereas soil compaction may take hundreds of years. The indirect impacts analysis was divided into the following working groups: saltwater intrusion, sedimentation/subsidence, and landscape patterns. The saltwater working group research goals were to identify and quantify the degree and extent of saltwater intrusion with and without OCS-related canals that contribute indirectly to wetlands loss. The sedimentation/subsidence working group was to examine accretion processes (e.g., sediment accumulation, peat formation, oxidation, submergence) as affected by man's alterations. The landscape patterns working group used remotely sensed data to conduct computer analyses of landloss patterns. This was coupled with statistical analyses to determine relationships between wetland loss and manmade and geomorphic features across the whole coastal zone. In order to investigate the degree and extent of saltwater intrusion, the saltwater working group conducted analyses of salinity records across coastal zones, developed a computer model of the influence of OCS canals on saltwater intrusion, and observed which salinity changes were significant to typical wetland plants.

The database on salinity trends was composed of 44 long-term (up to 49 years) tidal flow records collected by the Louisiana Department of Wildlife and Fisheries and the U.S. Army Corps of Engineers. A general conclusion was that salinity actually decreased at certain stations. This decrease was obviously in contrast to the widely held belief that a coastwide increase in salinity is responsible for plant death and subsequent wetland loss. However, interpretation of the data was difficult due to such factors as: 1) gauges usually measured near-surface salinities; 2) some records were only 5 years, some up to 49 years; and 3) the records were not long enough to determine inherent variability as opposed to manmade impacts.

Another goal of the saltwater working group was to develop a model for saltwater intrusion in coastal channels. This model described saltwater movement in relation to freshwater discharge and tidal exchange. Compared with undredged marshes, saltwater intrusion inland is more frequent and severe in manmade channels due to straightening and deepening from dredging activities.

The next important question addressed by the saltwater working group was how the saltwater moves from the bayous or canals into the marshes--by overland flooding or by migration through interstitial waters. To look at this question, intensive sampling was carried out on free-water salinities in groundwater over a 3-day period and was followed by the deployment of recording water level and salinity meters.

As a result of these data, it appeared that the major mechanism for salt transfer into the marsh is occasional overbank flooding with slow return flow. Water in the marsh is also strongly influenced by precipitation and evapotranspiration. The system is further complicated by the presence of multiple pathways. Variations in wind strength, direction, and spatial scale, as well as stream discharge, may generate small-scale gradients within the open water. These variations are added to the larger scale predictable gradients associated with tidal flooding. The water level changes of small spatial scale potentially are able to interact with the marsh topography to allow water to enter and flow within marsh channels by a variety of different paths. This means that the source of overbank flooding within the marsh may be locally or far-field driven.

The saltwater working group also addressed the question of how and to what extent increases in salinity would affect the vegetation of the various marsh types. The effects of

increased salinity and submergence on the dominant plant species were investigated in each on the three marsh habitats by simulation of saltwater intrusion and increased inundation under field and greenhouse conditions. Study results showed that the response of marsh vegetation to increases in salinity is influenced by a number of factors including vegetation type; level, duration, and abruptness of exposure to salinity; and level of inundation. Saltmarsh plant species were essentially unaffected by increased salinity and slightly affected by waterlogging. Brackish marsh plants were more sensitive to waterlogging and increased salinity. Although fresh marsh plants were adversely affected by waterlogging and increased salinities, their response tends to vary according to species. Thus, fresh marshes composed of more tolerant species might be able to survive salinity increases for short periods, but would probably quickly succumb to sudden increased salinities above 10 parts per thousand (ppt).

Since the vertical accretion of marshes is dependent on the accumulation of organic matter produced by marsh plants, any reduction in this source will slow the aggradation process. A sudden change that leads to a rapid biomass reduction or elimination would reduce the potential for marsh accretion to keep up with subsidence and/or sea level rise. The stresses associated with increase in flooding depth and duration could ultimately cause plant demise in areas where marsh accretion lags behind increasing water level. Saltwater intrusion, whether natural or man-induced, may accelerate this process in all marsh types.

The subsidence, water level rise, and sediments working group looked at the question of sea level rise in relation to subsidence and the ability of the marsh to compensate for it. Investigators looked at the ability of the Mississippi River to supply sediments, what portion of coastal submergence is due to sea level rise as opposed to subsidence, and the rates of sedimentation using short-term to long-term marking techniques.

Recent subsidence is the dominant geological process causing wetland inundation, not sea level rise. Geological subsidence rates of about 0.3 to 2.0 cm/yr seem constant over the last 40 to 50 years. Based on modeling studies, fluid withdrawal from oil/gas reservoirs may be an important local but not regional influence on land sinking.

Sea level rise appears to have been relatively constant over the last 80 years, at a rate of about 2.3 mm/yr. Basin water level changes significantly influence marsh water levels and, together with climatic effects, have produced decade-long rises and lowerings of water levels at tide gage stations of as much as 60 cm. Water level rise from climatic changes, subsidence, and sea level rise can often exceed additions of sediments at the marsh surface, at least over short time periods, resulting in accretion falling behind water level rise.

Using available data bases related to sediment concentrations, investigators found that suspended sediment supply from the Mississippi River has decreased dramatically in the last 100 years. Changes in bedload did not appear sufficient to compensate for the reduced suspended load. This decrease, coupled with the loss of direct input of sediments from overbank flooding, undoubtedly has influenced marsh sedimentation rates. Sediment deprivation appears to limit marsh growth in several regions of the coast.

Canals and spoil banks influence marsh sediment distribution. On a local scale an annual 0-6 mm increase or decrease in vertical accretion compared to natural waterways may occur. These differences are usually attributed to the influence of the spoil bank on marsh hydrology.

Short-term accretion rates were essentially the same behind adjacent natural and manmade waterways. This result does not preclude the possibility that a surface disparity could develop behind spoil levees but not behind natural levees. Spoil levees can influence surface hydrology and therefore marsh water levels. Thus, a disparity between marsh accretion and water level rise could develop near spoil levees but not near natural waterway sites, even though accretion rates were the same at both sites. More data would be needed to confirm the existence of such disparities.

The landscape pattern analysis group used aerial imagery of 1955/56 to 1978 habitats to analyze wetland changes that have occurred. Three projects were designed to examine the distribution and/or number of habitat changes with respect to geology, distance, and density measures. Identified factors associated with either wetland loss or landloss rates included 1) the age and thickness of previously deposited sediments, 2) the distance to sediment sources and freshwater, 3) indicators of hydrologic change, such as canals and spoil banks, and 4) various associated factors related to distance and density.

In general, loss rates are lower where sediment thickness is thin and the sediments old, where spoil banks, canals, and the seashore are far away, and where rivers are close. The reverse was also true: loss rates were highest where sediments are likely to consolidate the most, where new sediment sources are in shortest supply, and where canals and spoil banks are dense. However, the loss rates in specific areas may not always follow the general tendency. Because of the interactions between these factors, regions differ geologically, biologically, and physically. In terms of loss rates and the relationship between these factors, the Chenier Plain was distinct from the Deltaic Plain. Similarly, the Deltaic Plain could also be subdivided into smaller regions.

In conclusion, investigators estimated the impacts of OCS activities and the factors driving wetland losses in the study area. As previously noted of all direct impacts from 1955/56 to 1978, OCS development accounted for an estimated 14-16 percent, or 4-5 percent of the total wetland loss. Of all indirect impacts, OCS development accounted for an estimated 5-18 percent, or 4-13 percent of the total wetland loss. Combining the direct and indirect impacts, OCS development accounted for 8-17 percent of all wetland loss. Altogether 43-72 percent of the causes of all wetland losses were identified. Some of the remaining 28-57 percent may also be caused by OCS or non-OCS economic development,

agricultural and urban expansion, and oil and gas canals and spoil banks, but are likely to involve more nonmanageable influences, particularly water level rise, geological factors, and the decreased sediment content of the Mississippi River.

IMPACTS OF OCS-RELATED ACTIVITIES ON SENSITIVE COASTAL HABITATS

In order to further understand potential onshore impacts of OCS activities, the MMS contracted with Coastal Environments, Inc., to investigate the impacts of OCS-related activities (pipelines, navigation canals, and produced waters) on sensitive coastal habitats of the Gulf Coast from South Texas to northwest Florida. The sensitive coastal habitats included all barrier islands, beaches, and marshes except those studied in the previously described investigation. The main objective of this study was to document shoreline and habitat changes related to pipeline emplacement techniques (e.g., push ditch, flotational canal, directional drilling).

A total of 154 federal pipelines were located in Texas and Louisiana. Of the 11 pipelines studied in Mississippi and Alabama, only 2 carried products directly from OCS waters. As would be expected, the impacts of these OCS pipelines vary depending on the construction technique and the environmental processes active in the area. All pipeline sites were analyzed for the type and degree of impact. Field sampling of vegetative, hydrologic, and geologic parameters at 11 pipelines in the 4 coastal systems provided additional data for explaining the impact process and magnitude.

The push-ditch method with trench backfilling was very effective in reducing coastal impacts to a minimum. All pipelines in Texas were emplaced this way. In Louisiana approximately 9 of the 49 pipelines making landfall in the Chenier Plain region were installed using a flotation canal that was dammed at the beach. The remainder appear to have been installed using a push-ditch method, with most having been backfilled. In all cases, a dam was placed at the juncture of the push-point canal slip dredged through the beach and the push ditch. By 1988, beach material had plugged all of these cuts making shorelines at the pipeline right-of-way appear the same as the adjacent shoreline. Shoreline retreat has left many bulkheads in the Gulf, but new bulkheads have been constructed in several of the flotation canals. The remainder of the canals have been plugged naturally by beach sand and shell.

Of the 89 OCS pipelines making landfall in the Louisiana Deltaic Plain, only 39 cross barrier islands and beaches. Of these 39 lines, 5 appear to have been laid in water between barrier islands. Of the 26 remaining lines in the Deltaic Plain, 9 were in flotation canals that were dammed, 7 were in push ditches that appeared to have been backfilled, and 10 pipelines had undetermined emplacement.

Of the 6 pipelines studied in Mississippi, 3 were emplaced in a corridor using a push ditch, and 2 were in flotation canals dammed near the shoreline. All of these lines traversed marshes and none crossed barrier islands or beaches. All 5 of the pipelines studied in Alabama were emplaced using a directional drilling technique that had no impact on the bay shore.

Another aspect of this study was to document the environmental effects of discharges of formation waters associated with oil and gas production into coastal environments. These produced waters often have elevated concentrations of dissolved solids, higher concentrations of dissolved trace metals, little or no dissolved oxygen, high concentrations of sulfides, and varying concentrations of petroleum hydrocarbons.

Because of the lack of comprehensive information on the extent and location of produced water discharges in the northwestern Gulf of Mexico, data were assembled from the files of state and federal regulatory agencies. This information included location, volume of discharges, and characteristics of receiving waters of reported discharges into the coastal and estuarine environments of Louisiana and Texas. From summaries of these data, it appears that a total of 3.6 million barrels per day of produced waters are discharged into estuarine or offshore waters. Of this, approximately 1.8 million barrels per day are discharged into estuarine and nearshore waters of Louisiana and 0.8 million barrels per day into similar waters of Texas.

Three areas receiving significant OCS-generated produced water discharges were selected for preliminary field assessments of the effects on water and sediment quality and biota of the region. One of the sites assessed was Bayou Rigaud located behind Grand Isle, Louisiana. It received approximately 145,000 barrels per day of produced waters from two major facilities. Based on salinity distribution, the study data revealed that the effluents formed dense bottom plumes that were effectively dispersed within a few hundred meters by the large tidal flow through this channelized bayou.

Concentrations of benzene of up to 930 ng/ml were measured in water overlying the bottom within 100 m of the largest discharge. Bottom sediments near the discharges had concentrations of total hydrocarbons up to 1,600 ug/g decreasing with distance from the discharge. Macrobenthic organisms were essentially absent from the most heavily contaminated sediments. Their population densities and species richness increased with distance from the discharges and with decreasing sediment hydrocarbon concentrations. The presence of the polychaete *Capitella capitata* at more distant stations suggested an intermediate field organic enrichment effect. Sediments in Bayou Rigaud extending at least 1 km in either direction from the discharges showed evidence of hydrocarbon contamination and effects on benthic communities.

Although final analyses and interpretation of field data had not been completed at the time of drafting of this paper, it appears that this pattern of sediment contamination and benthic effects extending on the scale of 1 km from the discharge sites differs from others studies of the effects of produced water discharges in the Gulf region indicating

contamination effects restricted to within 100 m of the discharges. This is probably attributable to the much larger volume of the discharges studied here and the more enclosed nature of the receiving waters, which limits dilution and enhances the deposition of fine, contaminated sediments.

WETLANDS MITIGATION: A STUDY OF MARSH MANAGEMENT

Faced with extensive wetland loss, a major question is what methods of land management and conservation are effective in saving this valuable resource. To address this question, the MMS signed a cooperative agreement with the Louisiana Department of Natural Resources for a 2-year study effort. This study began in April 1988 and is in the early stages of information gathering.

Traditional approaches to marsh management utilize levees and water control structures to impound or partially impound wetlands, allowing control of water levels and salinity. These approaches have made it possible to enhance the productivity of some wetlands, especially for waterfowl and furbearers. But these techniques have been questioned as ineffective or actually contributing to wetland loss in some cases. There has also been concern regarding interference with the disruption of migratory patterns of commercial and recreational fisheries species. The most important objective of this wetlands mitigation study is to provide an objective assessment of the suitability and feasibility of using marsh management techniques to protect and enhance coastal wetlands and the renewable resources they produce.

The data acquisition phase will consist of three tasks. The first will identify the administrative procedures, legislation, and regulations controlling wetland management in Louisiana. The second task will inventory management activities in the wetlands including public interest goals, data sources, engineering and construction techniques, and economic considerations. It will also include mapping of the study area and marsh management projects; characterization of environmental conditions including habitat, hydrologic, and geologic conditions; and a review of management plans and information on permitted sites. The third task will involve monitoring habitat changes resulting from marsh management plan implementation. The monitoring program will include field studies of 24 sites.

The second phase--data synthesis, analysis, and interpretation--consists of four tasks, each drawing upon the data derived from the first phase. The first analysis deals with engineering and economic concerns; the second with study area conditions including habitats, hydrologic and geologic conditions, and management plans. The third task will analyze the monitoring data and ecological factors. The fourth task will assess the feasibility and suitability of marsh management practices and will include maps portraying suitable and unsuitable areas.

A final report will synthesize all elements of the first two phases. Information from this study will also be used by the U.S. Army Corps of Engineers in preparing a programmatic environmental impact statement dealing with marsh management practices.

SUMMARY

Although the contributions from OCS activities to coastal wetlands loss are small, their effects are measurable and, indeed, can be significant in local areas. Many of these impacts can be avoided by wise environmental planning. The Gulf of Mexico has been and will continue to be, at least for the next 10 years, the site for the majority of offshore oil and gas development in the United States (Boesch and Rabalais, 1985). Onshore impacts obviously will be an important consideration.

Wetlands loss is a continuing problem that can only effectively be addressed by the cooperation of a number of federal and state agencies sharing their resources. The cooperative agreement between the MMS and State of Louisiana in addressing the effectiveness of marsh management plans exemplifies such a constructive endeavor. A technical consensus is needed on the efficiency of many of the proposed mitigative approaches: backfilling canals, leveling spoil banks, levees, water control structures, locks on navigation canals, and freshwater diversions. Results of this study will be helpful to individual land owners and land managers in protecting their lands from wetlands loss while improving their value through resource management.

The impacts of coastal discharges of OCS-produced formation waters have been considered to be of significant concern to warrant further investigation. Existing information relevant to produced waters will be assimilated and integrated to evaluate components, especially total dissolved solids, oxygen-demanding wastes, trace metals, aromatic hydrocarbons, and radionuclides. Information on location of discharge sites, daily discharge rates at each site, and the nature of the environment in each area will be needed to determine the extent of impacts. The findings of this study will be used to assess the magnitude of present and possible future discharges of produced water, to assess the environmental consequences of these discharges, and to support development of mitigating measures, if warranted.

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IMPROVED U.S. STRATEGY FOR FISHERIES LAW ENFORCEMENT

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ABSTRACT

The nature of the threat to the fisheries resources of the United States has drastically changed in just the last few years. Enacting the 200 mile Exclusive Economic Zone in 1976 attempted, among other things, to stimulate the U. S. domestic fishing industry and exclude foreign fishing. It has been so successful in these objectives that our fisheries resources are still being endangered. The present U. S. law enforcement strategy, designed primarily for foreign fishing vessels, is inadequate for the present threat. Exacerbating this problem is a period of finite government resources. An analysis of the current strategy and an improved strategy is presented.

INTRODUCTION

The United States exercised fishing law enforcement from shortly after it emerged as a nation. This effort, in particular that of the U. S. Coast Guard and the National Marine Fisheries Service (NMFS), has continued to grow more complex with significantly increased responsibilities added by the 200 mile Exclusive Economic Zone (EEZ). Radical changes in the nature of these fisheries operations during the last few years call for improvements in our strategy. Emphasis is necessary on enforcement of domestic fisheries as U. S. industry continues to grow and replace foreign competitors in the EEZ.

I intend to examine the current U. S. strategy for fisheries management (in particular law enforcement in Alaska) by applying a framework for the analysis of military strategy. The framework is based around that of Captain George Edmund Thibault, USN, previous Chairman of the Department of Military Strategy at the National War College, Washington, D.C. In particular, each of five major groups of elements common to all strategies will be assessed: context, capabilities, assumptions, objectives, and costs (benefits and risks). This systematic approach will enable me to recommend changes to our current strategy. The analysis is not concerned with specific tactics, such as employing ships on patrol in covert/overt modes.

CONTEXT

This is the environment within which the strategy must operate. These are the external factors that work upon the strategy and influence its success or failure.

Economic/Societal: Fishing ranks with agriculture as one of the earliest food producing endeavors by man. As the world population growth explodes, increasing world food supplies have not kept pace with escalating demand. Droughts and other weather catastrophies, industrialization, residential development, and soil erosion all accentuate this shortage. In turn, this creates severe competition for available food sources from the sea. Living sea resources are a critical component of the diet in many Asian countries and a major part of their industry. Many developing nations have rising aspirations to share in the ocean resource wealth and see indigenous fishing industries as a means to increase both basic nutritional levels and GNP. Meanwhile, new markets are developing for species previously considered either uneconomical or unappetizing. U. S. fish consumption continues to increase, most likely due to increasing health consciousness. These factors increase the instances of resource exploitation. Overfishing of a particular region is not generally identified until the catch declines for a sustained period. Severely decreasing yields are observed in many species. The economic incentive is a powerful motivating force in the quest for living resources. Major capital investments can lead to major profits if the right fish is economically harvested. Taken as a whole, the economic/societal element encourages exploiting for profit.

Technological: The drive for economy in fishing is best exemplified in the explosion of fishing technology. Larger and more efficient ships appear with improved methods of fish forecasting, locating, capture, and processing. These sensors coupled with advanced communications and navigation equipment have outpaced improved methods of surveillance (detection, location, and identification) available to law enforcement agencies. Diversity of fishing vessel types, sizes, methods, and gear add to the complexity.

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Political-Domestic: The U. S. Congress enacted Public Law 94-265 to prevent overfishing of U. S. fishing resources, rebuild overfished stocks, and develop the U. S. domestic fishing industry. The "Magnuson Fishery Conservation and Management Act of 1976" (MFCMA) established an exclusive fisheries conservation and management zone extending 200 nautical miles seaward of the U. S., effectively encompassing 20% of the world's fisheries resources. The U. S. Coast Guard and National Marine Fisheries Service were given enforcement and management responsibilities respectively under this act. This unilateral action was in response to a failure of the existing international fishery agreements to effectively prevent or terminate overfishing by foreign fishing vessels in our coastal seas. Because much of U. S. growth and commerce is tied to the coastal sea area, the U. S. public shows little tolerance of foreign infringements in this area. The U. S. commercial fishing industry, a special culture all its own in many areas, spawned powerful political interest groups that continue to strive for noninterference from federal regulation and general freedom of operation. This is an especially important force considering the extraordinary resurgence of the U. S. commercial fishing fleet in recent years. Overlapping this atmosphere is increasing competition for scarce government funding which has major consequences for federal law enforcement needs: manpower, new technologies, and air and sea enforcement vehicles. Recent congressional budget problems for the Coast Guard caused an immediate 54% reduction in cutter days and a 55% reduction in aircraft flight hours in Alaska. Especially considering the ever increasing emphasis on drug interdiction, the political winds are not in favor of increasing funding of Coast Guard fisheries law enforcement. Another highly charged political area involves animal rights activists who are striving to curtail incidental killing of marine mammals. This is likely to have a severe impact on existing or proposed international fishing agreements.

Political-International: This is an extremely complex area with tensions heightened by: lack of consensus on numerous fishing issues, jurisdictional disputes between nations, resentment between developed and developing nations, and trade relations problems. The rapid move towards Americanization or "full utilization" of the Alaskan groundfish fisheries in the EEZ has moved the U. S. to curtail directed foreign fishing in the Bering Sea and Gulf of Alaska. Gradually, foreign processors on joint ventures will also be forced out. In 1986, U. S. fishermen caught 80% of the 6.7 billion pounds of fish taken from U. S. waters. This trend coupled with such recent activities as "Japan bashing" and trade balance problems is not making the international environment conducive for cooperative law enforcement. Exclusion of foreign fishing vessels (FFV) from the EEZ and either lack of or inadequate agreements with other countries result in little or no enforcement leverage on FFV's. Differing objectives of the U. S. State Department and National Marine Fisheries Service (NMFS) have compounded this problem, the former concerned with the larger national security interests and the latter with protection and development of valuable national resources.

Physical Environment: The Alaskan region provides the most complex and diversified law enforcement problem. Consider the major aspects: 6554 miles of coastline (54% of total U. S.), vast foreign and domestic interests, and numerous stocks of important fish (salmon, halibut, king crab, tanner crab, plus other species such as pollock, ocean perch, turbot, sablefish). This creates a complex set of requirements: closed areas/varied seasons, fishing gear restrictions, different governments, disparate species, dissimilar fishing fleets and methods, high density of fishing vessels, and numerous and complex laws and international agreements. Severe weather conditions year round including frigid sea and air temperatures makes for one of the harshest seagoing operating environments in the world.

ASSUMPTIONS

Each assumption must be explicitly stated because each identifies a risk or concern that will form the basis for the strategy. These are my assumptions:

Fish resources are scarce enough and demand for fish products high enough to conclude that foreign and domestic fishermen can justify the risk of violating existing regulations and the U. S. can justify some level of effort and expense of enforcing them.

Foreign governments are not helpful in deterring violations by their fishing fleets without some economic quid pro quo for their fishing industry.

State Department decisions will override Coast Guard enforcement decisions due to foreign policy or diplomatic implications.

It is imperative to gain cooperation of the foreign governments to effectively enforce fishing regulations.

There is inadequate scientific data to develop effective fisheries management plans which in turn direct enforcement requirements. Accentuating the problem is a lack of NMFS scientific data observers on fishing vessels within the EEZ (none on domestic vessels).

There does not exist, nor is there likely to be developed in the near term, an effective model to make cost-benefit estimates of alternative enforcement strategies, i.e. mix of sensors, vehicles, and personnel.

Coast Guard resources available for fisheries law enforcement will remain severely limited due to budget constraints and the priority of drug enforcement.

Current efforts are not adequate to deter violations.

Cooperation from Department of Defense agencies on surveillance/monitoring of fisheries is extremely limited.

Fisheries will remain regulated, not prohibited.

Most effective law enforcement method is to deter by (1) presence and (2) detection.

Random detection techniques are inadequate, systematic methods are needed.

Strict on-site enforcement is needed to monitor harvest quantities, resolve conflicts among fishermen (domestic and foreign), and apply the myriad specific regulation requirements (type of gear, net mesh size, prohibited species, size of fish, licensing, etc.). Detection and identification alone do not constitute enforcement.

To obtain data for scientific analysis in support of fisheries management plans, NMFS observers are needed in sufficient numbers on board fishing vessels throughout the EEZ.

While there exists some possibility that NMFS observers may be bribed, harmed, or deceived, their value for scientific and law enforcement (deterrence) functions far exceeds these possible drawbacks.

Alaskan environment is not suitable for "high tech" vehicles, such as hydrofoils or surface effect ships.

Aircraft remain the cost effective surveillance vehicles providing primarily detection and minor deterrence functions effective over large areas.

Space based satellite surveillance/monitoring systems are not realistic options (besides prohibitive cost, severely limited in ability to make specific identification and determine activity in sufficient detail to make law enforcement decisions).

Surface ships are the primary law enforcement vehicles capable of identifying, determining activity, boarding, and inspecting in detail. Ships are not effective in detecting nor deterring alone because their functions are confined to very local areas. However, they establish the credibility of the aircraft detection and other "presence" law enforcement functions. Ships are extremely hampered in law enforcement activities without a helicopter assigned.

Intensive political action is necessary for an effective fisheries management program. Concentrated lobbying efforts are expected in response to any tightening of requirements and increasing law enforcement activities on domestic fishermen.

With the Americanization of Alaskan fisheries, domestic fishermen pose the major problem to long range conservation of groundfish.

The general U. S. public is concerned with ecological problems of the oceans and can be counted upon to express indignation at failures in this area.

CAPABILITIES

This entails just what are our law enforcement forces and what are the "forces" which oppose them (Alaskan area).

Government Capabilities (based on CY 1987 figures).

The U. S. Coast Guard, Department of Transportation, is the agency with major statutory authority for maritime law enforcement in areas of U. S. jurisdiction. The Coast Guard expends approximately $105 million (6% of its annual budget) on fisheries law enforcement (East, West, and Gulf Coasts included).

Two medium endurance cutters dedicated to fisheries law enforcement (30-45 day patrols), eight multi-mission high endurance cutters part-time dedicated (45-60 day patrols), and miscellaneous smaller vessels on occasional patrols for a total of approximately 600 cutter patrol days per year. A total of three short range helicopters are available for deployment on the high endurance cutters.

Six long range surveillance aircraft for a total of approximately 1500 patrol hours per year.

Land based command, control, communications and intelligance operations in Juneau, Alaska. Logistics and communications support provided by the Coast Guard centers at Kodiak, Alaska.

With the exception of some of the dedicated resources, Coast Guard personnel on the multi-mission cutters engaged part-time in Alaskan waters are minimally trained and often inexperienced in fisheries law enforcement.

The National Marine Fisheries Service, Department of Commerce, is the agency tasked with primary management and scientific responsibilities of U. S. resources in the sea. It shares the enforcement function with the Coast Guard. NMFS forces consist of experienced enforcement agents and trained "observers." The former work closely

with the Coast Guard and State officials in law enforcement while the latter, stationed aboard FFV's under permit in U. S. waters, primarily perform scientific data collection with some assistance in detecting violations. Currently the only vessels which have observers assigned are foreign processors involved in joint ventures working with domestic catcher boats.

Foreign/Domestic Fishing Capabilities (based on CY 1987 figures).

Approximately 8000 vessels identified from seven (7) countries including the U. S. (75% are domestic).

Hundreds of foreign vessels operate outside the EEZ with potential to poach U. S. resources by covertly fishing within the EEZ. There is no U.S. enforcement jurisdiction unless they are caught in the act.

Sophisticated communications capabilities to warn of Coast Guard law enforcement presence, exploiting probably other intelligence methods to avoid detection of violations.

Lack of explicit fish catch/transfer log keeping requirements on joint venture and domestic vessels provides significant latitude for violation nullifying law enforcement actions.

Technically sophisticated fishing fleets using the latest methods to detect, harvest, and process fish.

Numerous fishing techniques and complex regulations, often with lax enforcement requirements, increases the capacity to violate with decreased risk of detection.

Balance of "forces" based on CY 1987 figures of total fishing vessels in Alaskan waters:

% vessels sighted (FFV's only):	30%
% vessels boarded:	6-7%
% boardings resulting in incidents:	9%

It should be apparent that the "numbers" balance greatly favors the side of the foreign and domestic fishing industry.

OBJECTIVE

A clear and precise objective serves two purposes. It describes what the strategy is designed to achieve and is a measure of success, i.e. determines when the objective is achieved. It should be considered a grade sheet (measure of merit) and assessed against the problem it is designed to solve. The military objective (in this case the law enforcement objective) must carry out national policy. It should flow directly from the political objective. In particular, maritime law enforcement strategy is the art and science of employing enforcement agencies to secure the objectives of national policy by the application of force or the threat of force.

Our current objectives:

National (Political Policy) Objectives

Long range conservation and management of fishing resources.

Stimulation of the economic well-being of the domestic fishing industry.

Protection of the resources for the exclusive use of U. S. fishermen (control foreign fishing).

Promote the use of non-traditional (underutilized) species.

Fisheries Law Enforcement Objectives

Enforce the federal fisheries statutes.

Enforce international fisheries treaties and agreements.

Conduct surveillance in support of enforcement activities and other agencies for fisheries conservation purposes.

The first observation that we can make is that there are really conflicting political objectives. For instance, eventually conservation of fisheries will run headlong into economic concerns of the domestic fishing industry. Also, how does exclusive use by U. S. fishermen mesh with national security objectives of promoting a well-functioning international economic system and ensuring U. S. access to foreign markets? Besides these conflicts, the law enforcement objectives do not relate directly to the political objectives nor are they measures of success. There is no way of knowing when the objectives have been met. The major "measure of effectiveness" used by the Coast Guard is patrol effort, i.e. expended cutter days and aircraft hours. In Alaska, the Coast Guard has attempted to define a goal of boarding all FFV's that have been on the fishing grounds for a specific period of time.

AN IMPROVED STRATEGY

First, given the context (environment), what is the current "threat," i.e. problem to be solved? Going back to one of the original intents of the MFCMA, it can be simply stated as "to prevent an overfishing of U. S. fishery resources, rebuild overfished stocks, and insure conservation to provide optimum yields on a continuing basis." Given my assumptions, what should be the objective? I believe the best objective would be to "deter overfishing of U. S. fisheries resources by law enforcement presence supported with collection and processing of scientific data to maintain optimum fishery yields." Note that

it concentrates on "deterrence" to prohibit violations from ever happening in the first place rather than "enforcement" of regulations. Further, we will know when the objective has been met by sustaining "optimum fisheries yields." On the surface, the overwhelming opposition forces (fishing vessels) facing our limited law enforcement produce an apparent dilemma. However, the true law enforcement balance lies not in equality of forces alone, but in the combination of force and strategy.

COSTS (BENEFITS AND RISKS)

What are the additional means that must be employed to achieve this end and the corresponding costs, benefits, and risks? We should:

Make sweeping changes to the current domestic fishing regulations to simplify, close up "loopholes," tighten log keeping requirements, and increase penalties.

Institute a 100% observer program for all major fishing vessels in the EEZ, domestic as well as foreign. This will provide for significantly increased deterrence along with the presently missing scientific data collection.

Commence an education program for all domestic fishermen to stress the importance and means of fisheries conservation and awareness of applicable laws, including penalties. The intent is to enhance the Coast Guard and NMFS images and improve relations with this important political group.

Insure some percentage of the annual fisheries yield is allocated to foreign fishing industries. This should provide some leverage against violations by "poachers" and fit better with other national security objectives. Enhanced cooperation of foreign governments and the State Department is necessary in our law enforcement efforts.

Undertake a campaign to better inform the public on fisheries conservation problems. Pressure on legislators is necessary to insure success on any of these means.

These additional actions coupled with the current Coast Guard and NMFS efforts will provide the essential elements of a "classic" effective law enforcement mission:

Education program to inform those affected.

Compliance through patrol and surveillance.

Deterrence by presence, penalty provisions, and punitive measures.

How should this be funded? Costs are generally small with the exception of the 100% observer program. Based on 1987 NMFS data, the program cost would be on the order of $6200/observer/month. I would suggest all or most of the costs be born by the fishing industry as has been the practice with the FFV's. One means could be prorating costs by vessel tonnage. Special compensation could be made for "small" inefficient catchers. Given some of the net profits available, it does not appear that this would be unreasonable to help us achieve the goal of maintaining optimum fisheries yields. In the long haul, this would sustain a level of catches with maximum economic gain, avoiding the boom and bust cycle of depleted fisheries.

The risks are self-evident. Politically there is much exposure in combating a powerful domestic fishing group that shuns federal regulation. The other alternative is equally as clear, but with an increased hazard. Failure will result in depleting species to the point where their survival is threatened and the entire fishing industry suffers, domestic and international. Furthermore, significant continued reduction of fisheries could have unimaginable affects on the world ecological balance. It is time to embrace a new strategy.

CALIFORNIA SEA OTTER: IMPACT ASSESSMENT AND MITIGATION

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ABSTRACT

This paper examines oil containment equipment effectiveness and some of its limiting factors in the California sea otter range. Some critics of OCS oil and gas activities have tended to entirely discount the usefulness of oil spill cleanup and containment equipment as mitigation for potential impacts of OCS accidents upon sea otters, thereby overstating potential oil spill impacts. This paper cites oil spill-occurrence probability from OCS activities; examines the types of equipment available within 24 hours to points within the California sea otter range; and, using data compiled in a new Minerals Management Service study, provides an estimate on the percent of time this equipment could be deployed and effectively used under sea and weather conditions typical to the sea otter range.

1. INTRODUCTION

The Department of the Interior's Minerals Management Service (MMS) has been involved in the regulation of exploration, development, and production of oil and gas resources on the Federal Outer Continental Shelf (OCS) since 1953 [1]. The MMS Environmental Studies Program was started in 1974 to provide environmental information and analysis of marine and coastal ecosystems. The California sea otter, *Enhydra lutris*, is an important study topic of this program.

The sea otter inhabits the northern Pacific coast intertidal and shallow subtidal areas, with populations in the Soviet Union, Alaska, Canada (British Columbia), Washington, and California.

The California sea otter population, estimated in 1988 at about 1600 animals, is considered a "threatened" species under the Endangered Species Act [2]. This designation, made in 1977, was based on the small population size, limited range, and the risk of oil from a major tanker spill contacting and killing a large number of California sea otters [2]. Unlike most other marine mammals, sea otters lack an insulating subcutaneous fat layer (blubber). Instead, they depend upon air trapped within their dense fur for insulation.

The California sea otter's range extends from Año Nuevo, about 65 km south of San Francisco, to Point Sal, about 50 km north of Santa Barbara. Sea otters are more often seen in waters 60 m or less. In 1987 the U. S. Fish and Wildlife Service (FWS) moved 60 animals from the above range to San Nicolas Island, located about 80 km west of Los Angeles. This is the first installment of a total of 250 animals that FWS plans to translocate to San Nicolas Island in their attempt to expedite the species recovery.

The sea otter population has remained relatively stable until just the last few years when an increase in the population was noted. This increase coincided with a 1985 State law (Senate Bill No. 89) restricting the gill-net fisheries to depths greater than 15 fathoms (18 m) in areas of sea otter occupation. The Marine Mammal Commission in their 1985 annual report [3] estimated gill-net related mortality between the years of 1973 and 1983 to be about 105 animals per year. The FWS recently estimated the gill-net mortality caused a 6% annual reduction of the sea otter population over a 10-year period [2]. The restrictions on gill-net fisheries have reduced this source of sea otter mortality.

The MMS Environmental Studies Program has been extensively involved in sea otter research. The MMS funded one of the first studies to document the effects of oil on sea otter fur [4]. Since 1983, MMS has continually funded studies on the biology and behavior of this species.

2. EVALUATION OF THE EFFECTIVENESS OF OIL SPILL CONTAINMENT WITHIN CALIFORNIA SEA OTTER HABITAT

A. Potential Oil Spill Sources

The potential oil spill sources associated with offshore oil activities include platforms, pipelines, and tankering. The spill rates for platforms, pipelines, and tankers are respectively 1.0, 1.6, and 1.3 spills of over 1,000 barrels (bbl) per billion barrels produced, or transported [5]. These estimates are based on the amount of oil spilled divided by the amount of oil produced or transported.

Oil spills originating from offshore exploratory rigs or production platforms are extremely rare. Since 1963, over 950 wells, either for exploration or development, have been drilled on the Pacific OCS [6], with the 1969 Santa Barbara oil spill,

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estimated at 10,000 bbl [7], being the only significant accident.

The most probable spills are small and associated with routine platform operations and are anticipated to be less than 100 bbl [8].

Woodward-Clyde [9] developed a model to estimate oil slick size 24 h after a spill, as a function of oil spill volume. ARCO [8] also developed a model using different oil viscosities and instantaneous oil spill volumes to determine spill radii. ARCO's and Woodward-Clyde's models show a 10,000 bbl spill having a radius of about 1.6 km and 2.9 km, respectively. The large discrepancy in these models is expected. Slick size is highly variable and dependent on many factors such as wind and wave conditions and oil type.

B. Equipment

Oil spill containment equipment from OCS operators, government agencies, and private sources is available for emergency deployment in sea otter habitat. Containment booms, skimmers, work boats, and other specialized equipment are maintained on or at OCS platforms, at the site of exploratory operations, and at shore-based support facilities. This equipment is available for immediate deployment.

For spills larger than 10 bbl, shore-based equipment is deployed. This equipment is maintained and used by spill response cooperatives. Two major cooperatives are located near the ends of the sea otter range: Clean Bay, Inc., which operates in the vicinity of San Francisco Bay; and Clean Seas Cooperative, which is located near Santa Barbara, California.

Clean Seas equipment can be deployed to areas of current OCS oil and gas operations in less than 4 h. The area of existing OCS operations extends from just north of Point Conception, offshore of Santa Barbara County, south to offshore of Orange County. Additional equipment is also available in Long Beach at the Clean Coastal Waters Cooperative, in San Francisco at the U.S. Coast Guard Pacific Strike Team, and the U.S. Navy in Stockton. In addition, numerous emergency response contractors are located in the southern California and San Francisco Bay regions. Response times from these locations to points within the sea otter range are estimated at 24-48 h.

Three open ocean vessels are the dedicated response vessels for the Clean Seas Cooperative, each with operating speeds of 8 - 12 kn. *Mr. Clean I* is a 42-m vessel based in Santa Barbara; *Mr. Clean II* is a 40-m vessel based in Avila Bay, San Luis Obispo County; and *Mr. Clean III* is a 55-m vessel based at sea, northwest of Point Conception at Platform Harvest. Before the end of 1988 Clean Bay will purchase a 42- to 50-m vessel similar in design and function to the Clean Seas vessels. These cooperatives also have many smaller vessels.

Mr. Clean II and the Clean Bay vessels are capable of reaching Point Lobos, Monterey County, within 12 h [10] (assuming a 1 h mobilization time and average speed of 8 kn).

Oil spill containment booms, skimmers, absorbent materials, and vessels used to deploy this equipment and pick up the oil are the basic tools used in oil spill containment and cleanup.

Booms are used to actively capture and contain oil by boats pulling the boom around a slick, or used passively to divert or exclude oil from an area. Booms range in size from 30 cm to over 2 m in height and up to 600 m in length. Texaco [10] listed over 21 km of offshore booms capable of being deployed in the sea otter range.

For a large, quickly debouching spill, such as a tanker spill heading towards shore, booms would probably be deployed in overlapping lengths of up to 600 m along the leading edge(s) of the moving spill to attempt to contain the oil. For continuing spills (e.g., platform blowouts) semipermanent booms may be deployed, if feasible to contain the oil. Advancing mode skimmers and stationary skimmers would pick up the oil. Dispersants may have to be used in the offshore environment for the larger spills where other methods are not working. Dispersant use would require State and Federal Government approval.

Booms have been tested offshore, but these tests have not usually involved actual oil slicks. An offshore boom was tested by the U. S. Coast Guard in significant wave heights of 2.4-4.3 m. No structural failures occurred, although there was some minor boom damage. Occasionally splash-over was observed. The Coast Guard also deployed a self-inflating boom in waves up to 2.1 m. The boom experienced no mechanical failures, but splash-over and drainage failure could have occurred if oil had been used during the test [11].

A test using crude oil, performed off Newfoundland in 1987, was conducted by the Canadian Coast Guard, Environment Canada, and Minerals Management Service. About 475 bbl of crude oil was spilled in waves ranging from 1.8 to 2.0 m and winds up to 30 kn. Recovery of oil was successful when the containment booms were being towed downwind [12].

Skimmers are used to recover spilled oil and transport it to vessels or to shore. Waves affect skimmer performance because high seas move the oil collection mechanism away from the surface. Currents can affect the performance by allowing oil to escape under the collection mechanism. Some skimmers can effectively work in 3.1 m waves and currents up to 1.5 kn [13]. Walosep-type skimmers (W3 and W4) have been documented in field tests by the Norwegian government as performing well in 2-3 m sea conditions and winds in the 15-25 kn range [14]. The oil spill cooperatives have this type of skimmer and others in their inventories.

C. Environmental Limitations

The California sea otter range includes a variety of shoreline types. Protected bays, sandy beaches and exposed rocky shores with steep cliffs and offshore chimneys, stacks and shores are some examples. The rocky, steep cliff coastline found between Morro and Monterey Bays presents serious limitations to deployment of shore-based oil spill containment and cleanup equipment. Deployment of equipment can be accomplished by air or by vessel from ports adjacent to these areas. Travel time and other factors such as weather condition, visibility, and time of day may limit effectiveness of the equipment deployment.

Winds along the central California coast within the sea otter habitat are from the northwest during most of the year. The summer is dominated by northwest winds; the winter winds are variable. Winds in excess of 33 kn (winds high enough to generate surface currents in excess of 1 kn and thus limit the effectiveness of the containment equipment) occur about 3 percent of the time [15].

Because fog and darkness have been a limitation in finding a spill and in deploying containment equipment, the Newfoundland test [16] examined the use of shipboard radar as an oil tracking tool. They found that existing ship's radar proved effective in tracking oil slicks in Beaufort sea states of 1-5, provided that heavy swells were not also present. Procedures for using this technique include adjusting interference filters to locate areas of reduced sea return, which indicate slicks.

Wave height and period of wave energy are critical factors for deployment of oil spill containment equipment. Data compiled for the MMS Coastal Wave Statistical Data Base Study [17] are used in this report. In addition to wave height and wave period, Earle and Eckard also examined the wave direction. These data are exclusively high quality observations of waves gathered by instruments over a 10-year period. Figure 1 shows the 12 locations that were used to describe the nearshore and offshore waves in and near the sea otter range. The water depths of the six offshore locations range from 70 to 1138 m (Table 1). The six nearshore sites ranged in water depth from 5 to 23 m.

Tables 2 and 3 show the average winter and annual wave height and peak wave periods for the total sea otter range and its nearshore and offshore components. The tables also show the percent of waves less than 2 m and less than 3 m in height and wave periods greater than six seconds for the same time and areas. A 2 m wave height is considered by some critics as the upper operational limit of containment equipment [18]. The other parameter that influences containment effectiveness is "period of maximum wave energy." This is the period of the waves with the most energy and is proportional to wave height squared. It is also the time interval between the observed larger waves. Periods of wave energy of less than six seconds are associated with short, choppy

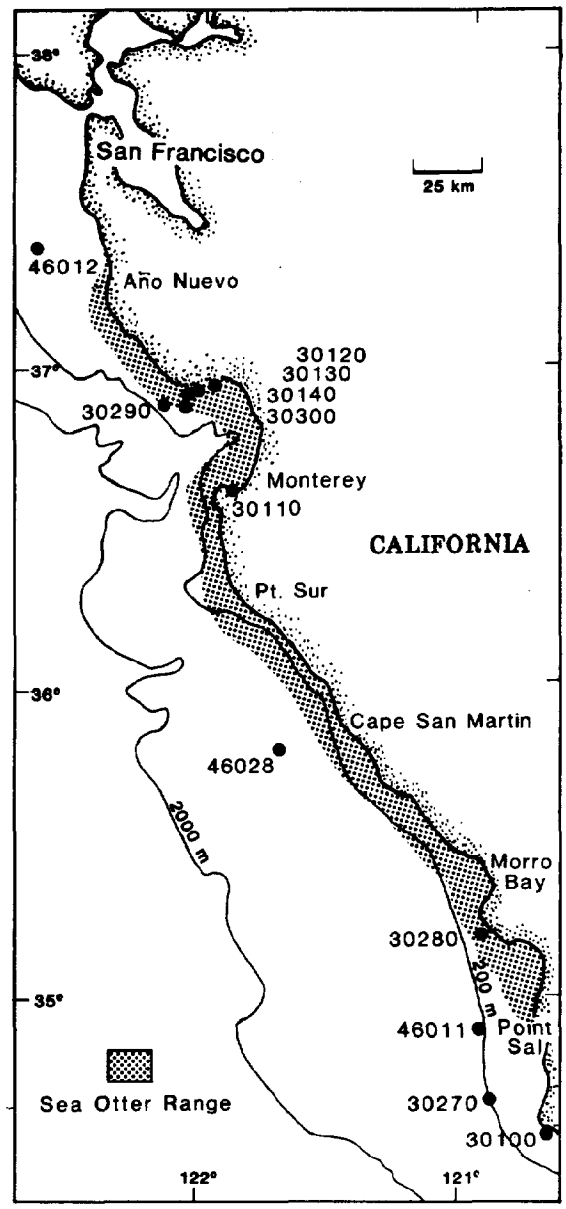

Figure 1. Sea Otter Range and Wave Measurement Site Locations.

waves that could limit the effectiveness of the oil spill containment equipment.

Average annual wave height and wave period for the total range, nearshore area, and offshore area are,respectively, 1.5 m and 11.7 s, 0.8 m and 13.2 s, and 2.0 m and 10.5 s. The winter averages, for the period from December to March, were, respectively, 1.8 m and 12.9 s, 1.0 m and 13.7 s, and 2.4 m and 12.5 s.

The annual frequency of waves 2 m in height or less were 62%, 96%, and 57% for the total range, nearshore area and offshore area. For the winter, the figures were 46%, 91%, and 38%.

Table 1.
Wave Measurement Sites Within Sea Otter Range

ID	SITE NAME	LAT.	LONG.	DEPTH (m)
	Offshore Locations			
30270	Point Arguello Buoy	34.50	120.73	201
30290	N Monterey Bay Buoy	36.86	122.15	99
30300	Santa Cruz Buoy	36.89	122.07	70
46011	Santa Maria	34.90	120.90	200
46012	Santa Cruz	37.40	122.70	82
46028	Cape San Martin	35.80	121.70	1138
	Nearshore Locations			
30100	Pt. Arguello Harbor	34.57	120.63	6
30110	Monterey Harbor	36.60	121.89	14
30120	Capitola	36.97	121.95	5
30130	Santa Cruz Harbor	36.96	122.01	13
30140	Santa Cruz Pier	36.90	122.02	7
30280	Diablo Canyon Buoy	35.21	120.86	23

Table 2.
Sea Otter Range Frequency Distribution of Periods of Maximum Wave Energy

Average Period (seconds)	Offshore	Nearshore	Total
Annual	10.5	13.2	11.7
Winter	12.5	13.7	12.9
Frequency Of Waves Greater Than 6 Seconds			
Annual	95%	90%	95%
Winter	98%	94%	98%

Earle and Eckard [17] also provided a two-dimensional presentation of the above parameters. The significant wave height and maximum wave energy distributions which together represent the most likely environmental factors that could limit the effectiveness of the containment equipment, were examined. These data were presented in a matrix from which the frequency, expressed as a percentage of occurrence of waves less than 2.0 m in height and/or a period of greater than six seconds, could be gleaned. The annual percentages total for the entire range and offshore and nearshore areas were 57%, 52%, and 84% respectively. For the winter, the corresponding percentages were 44%, 37%, and 70%. The matrix for the total sea otter range wave data is shown in Table 4. The percentage of time containment equipment could be deployed increases significantly when one considers other sea conditions such as small waves with short periods or large waves with long periods as summarized in Table 5.

Table 3.
Significant Wave Height

Average Wave Height (meters)	Offshore	Nearshore	Total
Annual	2.0	0.8	1.5
Winter	.4	1.0	1.8
Frequency			
Less than 2 meters			
Annual	57%	96%	62%
Winter	38%	91%	46%
Less than 3 meters			
Annual	86%	99%	88%
Winter	73%	98%	77%

3. CONCLUSIONS

A significant amount of oil spill containment and cleanup equipment is available within and near the sea otter range and can be mobilized in all parts of this range within 12 h of notification. Woodward-Clyde's [8] and ARCO's [9] oil spill spreading models indicate that a spill as large as 10,000 bbl could be contained by the booms readily available from the nearby oil spill response cooperatives.

Based upon recent data [17], the seas in the sea otter range should provide no apparent restrictions to the successful deployment of equipment and the recovery of a portion of the spilled oil 57% of the time during the year. For the winter months the rate decreases to 44%.

It should again be noted that these estimates are conservative. These numbers do not consider very small waves, less than 2.0 m, when the period is 6 seconds or less and large gentle waves with a period over 10 seconds. Recovery under these conditions has at times been successful, for example the 475 bbl off Newfoundland. Small waves, less than 1 m, with short wave periods and large, long period waves are believed to be within the deployment and operational limits of the equipment. If these conditions are considered, the percentage of time over the year, and also during the winter, that this equipment could be deployed goes up to 85%.

This paper has shown that adequate equipment is available to contain up to 10,000 bbl of spilled crude oil, that vessels are available to transport equipment to the site of the spill within 12 h, and that sea conditions should allow deployment and containment of oil spills a majority of the time.

In conclusion, oil spill containment can be an effective tool in reducing the impacts of oil in the marine environment and should be considered an important factor that mitigates the potential impacts of OCS development upon sea otters.

Table 5.
Sea Otter Range Wave Height and Period Percentages

Period	Wave Condition*	Total	Offshore	Nearshore
Winter				
	Both Height & Period	43.9	36.5	70.3
	Height and /or Period	84.7	82.2	80.9
Annual				
	Both Height & Period	56.8	52.1	84.1
	Height and /or Period	85.1	82.8	95.4

* Wave Condition defines conditions when the wave height is less than two meters or the wave period is greater than six seconds or both.

TABLE 4.
Sea Otter Range - Wave Data Distribution
(percentage in range)
January-December

PEAK WAVE PERIOD

WAVE HEIGHTS (M)\(S)	0.00-	4.00-	6.00-	8.00-	10.00-	12.00-	14.00-	16.00-	18.00-	20.00-	22.00-	24.00-	ROW TOTL
7.5- 8.0	.	.	.	.	.	.	.	.	0.0	.	.	.	0.0
7.0- 7.5	.	.	.	.	.	.	.	0.0	0.0	.	.	.	0.0
6.5- 7.0	.	.	.	.	.	0.0	0.0	0.0	0.0	.	.	.	0.1
6.0- 6.5	.	.	.	0.0	0.0	0.0	0.0	0.1	0.0	.	.	.	0.1
5.5- 6.0	.	.	.	0.0	0.0	0.0	0.1	0.1	0.0	.	.	.	0.3
5.0- 5.5	.	.	.	0.1	0.1	0.1	0.1	0.2	0.0	.	.	.	0.5
4.5- 5.0	.	.	0.0	0.1	0.1	0.1	0.2	0.3	0.0	.	.	.	0.9
4.0- 4.5	.	.	0.0	0.2	0.2	0.3	0.5	0.4	0.0	.	.	.	1.7
3.5- 4.0	.	.	0.1	0.6	0.3	0.5	0.9	0.6	0.1	.	.	.	3.0
3.0- 3.5	.	0.0	0.4	1.4	0.6	1.0	1.6	0.6	0.1	.	.	.	5.6
2.5- 3.0	.	0.0	1.1	2.8	1.2	2.0	1.9	0.7	0.2	.	.	0.0	9.9
2.0- 2.5	.	0.3	2.7	4.7	2.1	3.0	2.2	0.8	0.2	.	.	0.0	16.0
1.5- 2.0	.	1.1	4.1	6.8	3.1	3.4	2.3	0.9	0.2	.	.	0.0	21.8
1.0- 1.5	0.1	2.1	3.8	7.3	2.9	2.9	2.4	1.1	0.2	.	.	0.0	22.8
0.5- 1.0	0.1	1.2	1.2	3.1	1.2	2.0	1.9	0.9	0.3	0.1	.	.	12.0
0.0- 0.5	0.0	0.7	0.4	0.3	0.3	1.0	0.8	0.4	0.1	1.4	0.0	.	5.3
COL TOTAL	0.2	5.3	13.8	27.3	12.0	16.4	15.0	6.8	1.6	1.5	0.0	0.1	100.0

Waves 2 meters or less and with peak wave periods greater than 6 seconds.

Waves 2 meters or less and/or with peak wave periods greater than 6 seconds.

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THEORETICAL ANALYSIS OF FISH SCHOOL DENSITY

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ABSTRACT

In marine fisheries, the correct evaluation of the fish school density has the practical value of reference for the increase of the fish catches.

Based on the technical datum of a fisheries sonar, and the relation between the sonar function and the target strength of an individual fish measured (E.G. the greater croaker of Cnina), and then through yhe medium of theoretical analysis, the fish school density is calculated of the quantity of the fish catches is made possible.

By the same methed, we can also obtain the similar results for any other fish or prawn etc.. These results have the universal significance as reference for fisheries workers.

1. INTRODUCTION

Fish target strength is a pivotal quantity in the acoustic assessment of fish abundance. Many people have measured the target strength or acoustic scattering cross sections of fish. The target strength is relating to the detection frequency of fisheries sonar (f), the fish length (l) and species etc.. For example, in China, the dorsal-aspect target strength of divers individual fish and prawn (TS_1) is shown in Table 1.

Table 1

Name	TS_1(dB) / l(cm)	f(khz) 30	50	200
The greater croaker	45	-30	-28	-22
The greater croaker	30	-35	-33	-27
Hairtail	100	-40	-38	-32
Prawn	20	-43	-41	-35

These reasonable approximation of the target strengths of an individual fish or prawn is essential for the design or utilization of such fisheries sonars (active-sonar systems).

This paper only discusses how to utilize these TS_1 to estimate fish school density that a fish-finding sonar (downward-looking sonar) may detect from theoretical analysis.

2. SONAR PARAMETERS AND EQUATIONS

A fish boat equipped with a fish-finding sonar (sonar is refered for short in the below text). The major technical datum of this sonar as following: work frequency (acoustic frequency) f=200khz or wavelength $\lambda=c/f=0.75$cm, where the sound speed in water c=1500m/s; transmitting electrical power (output power) W=1000wt; transmitting pulse length τ_0=1ms; transmitting area of the transducer (Ammonium Dihydrogen Phosphate---ADP) A=50.26cm^2, where it is the plane circular piston and diameter ø=8cm; electricity-sound efficiency of the transducer η=80%; all bandwidths of the receiver ω=4.5khz; survey fish depth H=500m; the speed of fishing boat v=10.5knots.

It is well known, the active-sonar equation consists of two parts, the echo level on the left-hand side and the noise-marking background level on the right, i.e.

$$SL-2TL+TS=NL-DI+DT \quad (1)$$

where TS---target strength of fish school (dB),
SL---transmitting source level (dB),
TL---transmission loss (dB),
NL---noise level (dB),
DI---receiving directivity index (dB),
DT---detection threshold (dB).

From this equation, we can obtain the target strength of fish school and it is

$$TS=NL+2TL+DT-SL-DI \quad (2)$$

these parsmeters can be calculated from the above technical datum od the sonar, they are

$DI=10Log(4\pi A)/\lambda^2=30.5$ dB,
$SL=70.8+10Log(W*\eta)+DI=133.2$ dB,
DT=10 dB (from experience),
$TL=20LogH+\alpha H=89.77$ dB (where, the absorption coefficient α=71.6 dB/km),

$NL=N_0 L+10\mathrm{Log}\,\omega - DI=-38.26$ dB {where, $N_0L=-36+20\mathrm{Log}(50/f)+1.5(v-8)=-44.29$ dB. While considering the receiver bandwidth ω, then the noise power received is the ω times larger than 1 hz bandwidth. IN the same time, as a result of DI, the DI dB will be reduced when isotropic noise is received by the transducer}.

Thus, the target strength of fish school is

$$TS=-38.26+(2*89.77)+10-133.2-30.5$$
$$=-12.42 \text{ dB}.$$

3. EMPIRICAL EQUATION OF TS

People used to utilize the empirical equation of TS as following

$$TS=TS_1+10\mathrm{Log}N-10\mathrm{Log}(\tau_e/\tau_o) \quad (3)$$

where TS_1---target strength of an individual fish,
N---number of fish school,
τ_e---received pulse length, $\tau_e \doteq 2\tau_o$ under normal conditions. As the pulse of fish school's echo is expended, the target strength of fish school is reduced.

Now, we choose $TS_1=-22$ dB from the Table 1 (the greater croaker under f=200khz), and then by the formula (3), we have

$$10\ \mathrm{Log}N=12.58,$$

or $N=18.11$ (twiy).

4. FISH SCHOOL DENSITY

Based on the half power directional angle of sound beam is transmitted by the plane circular piston transducer, the fish number (N) is surveyed

$$N=M*B*S \quad (4)$$

where M---density of fish school (twig/m^3),
B---the length is surveyed by a pulse action in the water (distance, m) and $B=c*\lambda/2=0.75$m,
S---the area is surveyed by the angle of sound beam in depth H, see Fig. 1.

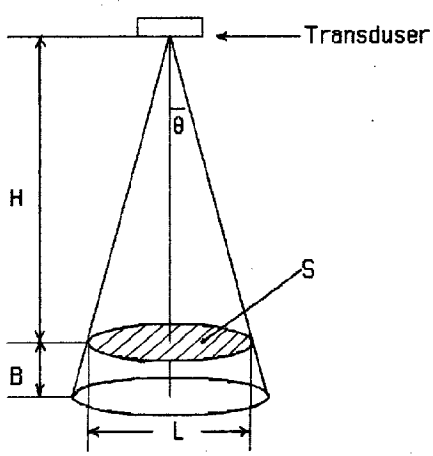

Fig. 1

Here, the directional angle in -3dB can be calculated as following: as the transducer is the plane circular piston source, its directional function is

$$P_\theta/P_0=2J_1(X_\theta)/X_\theta \quad (5)$$

where P_θ---pressure of sound in angle ,
P_0---pressure of sound in angle axis,
$J_1(X_\theta)$---the first-order Bessel function,

and $J_1(X_\theta)=(X_\theta/2)-(X_\theta/2)^3/(1^2*2)+(X_\theta/2)^5/(1^2*2^2*3)-$ (6)

where $X_\theta=2\,a(\sin\theta_{-3dB})/\lambda=\pi\phi(\sin\theta_{-3dB})/\lambda$ (7)
a---radius of circular piston (transducer),
λ---wavelength, and $\lambda=0.75$cm.

Let $P_\theta/P_0=1/\sqrt{2}=0.707$ (in -3dB) (8)

as X_θ is very small, third and succeeding term of the formula (6) can be deleted, and from the formula (5), (6) and (8), we obtain

$$P_\theta/P_0=2J_1(X_\theta)/X_\theta$$
$$=2\{(X_\theta/2)-(X_\theta/2)^3/(1^2*2)\}/X_\theta$$
$$=0.707,$$

therefore, $X_\theta^2=2.344$,

or $X_\theta=1.531$ (9)

and then, from the formula (7) and (9), we have

$$X_\theta=\pi\phi(\sin\theta_{-3dB})/\lambda=1.531,$$
$$\sin\theta_{-3dB}=(1.531*\lambda)/\pi\phi=0.04568,$$

hence $\theta_{-3dB}=2.618°$

Let $\theta_{-3dB}=2.7°$, then when H=500 m, we obtain

$L=2H(\mathrm{tg}\,\theta_{-3dB})=47.15$ m, see Fig. 1,

thus $S=\pi(L/2)^2=3.1416*(47.15/2)^2$
$=1746.68$ m^2,

at last, the formula (4) then becomes

$$M=N/(S*B)=18.11/(1746.68*0.75)$$
$$=0.01382 \text{ (twig/m}^3\text{)}.$$

For the above equation (2), (3) and (4), the corresponding values of M, N and TS can be calculated in Table 2.

And then, from the diagram relating to the fish school density (M) and target strength (TS) is drawm in Fig. 2 and Fig. 3 (common logarithm).

Here, special mention chould be made of the use of 1 yd or 1 m as the reference distance for target strength. This arbitrary reference often causes many underwater objects to have positive values of target strength. Such positive values should not be interpreted as meaning that more sound is coming back from the target than is incident upon it; rather, they should be regarded as a consequence of the arbitrary reference distance. If, instead of 1 yd (or 1 m), 1 kyd (or 1 km) were used, all

customary target would have a negative target strength.

Table 2

M	N	T
0.000824	1.001	-24.99625
0.014909	18.109	-12.42104
0.100000	121.464	-4.15553
0.200000	242.928	-1.14523
0.300000	364.392	0.61569
0.500000	607.320	2.83418
0.700000	850.248	4.29546
0.900000	1093.176	5.38690
1.000000	1214.640	5.84448
3.000000	3643.920	10.61569
5.000000	6073.200	12.83418
7.000000	8502.481	14.29546
9.000000	10931.760	15.38689
10.000000	12146.400	15.84448
50.000000	60732.000	22.83418
100.000000	121464.000	25.84448

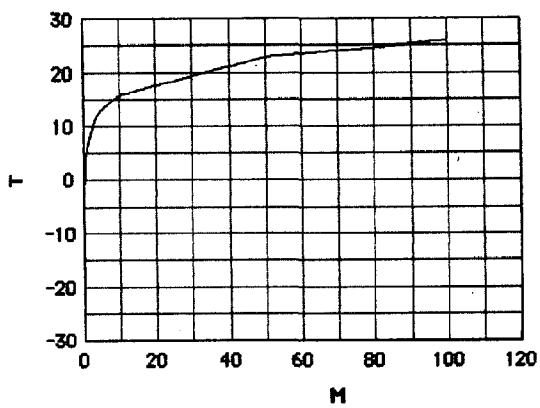

Fig. 2

From Fig. 2, we know: TS is an increase along with the increase of M, and when M is increased from 0 to 1, TS is the steep increase, the rate of increase is 25.4 dB/one unit M; when M from 1 to 10 is increased, TS is the faster increase, the rate of increase is 1.13 dB/one unit M; when M from 10 to 50 is increased, TS is the slower increase, the rate of increase is 0.28 dB/one unit M; when M from 50 to 100 is increased, TS is the very slow increase, the rate of increase is 0.06 one unit M.

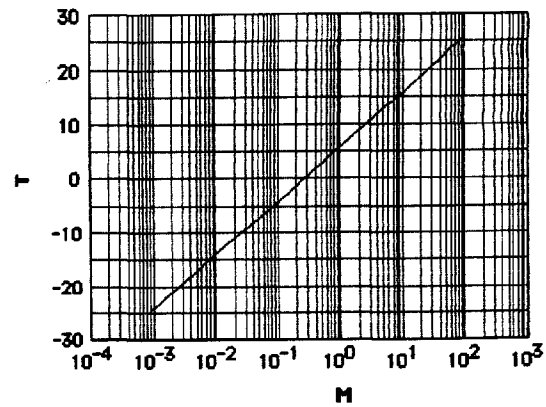

Fig. 3

Obviously, when M is increased to a certain number, the increase of TS has not been very obvious, or when the technical datum of the fish-finding sonar were determined, then the variation of TS is very small.

Applying the above principle, the corresponding curve (M-TS) will be drawn for the different fisheries sonars and the different fish or prawn. If the practical TS can be indicated in time, then look up the M in the curve and this will sive a greater convenience to the fisheries workers.

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MARINE FISHERIES TECHNOLOGY IN THE UNITED STATES: STATUS, TRENDS AND FUTURE DIRECTIONS

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ABSTRACT

In 1969, the Stratton Commission on Marine Science, Engineering, and Resource Development issued a comprehensive report reviewing the status of marine science and technology in the United States. Since publication of the Stratton Commission Report, unprecedented and unimagined advances in marine fisheries technology have occurred revolutionizing fishing practices, enhancing fishery performance, and transforming the scope and focus of fisheries management. These technological developments are reviewed with respect to resource utilization and fishery expansion, and the role of fishery technology in addressing both unfulfilled needs and problems envisaged in the future. The concept of resource enhancement is also examined since significant opportunities exist for applying marine fisheries technology to augment natural production. Management implications of current and anticipated technological advances are identified and discussed.

INTRODUCTION

Since the moment that man first used a hook and line rather than his hands to capture fish, technology has been applied to improve fishing efficiency and fishery yields. The Report of the USA Stratton Commission on Marine Science, Engineering, and Resource Development issued in 1969, millennia after the use of that first fish hook, advocated that "fishing technology should be directed toward maximum utilization of food resources and development of efficient means of exploiting them... focus[ing] on maximizing efficiency in catching fish." At the time the report was issued, the potential for technology to engender rapid depletions in fish stocks was not considered a major danger. As a result, the Commission's recommendations were heeded all to well, mostly by people who never read the Report.

Indeed, growth of the USA fishing industry during the past 20 years has been impressive. Between 1967 and 1987, the commercial catch of the United States increased by 70 percent, from 4.1 to 6.9 billion pounds. Ex-vessel revenues increased seven-fold, from $440 million to $3.1 billion, while the value of processed fishery products rose from $1.2 billion to $5.5 billion. The accompanying increases in fishery employment and fleet size have equally been striking (Table 1). Advances in harvesting and processing technology during this period generated remarkable gains in fishing performance, harvesting potential, and landings. As demand for seafood has grown due to the heightened popularity of fish products for dietary and health reasons, fisheries technology has expanded to address this demand.

However, the technological thrust to maximize domestic harvesting efficiency has not been a panacea for USA fishery problems. New technologies, many not envisioned in 1969 by the Stratton Commission, were quickly developed and rapidly applied in harvesting both traditional and non-traditional fishery resources. Over-exploitation soon became a central problem for management authorities and the fishing industry alike. Fishery regulatory schemes were, and continue to be, enacted to constrain rather than promote harvesting efficiency to attain resource conservation goals. Now, more than ever, technological aspects of fisheries are being scrutinized and, in many instances, regulated. Did the Stratton Commission's call for improvements in fishing efficiency succeed 'all too well'? Have technological advancements been "Pyrrhic victories"? Can present and future technology be guided to promote the sound utilization and enhancement of fishery resources?

HARVESTING

Since the mid-1960's, the harvesting sector trends identified in the Stratton Report have continued but at an accelerated pace. Fishing vessels are generally larger, possess greater speed and fishing power, and are equipped with more efficient fishing gear and navigation equipment than ever before. Trawls are now designed with the aid of computers with performance pre-tested using scale models in tow tanks. New materials, such as strong synthetic fibers, are used in net construction allowing for gear designs previously not thought possible (ie., large mesh - low drag). Underwater vehicles fitted with video cameras have provided new insight into fish behavior relative to trawl performance characteristics, facilitating major design and operating improvements.

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The changes wrought in vessel and gear characteristics by these technological advances are staggering. Twenty year ago, large domestic trawlers were towing nets with headropes of 100 feet in length opening vertically to a height of 15 feet off bottom. At the time, such a trawl cost about $3000. Today, the larger Alaskan trawlers use nets having headropes approaching 500 feet in length with vertical openings of hundreds of feet. The trawls are valued over $25,000 and a top earning boat can gross $50,000 per day.

Trawl openings are now larger for a given horsepower than in the past. A modern 2700 Hp vessel can tow a net with a vertical opening of 270 feet, while a smaller 300 Hp vessel can tow a trawl opening 100 feet in both horizontal and vertical directions. Vessels now have the ability to trade off net size against towing speed to improve catch efficiency on certain species. These developments are even more imposing when one realizes that overall horsepower of the USA fleet has increased markedly over the past two decades. Twenty years ago, the larger trawlers ranged between 600-1000 in horsepower; today, it is not uncommon for large trawlers to exceed 2000 Hp. In fact, some factory trawlers are now in excess of 5000 Hp.

Although the size of fishing vessels has become larger since 1969, vessel sizes have not increased proportional to horsepower. This is because horsepower is now provided by a new generation of turbo-charged fuel efficient diesels. These are light-weight, smooth-running engines of high Hp to weight ratios compared to their ancestors of the 1960's. Overall propulsive efficiency has also been improved by use of controllable pitch propellers and Kort nozzles.

Advances and refinements in hydraulics engineering and hydraulic equipment have mechanized fishing operations almost beyond belief. Larger gear can now be handled by smaller vessels with fewer men. The net reel is a major example of this improvement. Techniques such as pair trawling, which allows two smaller vessels working in tandem to tow one large net, is but one application where fishing power and harvesting efficiency have effectively been increased due to improvements in hydraulics technology.

Electronic innovations have revolutionized the process of locating, tracking, and identifying fish concentrations. Computer-enhanced fish finders/depth sounders, which can now identify bottom type, species of fish and the position and density of fish schools in the water column, have virtually eliminated trial-and-error fishing patterns. Off-the-shelf sensors such as net-mounted scanning sonar, doppler speed logs, tensionmeters, and pressure transducers are now available to monitor gear performance on a real-time basis. With this equipment, fish can be observed in relation to the net as it is towed, and even counted as they enter the trawl. Integrated computer-based systems are also becoming more commonplace in determining fishing tactics. For example, in purse seine fisheries, computer systems monitor the speed, direction, and locations of fish schools and calculate the proper vessel and gear positions to entrap the catch.

In addition to improving harvesting efficiency, electronics have significantly enhanced fisheries navigation, communication, and safety. Integrated-positioning-systems that combine steering, main propulsion, and thrusters along with the navigation suite are becoming standard equipment on many vessels. Navigation is now accomplished using LORAN or Sat-Nav sets equipped with track plotters and video displays indicating vessel position and path. Some systems even have pre-recorded electronic charts to which a fisherman can add position data on the locations of rocks, wrecks, and other obstructions.

Although communications capability has always been important to fishermen, communications systems, even in the recent past, were often limited in range and reliability. Today, while most distant ranging vessels carry Sat-Coms, most large trawlers are equipped with single side band, all-frequency transceivers and/or multi-crystal sets, two or more VHF sets, and high powered CB radios which can automatically scan hundreds of channels for traffic. This latter feature is often used for 'intelligence' gathering to reduce searching time involved with finding fish. To protect this information, many vessels are now equipped with voice scramblers to encode catch data, arrival times, price information, etc. As a result, Radio Direction Finders (RDF), which have primarily been used for navigation, are now being used to locate the position of a vessel communicating fishing information, particularly when messages are encrypted. RDF's also serve operationally to locate fishing gear possessing transponders such as surface-set drift longlines and gillnets.

Weatherfax machines onboard vessels allow for the receipt of many different types of weather and oceanographic maps. Satellite images of oceanographic features (warm-core rings, eddies, temperature and current boundaries, etc.) are evaluated to determine prime fishing areas. As an example, satellite pictures of the Gulf Stream, depicting temperature boundaries and eddies, are routinely used by fishermen in locating swordfish and other large pelagics.

Technological advances have also occurred in other types of fishing apart from trawling. In the 1960's, longlining or "tub-trawling" was much the same as it was one hundred years before. Fishermen manually cut bait and baited hooks; hauling and setting was performed manually with limited mechanical assistance. Today, many longline vessels have machines that automatically cut bait, bait the hooks, replace lost hooks, and mechanically set and haul the gear with minimum

involvement of labor. In these operations, handling 40,000 hooks per day is not uncommon. Hook configurations have also changed (ie., circle hooks) resulting in marked increases in catch per hook.

Even the small vessel pot fishery has come of age. Twenty years ago, a typical pot fishermen would set 100 wooden traps within sight of land using no electronics. Today, the same fisherman can fish upwards of 1000 plastic or plastic coated wire traps using electronic navigation and sounding equipment to precisely place his gear on the fishing grounds. As a consequence of this capability, catch rates have doubled in some fisheries. Equally, radar and LORAN have allowed fishing to proceed in fog, at night, and further offshore than before. Good positioning equipment has also facilitated the recovery of lost gear, while hydraulic and electric pot haulers now enable more gear to be fished at deeper depths. Today, it is common for offshore strings, with hundreds of traps, to stretch for miles in water depths exceeding 200 fathoms.

Jigging (one of the oldest forms of fishing) was, until quite recently, conducted in the traditional fashion by manually lowering a line with hooks and a sinker over the side. Auto-jiggers today automatically lower the line to the bottom or to a pre-set depth, jig up and down over a pre-set range, and haul back when a selected weight of fish is hooked. Some squid jigging machines bring the catch over the rail, shake it loose and automatically reset the gear.

One of the newest commercial fisheries, whale-watching, is "non-consumptive". Whale watching is estimated to be worth $35 million to the USA economy. Even whale-watchers depend on scanning sonar to follow whales as they swim underwater. Unlike consumptive fisheries, the whale-watch fishery is vitally dependent on open communications between vessels.

Onboard processing in another area where marine technology has contributed to the development of the domestic fleet in recent years. Today, an advanced system on a trawler/processor has fish coming aboard and being dumped from the cod end into a below-deck holding tank. Fish are then conveyed to computer operated machines that automatically sort by species and grade by size, enabling small crews to handle large catches. From the various outflows, the fish are processed, weighed, and boxed; electronic scales send the data to the vessel's central computer. Once boxed, fish go to a plate freezer and then into frozen storage aboard ship. In operations requiring filleting, automatic machines do the work and allow smaller sizes of fish to be processed than would have been economically feasible in the past.

Quality is now a major concern, and for vessels that do not process at sea many advanced storage techniques are employed. On many small vessels, fish are packed on ice in plastic fish boxes to prevent compression and minimize handling. Other vessels have holds filled with slush ice and speed the chilling process by pumping cold air through the hold. Where ice is difficult to acquire or maintain, refrigerated salt water systems are used.

An innovation to check quality dockside during offloading is a freshness grading machine. This machine measures changes in resistance and dielectric properties of fish flesh that differ depending on product quality. In the process of evaluating product freshness with this machine, fish are also weighed, measured, and graded.

Computers onboard vessels today are used to archive information such as catch, time, place, bottom conditions, weather, gear used, and processed product data. The latest advances in computer data storage and memory capacity are demonstrated at nearly all commercial fisheries trade shows as computers and computerized equipment have quickly become indispensible in commercial fishing operations.

Vessel safety has also improved due to technological achievements. Emergency beacons (EPIRBS) that transmit vessel location data via satellite search and rescue frequencies are now becoming standard safety equipment. Engine and bridge alarm systems are almost universally in place. Failing all else, the modern survival suit has proved to be a lifesaver.

Over the past 20 years, technology has "solved" most of the harvesting "problems" identified in the Stratton Report. However, different problems remain today. Rather than enhancing harvesting efficiency, harvesting technology now needs to be directed towards maximizing utilization of the resource base. This entails:

- designing gear from a conservation basis (improving size/species selectivity; reducing non-catch mortality; minimizing habitat destruction);
- developing harvesting techniques which enhance product quality and enable full utilization of the catch; and
- reducing energy consumption and production costs.

Harvesting technology must be kept in perspective if the major goal of management is expansion of domestic industries. Fisheries resources, albeit renewable, are finite in time and space. Harvests are rapidly approaching the limits of natural production.

RESOURCE ENHANCEMENT

The Stratton Report recognized the potential to augment natural production through aquacultural activities, and incisively

identified the necessary scientific and technological advances for fostering its growth. Although aquaculture production has rapidly increased world-wide in the past 20 years, mariculture in the USA still remains in a fledgling stage. The open-ocean applications of aquaculture, particularly the enhancement of natural populations (through stocking) and the enhancement of the environment (man-made reefs, artificially-induced upwelling; 'fertilization' with organic wastes, etc), have significant potential in augmenting oceanic production. For example, worldwide production of pen-reared salmon was 6,880 metric tons (mt) in 1980; in 1986, it was 20,000 mt. By 1990, worldwide projections call for 223,000 mt. Projected USA production, however, is only 1,000 to 5,000 mt despite the fact that the USA has excellent potential for this type of activity. USA progress in these areas remains limited due to the interrelated fiscal-legal-regulatory impediments that beset nascent enterprises. Upon removal of these barriers, the economic viability of resource enhancement will hinge on scientific research and technological advances.

One example may serve to illustrate the relationship of science and technology to future advances in aquaculture. More than 100 years ago, scientists believed that the natural production of the oceans could be augmented by releasing hatchery-reared fish into the wild. While hatcheries producing salmonids are now commonplace, those built to release fry of true oceanic species are a rarity. During the early part of this century, billions of cod and flounder fry were released into the ocean but the available evidence indicated these programs were not successful.

Today, it is well-appreciated that environmental conditions play a significant role during the first year of life of a cohort of fish and that blindly releasing fry into the ocean has little chance of success. Recent laboratory experiments, for example, indicate that survival and growth of haddock fry depends on encountering dense concentrations of prey. Traditional field sampling techniques, however, seldom found such concentrations of prey in the ocean. With the introduction of electronically-controlled, multiple opening and closing sampling devices, plankton and juvenile fish have been collected from discrete and identifiable parts of the water column. These sampling data indicate that haddock fry and their prey are concentrated near the thermocline. When storm events disrupt the thermocline, both haddock fry and their food disperse. Afterward, when the thermocline is reformed, prey aggregations reappear but the haddock fry are either missing (presumably suffering high mortality from either starvation or increased predation due to reduced growth), or re-appear in poor condition. Although the factors affecting year class strength in haddock (or most fish stocks, for that matter) are not well known, these observations suggest that environmental processes may be quite important.

Armed with an understanding of haddock life history based on new and evolving knowledge, it is exciting to speculate on future possibilities. Data from satellites monitoring oceanographic conditions could be used to determine propitious environmental circumstances promoting survival of larval and juvenile haddock. During this time, the release of millions of hatchery reared fry might have a significant impact on year class strength. While this can only be considered a science fiction scenario now, the prospect of producing a successful year class of haddock where none would otherwise have existed would be worth hundreds of millions of dollars to the economy. This may be one form that open-ocean mariculture will take in the future.

MANAGEMENT

Guiding technology to promote maximum resource utilization is the greatest challenge that management faces in the future. The current picture is one of "high-tech" fisheries and "low-tech" management. Presently, management's norm is to restrict and allocate **fishery production** (ie., cutting and serving the resource "pie"); little, if any, attention is directed toward increasing **fish production** (ie, baking a larger "pie"). In a competitive world, a growth-oriented approach is a prerequisite for economic survival. The success of fisheries technology in increasing harvesting efficiency should not be treated in a negative fashion. The imposing capabilities that stimulated this achievement need to be channeled towards expanding the resource base and utilizing present harvests more efficiently. "High-tech" management's role in directing this technology will be through leadership in eliminating legal/regulatory constraints hindering innovation, promoting ecosystem-oriented research to gain better understanding of the behavior and limits of fishery systems, and providing encouragement to government/industry to tackle the technological challenges ahead.

CONCLUSIONS

Experience with the application of fisheries technology has shown that technological development cannot be evaluated in isolation, but must be viewed in an ecosystem perspective. Tomorrow's fisheries will be more dependent than ever on a successful amalgam of science and technology.

Table 1. Key indicators of the growth of the USA fishing industry (from Fisheries of the United States).

	1967	1987
Catch ($)	440 million	3.1 billion
Catch (lbs)	4.1 billion	6.9 billion
Processed Value ($)	1.2 billion	5.5 billion
	1966	**1986**
Employment		
Fishermen	136,000	247,000
Processing/ Wholesaling	89,000	100,000
Total:	225,000	347,000
Fleet Size		
Vessels over 5 tons	12,700	38,200
Motor Boats	66,900	88,400
Other Boats	2,500	1,600
Total:	82,100	128,200

PUBLIC AQUACULTURE IN DOWNEAST MAINE: THE SOFT-SHELL CLAM STORY

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ABSTRACT

The soft-shell clam, Mya arenaria L., is vitally important to the economy and culture of the Maine coast. Annually, clamming is a $10 million industry to harvesters alone and historically ranks second in economic importance of all Maine's marine resources behind lobsters.

During the past four years, clam landings have declined by 53% due to several biotic and abiotic factors. This dramatic reduction in existing stocks prompted six Downeast coastal communities to form, in 1987, the first-ever regional shellfish management program based on stock enhancement using hatchery-reared juveniles of the soft-shell clam.

This paper will trace the development of the hatchery program, present first year survivorship data, and discuss the mechanism that has permitted ten Downeast towns to participate during 1988.

INTRODUCTION

In Maine, the soft-shell clam is a commercially important and ubiquitous bivalve that is manually harvested from soft-sediments during periods of low tide. Harvesters, using conventional garden hoes modified with shortened handles, bend over to dig or excavate individual legal-size clams ($\geq$ 2 inches from anterior to posterior shell margin) that are positioned in the substrate to depths between 8 and 16 inches. After working three to four hours per tide, clam diggers sell their catch by volume or by weight to shellfish dealers. Dealers sell whole clams (steamers) or a processed product (shucked and shipped in gallon containers) to retail distributors such as restaurants, fish markets, or grocery stores.

Over the past four years, dockside revenues for this bivalve have fluctuated between $11.6 million in 1984 and $8.3 million in 1987. Average price per bushel has increased 40% from $33.00 in 1984 to $46.00 in 1987 while landings have decreased 53% from 5.2 million pounds to 2.7 million pounds during that same time interval (1). Landings are not uniform along the coast, however, as the two eastern counties usually account for between 45% and 55% of the yearly catch. In 1986, for example, 40% of the 3,791 licensed clam harvesters in the state were located in Washington County -- the easternmost and least populated.

Maine's coastal communities with clamming habitat have the right to exercise some control over their resource. Approximately 60% of these towns directly manage their clam flats through a state-approved ordinance scheme that 1) restricts the number of local (town resident) licenses, 2) regulates which clam flats should, or should not, be harvested, 3) allows transplanting local clams from regions where growth rates are slow to areas where growth is faster, and 4) mandates that the ordinance be lawfully upheld. Those communities not opting for local management of their clamming resource have no ordinance system and permit anyone with a valid state license to dig clams anytime in any area opened for shellfishing. Townsend (2) reported that yield per unit effort was higher in the managed portion of the fishery by 15%.

The significant decreases in standing stock of soft-shell clams in Maine can be attributed to at least three interdependent factors: continual poor natural recruitment and/or post-settlement mortality, increased predation rates on juvenile populations by green crabs, fish, gulls, moonsnails and other infaunal carnivores, and over-harvesting. In addition, a 1984 law establishing a 2-inch size limit also reduced the number of marketable clams. Various attempts since then to increase the number of clams within a variety of flats along the coast by both town officials and state biologists have not resulted in consistent or improved enhancement.

These unsuccessful attempts to increase clam harvests in Maine have made harvesters, dealers, and town officials very cynical about trying anything else that is purported to significantly enhance existing, but dwindling, stocks. One method that some Downeasters are willing to try is aquaculture. Recently, private aquaculture has invaded the Maine coast which has seen a boom of successful mussel, oyster, salmon and trout aquaculture leases. During the mid-1970's, the Maine/New Hampshire Sea Grant Program supported several pilot projects focusing on soft-shell clam aquaculture. The principal investigator and aquaculture specialist at the University of Maine's Darling Marine Center, Samuel Chapman, led the research that

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resulted in efficient mass spawning, culture, and rearing methods using Mya arenaria.

This early, experimental work caught the attention of some coastal communities who began to think that clam flat enhancement, using juveniles that had been reared in a hatchery, might be a valid management tool. During the summer of 1981, 3 million juvenile "seed" clams were produced at the Darling Marine Center and were divided amongst eight coastal communities. Unfortunately, no mechanism was established to either 1) determine how these hatchery-reared individuals grew or survived or 2) continue the program. As a result, no definitive information was collected and the hatchery effort was curtailed.

Two summers later, in 1983, a Cooperative Extension agent in the Washington County office contacted Chapman and together they began work on a small-scale hatchery project for a handful of 4-H youth in Jonesboro. The town donated the use of the basement of the run-down, unused elementary school for the project. Using mainly jury-rigged equipment and an occasional tank, tubing, and fittings from the University's hatchery, Chapman demonstrated to the 4-H'ers the how's and why's of soft-shell clam aquaculture. As with many youth-oriented projects there was a concomitant carry-over effect that simarly excited the adult population of Jonesboro, a town of 500 residents and 100 licensed clam diggers.

Approximately 200,000 clams were reared that summer. The clams were held over the winter and seeded onto Jonesboro's flats the following spring. In situ growth and survival rates were monitored during 1984 and the 4-H hatchery experience was replicated for a second year. Although the program was discontinued due to funding considerations, the amount of support and goodwill demonstrated by the town and surrounding coastal areas was notable. Indeed, this small project in which children spawned, reared, and seeded soft-shell clams provided the impetus three years later for the beginning of a larger-scale and first-ever regional soft-shell clam hatchery in the Jonesboro area.

DISCUSSION

In August 1986 I received a copy of a call for pre-proposals from the National Coastal Resources Research and Development Institute (NCRI) located in Newport, Oregon. This federally-funded organization within the Department of Commerce seeks to fund marine-oriented projects that are designed to "promote the efficient and responsible development of ocean and coastal resources...(including) studies on the economic diversification and environmental protection of the nation's coastal areas."

After discussing the potential of a hatchery-based project with NCRI's Assistant Director Earle Buckley, I contacted Beals Island, Maine, businessman, Richard Carver. Carver, President of Carver's Shellfish, is owner of a 200-foot commercial wharf and attached 42-foot X 20-foot building. The building has served many functions during its 60-year history including general store, depot for island residents waiting to be ferried across Moosabec Reach to the mainland community of Jonesport, and, most recently, the site of a soft-shell clam shucking and processing plant. It had, however, been abandoned by Carver in 1984 when he decided to relocate his shellfish business elsewhere on Beals Island.

Carver decided, on the same day he was asked, to donate the use of the building and wharf to a hatchery project if funding could be leveraged. The next step was to contact a number of towns in and around the Beals Island area. After discussion with University of Maine at Machias President, Frederic Reynolds, the number was arbitrarily set at six towns. The areally contiguous towns of Addison, Jonesport, Beals, Jonesboro, Roque Bluffs, and Machiasport were contacted and after meetings in August 1986 with each town's Shellfish Committee (a group of between 5 and 10 residents who are charged with the shellfish management decisions for the town), all agreed to 1) contribute $500 to the project in the event that the proposal was funded ($500 is not much, however, in some cases it represents half of what is raised annually at Town Meeting for shellfish management), 2) join together to form a Hatchery Committee that among other things would oversee the hatchery progress, and 3) organize a crew of workers to help transplant the hatchery-reared seed clams to the clam flats during November 1987. In addition, Albert Carver, Vice President of Carver's Shellfish, contacted eleven local shellfish dealers and two banks that resulted in another $1,600 commitment for the project.

On 13 October 1986, the Board of Governors of the NCRI agreed to fund the project, "The Hatchery, Nursery, and Growout Phases of the Commercially Important Soft-Shell Clam (Mya arenaria) in Washington County, Maine," at the level of $37,300. In January 1987 a Hatchery Manager and Assistant Manager were hired to begin renovation of the former clam shop. Forty-eight 25-gallon fiberglass algae-rearing tubes, two 750-gallon fiberglass tanks for rearing clam larvae, two 80-gallon/minute seawater pumps, an air pump, water and air filters, hot water heater for both seawater and freshwater, graded series of nylon screening, material for 200 floating window screen-lined wooden trays, many feet of PVC piping, PVC and brass needle valves, fittings, lights, electrical wiring, lumber, and nails comprised the list of major items. In addition, another local businessman, Fred Kneeland, donated four 750-gallon rectangular tanks formerly used for grading lobsters.

By the end of May 1987, the clam shop had been transformed into a modern, hatchery/laboratory facility. A separate 12-foot X 20-foot greenhouse room was built and used as both a flask culture room and for housing half of the fiberglass algae tubes. The remaining tubes were kept in a small portable greenhouse of similar dimensions built and situated adjacent to the larger hatchery building. The algae species used throughout the first produc-

tion year was Isochrysis galbana.

On 6 June 1987, adult clams were spawned for the first time at the Beals Island Regional Shellfish Hatchery. Previous attempts, beginning in late May, failed because clams were not reproductively mature. Soft-shell clams in eastern Maine can be stimulated to spawn via standard thermal shocking techniques through the month of August.

Clam larvae were reared at 20°C and fed at 30,000 algal cells/ml for two and a half weeks. Approximately 8 million clams were successfully cultured. These were fed daily through the months of June and July. During the first week of August and continuing through the first week of September approximately four million clams measuring 1.7 mm were placed in floating trays and taken to a sheltered cove on Beals Island (Mud Hole Cove) where they remained until November. Also during August, another one million juvenile clams were added to an upwelling unit inside the hatchery facility. The arrangement was designed to pump ambient seawater through 24 individual units holding 40,000 clams each. The remaining three million juvenile clams were held in the rectangular-shaped 750-gallon tanks and fed cultured algae through November.

Clams placed in the window screen-lined floating trays in Mud Hole Cove during the first three weeks of August attained a size of 12 mm by 1 November. Clams added to floating trays after this period had an average shell length of 8 mm by the fall whereas individuals held in the upwelling system at the hatchery averaged 6 mm in length. Cultured Mya residing in large tanks and fed reared algae attained an average size of 3 mm by 1 November.

Beginning during the second week of November and continuing until 27 November hatchery-reared seed clams were transplanted to mud flats in each of the six towns. The original goal had been to produce 1 million clams per town. That goal had been realized, however, I did not feel that the three million clams that had only reached 3 mm would escape predation so it was decided to overwinter them at the Darling Marine Center. The remaining 5 million clams were divided equally among the six towns. November was chosen as the time of year to transplant seed clams to Washington County flats because results from the 1983-1984 Jonesboro 4-H project suggested that optimal survival (>60%) to at least one inch could be realized.

In October 1987 a technical assistance grant for $15,000 from another Department of Commerce agency, the Economic Development Administration, was received. Funds from this grant were used, among other things, to purchase enough 1/6" plastic mesh netting to cover approximately 1/6 of the clams on each of the six mud flats. The mesh netting, used to deter predators such as seagulls, ducks, green crabs, and benthic feeding fish, was added to the mudflat moments after the clams had been seeded at a density of 20/ft^2. Netting was cut into 12-feet wide by 100-feet long strips. Strips were affixed to the mud flat surface by walking around the periphery of the netting. The weight of one person was enough to push each of the four edges of the strip approximately six inches into the mud.

Three "planting treatments" were employed at each site. Transplanting (20 clams/ft) occurred during low water and took place in the mid to low tidal zone at each mud flat. 24,000 clams were each seeded into four 12-foot by 100-foot plots that received a single thickness of plastic netting while 12,000 were each placed under four 12-foot by 50-foot plots that received a double thickness of netting (a large strip folded in half). The remaining clams were broadcast into 10 to 12 50-ft^2 uncovered plots.

Overwinter survival at each site was assessed during April 1988. Areas where hatchery-reared clams had been seeded were sampled using a benthic coring device. Samples were sieved using a 1 mm mesh. Three sampling comparisons were made between: 1) seeded and unseeded areas, 2) protected and unprotected, and 3) single mesh protection and double mesh protection. At all six sites, there was between 20 to 40 times the number of clams in the seeded area versus the "control" or unseeded areas. Survivorship within the seeded areas ranged from 15% to 50% depending on site. No new shell growth had occurred between November 1987 and the April 1988 sampling as water temperatures during that time are less than 4°C which is the critical feeding temperature for this species (3).

At four of the six sites, the protective mesh netting was missing due to ice formation on the mesh surface and subsequent lifting of the mesh from the mud flat. Mesh removal occurred between the middle of January and the first two weeks of February as air temperatures during that time were bitter for periods of 8 to 12 days. Mesh was missing from sites where clams had been seeded between mid and low tide level. Mesh remained at two sites where clams were seeded at the lowest tidal levels. That meant that at those two sites, exposure to air was minimized and ice build-up on the mesh surface was significantly reduced.

At the four sites where mesh had been physically removed by ice, clam survivorship was significantly higher than in control areas where no mesh had been placed. Apparently, some mortality agents were active during the period when mesh was covering the clams and that the mesh was, albiet for a short time, somewhat effective. In places where the mesh remained the entire winter, survival rates were five to ten times higher than in control areas. There was no significant difference in survivorship between plots which received double rather than single mesh protection.

It was apparent after the first year of operation that there were at least two limiting factors which seriously affected juvenile clam production. The first was the timing of the adult spawning. The majority of juvenile clams produced from the early June 1987 spawning did not reach window screen-size (ca. 1.7 mm) until the middle of August. Those that had reached this critical size before 20 August, and subsequently placed in floating trays at the protected cove on Beals

Island, attained 12 mm by 1 November. Juvenile clams that did not grow rapidly under hatchery conditions, and that were placed into floating trays later that 20 August, did not reach this half-inch size. Transplant size is perhaps the most important facit of this stock enhancement program. The larger the size of the juvenile clam which is transplanted to the mud flat during November, the better the chance of its survival. Therefore, if clams could be "conditioned" to spawn earlier than they normally do, the season could be expanded with the ultimate goal of producing larger transplantable hatchery-reared seed. The second limiting factor was the ability to produce enough algae for the number of clams that could be reared. More algae could mean 1) enough food to produce faster growth to the 1.7 mm (window screen) size, and, more importantly, 2) the potential for raising more clams which would mean that additional towns could be invited to join the hatchery program.

In February 1988 a third hatchery grant ($32,000), "Development of a Hatchery-Based Shellfish Management Program for Downeast Coastal Communities," was received from the Maine Science and Technology Board (MSTB). The grant, awarded for physical expansion of the hatchery facility, was used to construct a 51-foot by 22-foot greenhouse to provide additional space for raising more algae (approximately 3.5 times the level for 1987) and more tanks for post-settled clams. The greenhouse is situated on land donated by Richard Carver and is adjacent to the 200-foot wharf and hatchery building.

The same six towns that participated in the stock enhancement management effort during 1987 are again active during 1988. With the new MSTB funding, four more towns were encouraged to participate in the project. Cutler, Whiting, Steuben, and the Mount Desert Island-wide shellfish council each accepted the invitation. Each of the 10 towns contributed $1,000 to the program. Production goals per town (1 million) are the same for the 1988 season.

Clams were spawned in May 1988, one month earlier than the first spawning in 1987. During the second week of February 1988, clams dug from Beals Island mud flats were transported to the Darling Marine Center. This research facility, operated by the University of Maine, has the ability to pump seawater year-round. The 300 to 400 two- to three-inch clams were placed in 30-gallon plastic boxes containing beach sand. Clams experienced a 1°C rise in water temperature (above ambient conditions) every two weeks. By the first week of May, clams were "conditioned" or acclimated to temperatures normally encountered around the second week of June in eastern Maine waters. Clams were returned to the Beals Island Hatchery on 5 May and successful spawning took place the next day.

This hatchery or stock enhancement effort marks a significant shift of attitudes and ways of thinking about managing Maine's marine resources. Although it is late in the 1980's many people still believe that natural resources, especially those in the marine realm, are limitless. This perception is easily erased when resource scarcity occurs. This is the case of the soft-shell clam in Maine today. Landings have been declining and fewer and fewer shellfish harvesters are able to make an annual income from the mud flats alone. Five or ten years ago the idea of an aquaculture program focusing on transplanting small, hatchery-reared juvenile soft-shell clams to mud flats to enhance existing stocks would have been met with serious opposition. The same idea beginning in 1987 and continuing through 1988 has gained serious attention, hope and encouragement from both the industry and the layman.

A hatchery-based stock enhancement program will not be the cure-all for what threatens the clamming industry in Maine, but it is a beginning towards a more complete management scheme. It is anticipated that it will take a minimum of five years of producing clams in the hatchery and transplanting them to local flats to unambiguously assess the efficacy of this type of stock enhancement effort. If successful, the clamming industry--the ultimate beneficiary--must make the final decision about the fate of this hatchery-based program.

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Long Term Assessment of a Derelict Gillnet found in the Gulf of Maine

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A commercial, demersal gillnet, first found in 1984 was surveyed by submersible in June 1984,1985,1986 and by ROV in March 1988. We recorded our observations on a variety of parameters including vertical profile, epibenthic growth, and catch of marine life in the net. The most recent survey of a section of the net by ROV is highlighted because this is the period that groundfish, particularly cod, are present. We undertook four ROV dives and surveyed a 300 foot section of net during day, dusk, night and dawn. Extensive video recordings of the net characteristics and behavior of cod near the net were taken and are included in the presentation.

INTRODUCTION

In 1986, a three year study to determine the abundance and likely impact of lost (ghost) demersal gillnets on two important fishing grounds in the Gulf of Maine was concluded by the National Marine Fisheries Service, the National Undersea Research Program at the University of Connecticut (NURP-UCAP), and the Massachusetts Division of Marine Fisheries (1). This study resulted from the concern by recreational and commercial fishermen and the New England Fishery Management Council (NEFMC) that many derelict demersal gillnets existed in the Gulf of Maine from a gillnet fishery that began in the 1970's and peaked in effort between 1979-81. The number of gillnet vessels along the northern Massachusetts coast, New Hampshire, and southern Maine coast increased from 23 in 1970 to 170 in 1979. This escalation in effort and introduction into the fishery by many who were not skilled in commercial gillnetting led to the belief that many nets were being lost. Some evidence also existed that these ghost gillnets continue to catch fish and crustaceans for years (Way, 1977). The primary concern of the NEFMC was the impact on important groundfish species, cod, Gadus morhua, pollock, Polachius virens, and haddock, Melanogrammus aeglefinus.

The demersal gillnet fishery uses a series of bottom-tending nets that are marked by floats at each end. The net body is made of monofilament webbing that usually has a vertical profile between the floatline and leadline of 1.8 m and a mesh size of 15.2 cm (6 in). Each net is 91 m long (50 fathoms). In the Gulf of Maine, demersal gillnets are usually set in a continuous string of 10 to 12 nets that total 914 to 1,097 m (500 to 600 fathoms). A single vessel sets between five to six strings.

The three year study estimated the number of ghost gillnets on Jeffries Ledge and Stellwagen Bank, two important commercial gillnet grounds, and determined that the impact of these derelict gillnets during these observations was probably minimal on cod, haddock and pollock (1). No gadid fish were caught in the derelict gillnets nor did we find indentifiable skeletal remains of that family on the bottom near the nets. The observations during this study were restricted to June of each year when the principal observational vehicle of the study, submersibles, were available. During the remaining months, no observations were made. Unfortunately, the cooler months are when the more important commercial species, such as cod, are most likely to be in the vicinity of the net. Although the lack of skeletal material near the net suggests that little impact to the gadids occurred for several months prior to the June observations, we believed direct observations were needed to substantiate this.

The purpose of this investigation was to determine the impact of a derelict gillnet in March when cod and other members of the gadid family would normally be present. This effort was facilitated by the recent

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availability of a Remote Operated Vehicle (ROV).

The net we investigated was first found with the Submersible Johnson-Sea-Link II, during the first year of the three year study mentioned above. The net was surveyed again by submersible in 1985 and 1986. A previous attempt to complete a series of ROV dives on this site in July 1987 was thwarted because of our inability to achieve a stable three point moor. The depth was 52 m and substratum hard, consisting of cobble and scattered 0.5-1.0 m boulders.

METHODS AND MATERIALS

The March 14-18, 1988 survey of the derelict gillnet was accomplished using the 65 foot NOAA R\V GLORIA MICHELLE and the NURP-UCAP ROV Mini Rover II.

A three point moor was established over the site. Each leg of the anchoring system consisted of two 68 kg. Northill-type anchors separated by 9 m of 1/2 inch chain. A second 9 m length of chain connected one of the anchors to 3/8 in wire that was connected to the research vessel. Two 45.4 kg lead weights were attached one to the point where the chain met the wire and another on the wire, 183 m from the anchors. The anchor scope was 10:1. Each of the legs was attached to a deck winch to facilitate repositioning of the vessel by modifying wire length. We placed 61 m of line and a tuna buoy on the end of each wire when that leg had to be released from the vessel.

A Loran C receiver was the primary navigational device. We placed a reference buoy in the most probable site and positioned the research vessel close to the buoy.

The Mini Rover II was operated off a small oceanographic winch. The ROV's umbilical was attached to a down weight wire. We terminated the attachment about three meters above the down weight and gave the ROV about 50 m of free tether. The initial ROV search for the gillnet was biased to north-south transects because the net stretched in an east-west direction.

Weather influenced the frequency and number of ROV surveys of the gillnet. We preferred to conduct surveys with replicates at daytime, dusk, nighttime, and dawn. Observations included the vertical profile of the net, fouling, catch, and presence and behavior of mobile marine species. All observations were recorded on 1/2 in VHS video tape.

Some of the fish observations are described as sightings. A sighting is defined as a separate visual encounter with a fish.

The estimated size of the cod is based on a visual comparison of the total length of the fish to known sizes of certain parts of the gillnet.

RESULTS AND DISCUSSION

We established a three point moor on the morning of 17 March, the fourth day of the expedition. Weather precluded any earlier operation. The derelict net previously surveyed during the 1984-86 study was found within four hours of establishing the three point moor. The R/V Gloria Michelle was repositioned only once.

Four ROV dives were made on a portion of the derelict gillnet during 17-18 March. We conducted these dives at dusk, night, predawn and daylight. Survey time for each dive averaged about two hours. Water depth at the site was 52-55 m. During the daytime dive, ambient light allowed us to view the net without artificial lights.

The surveys concentrated on a 80 m portion of the lost net. The vertical profile of the net varied from 0.1-2.0 m off the bottom. The leadline and floatline were frequently twisted around each other and tightly stretched between boulders. Where the net was not taut, it displayed some buoyancy. The floatline was less than 0.7 m off the bottom except for one unrestrained section that rose to 2.0 m. The webbing was often torn or fouled with a short, but heavy, unidentified, filamentous growth. This growth made the webbing more visible.

The vertical profile of the net (0.1-2.0 m) was consistent with the profile seen in previous surveys, except for the piece of net that reached a height of 2.0 m. In 1984, the profile was <0.2 to 1.0 m; in 1985 and 1986, <0.2 to 0.7 m. We believe that the higher profile of one piece of netting resulted from an anchor catching the net and bringing it to its full vertical profile. On the 1987 expedition the R/V Gloria Michelle snagged the net on its anchor several times and we have been informed that this also occurs with party boats that fish the area.

The only catch in the net was five Cancer crabs, Cancer borealis/irroratus. We saw no vertebrate skeletal remains and little

exoskeletal debris around or in the net. We believe what exoskeletal debris was sighted was that of Cancer crabs.

We observed cod, pollock, sculpin, Myoxocephalus octodecemspinosus, redfish, Sebastes marinus, and wolffish, Anarhichas lupis, in decreasing abundance, near the net. Pollock were seen briefly as they briefly as they swam by the ROV camera on one dive. Only one or two sculpin were observed on the bottom near the net. No finfish were caught in the gillnet.

Cod were observed on each ROV dive. These fish were all within 10 feet of the net. We saw three cod on the dusk and daylight dives. Fourteen sightings occurred in the predawn dive. Cod were most numerous on the night dive and were particularly found near one end of the net, the section with the highest vertical profile. We positioned the ROV on the bottom so that we could observe the high profile piece of netting and the behavior of the cod near it.

We observed 5-7 cod in a 36 minute period. They were between 30-64 cm (12-25 in) long. Cod swam casually except when they fed on the euphausiids. The cod did not appear to directly react to the lights. During this period of observation, arrowworms (Chaetognatha) and euphausiids were frequently seen. Whether these invertebrates were attracted to the artificial lights is uncertain but probable.

Cod reacted to the net as if it was part of the bottom. Larger cod turned when approaching the net and would swim around the net or under the leadline where the leadline was raised off the bottom. Smaller cod, 30-41 cm (12-16 in) in length, swam through the mesh. Upon encountering the net and just prior to touching it, these fish would stop, then alter their course enabling them to swim through the mesh. One larger fish, about 45 cm in length, swam through one mesh and, in altering its course upward to feed, caught its dorsal fin on the webbing. It continued swimming with no unusual reactions observed.

We believe the cod were attracted by the artificial lights and remained to feed on the euphausiids. This hypothesis is based on two series of observations that were made when we extinguished the lights for one and two minutes respectively. Cod were almost always in view prior to extinguishing the lights. When the lights were illuminated cod were not observed for 0.5-1.0 minutes.

The negative impact of this derelict net on cod appears minimal. We saw no cod entangled in the net, nor any evidence of recent entanglement in this net. This conclusion is important since cod were around the net in numbers and sizes that would become entangled.

The quantity and size of cod in the vicinity was also substantiated by the presence of a commercial gillnetter who fished so close to our site that we had to exercise care in deploying and retrieving one of our moorings. He had successfully fished this location for about one month. For the week of our investigation, he landed 1475 kg (3256 lbs) of cod of which 56% were large cod, approximately 81 cm (32 in) or more in total length; 40% were market cod 50-81 cm (20-32 in); and 4% were less than 50 cm (20 in) (Capt. F/V **Maureen Jane**, personal communication).

Because our observations were limited to a 80 m piece of the 470 m long derelict net and restricted to a period of less than one day, more ROV observations would be helpful to confirm our conclusion that this derelict net has a minimal negative impact to the gadid fishes.

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EFFECTS OF TRIBUTYLTIN ON SURVIVAL, GROWTH, MORPHOMETRY AND RNA-DNA RATIO OF LARVAL STRIPED BASS, *Morone saxatilis*

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ABSTRACT

The effects of tributyltin (TBT) on survival, growth, morphometry, and RNA-DNA ratio were assessed in larval striped bass, *Morone saxatilis*. A concentration of 2.284 µg TBT/L killed all 13 day old larvae in 5 days, while 1.498 µg/L killed all 16 day old larvae in 6 days. In 13 day old larvae exposed for 6 days, survival, head length, body depth, and dry weight were reduced at 0.766 µg/L. Body depth decreased at 0.067 µg/L. No changes occurred in these parameters in 16 day larvae exposed to 0, 0.052 or 0.444 µg/L for 7 days. Maximum TBT concentrations reported in Chesapeake Bay marinas would be likely to cause increased larval mortality. Longer-term exposures are recommended for the assessment of effects at <0.050 µg TBT/L, which may be more representative of habitat conditions.

INTRODUCTION

Tributyltin (TBT) compounds are introduced into the aquatic environment through their use in antifouling paints on boats and ships and in coatings on fish farming nets. TBT compounds are the subject of international concern because of their toxicity to non-target organisms at low and sub-part per billion concentrations (1). TBT has been detected in the edible tissues of chinook salmon (*Oncorhynchus tshawytscha*) and Atlantic salmon (*Salmo salar*) raised in treated net pens and mortalities have been reported when fish were transferred to newly treated nets (2, 3). Several U.S. states have restricted the use of TBT and federal regulations are now pending (4).

There are few data on the effects of TBT on the growth of fish. Seinen *et al.* (5) reported significant decreases in growth in rainbow trout (*Salmo gairdneri*) exposed to sublethal, nominal concentrations of 0.2 and 1 µg TBT chloride/L for 110 days beginning at the yolk sac fry stage. Mean body weights of these respective groups were 74.5% and 50.9% of the weights of the control group. Bushong *et al.* (6) exposed 17-19 day old inland silverside (*Menidia beryllina*) larvae to 0, 93, or 490 ng TBT/L for 28 days. There were significant decreases (20.6-21.6%) in wet weight of exposed larvae relative to controls. No differences were found, however, in measurements of notochord length, head length, eye diameter, head depth, or body depth. Ward *et al.* (7) reported no changes in the length or weight of adult sheepshead minnow (*Cyprinidon variegatus*) exposed to 0.18-1.0 µg TBTO/L for 167 days. Newton *et al.* (8) exposed fertilized California grunion (*Leuresthes tenuis*) eggs to 0-2.00 µg TBT/L until hatch (10 days). Neither hatch success nor notochord length at hatch was affected by TBT exposure.

The objectives of the present study were to assess the effects of short-term exposures to TBT on the survival and growth of larval striped bass (*Morone saxatilis*). Norberg & Mount (9) have found that the growth of larval fish is one of the most sensitive indicators of toxicant-induced stress. Morphometry, condition factor, and RNA-DNA ratio were used as indicators of the growth and condition of the larvae. TBT concentrations were selected to represent the range of values reported in the Chesapeake Bay and its tributaries, which are important habitats for young striped bass.

MATERIALS AND METHODS

Two batches of striped bass (*Morone saxatilis*) larvae were obtained from the Cedarville, MD hatchery. Larvae were maintained at the Chesapeake Biological Laboratory in 1000 L tanks under flowing water. Holding water was a mixture of well water and 5 µm filtered Chesapeake Bay water. Data on the age of the larvae and the water quality parameters for the holding and experimental periods are given in Table 1. Larvae over the age of 4 days were fed newly hatched *Artemia* nauplii (2000 nauplii/L) three times a day.

Aged tributyltin methacrylate painted panels were installed in a flow-through toxicity testing apparatus (10). Glass aquaria (37.8 L) were lined with 0.254 mm polycarbonate film (applied with silicone sealant) to minimize

adsorption. Larvae were exposed in 335 μm nylon-screened 8 L polycarbonate trays which were suspended in the aquaria such that 4.5 L of water was contained. The system was allowed to run for two weeks in order to stabilize TBT concentrations.

Two experiments were performed. In Experiment I, 13 day old larvae were exposed to TBT for 6 days. In Experiment II, 16 day old larvae were exposed to TBT for 7 days. The experiments were initiated by placing 25 larvae in each of four replicate aquaria at three

Table 1. Water quality data.

Experiment	Temp. (°C)	Salinity (ppt)	D.O. (mg/L)	pH	NH_4-N (mg/L)
I					
Holding[a]	17.0-19.0	0.5-1.5	6.6-7.9	7.74	--
Exposure	18.0-20.0	1.1-3.0	8.3-9.3	7.81-8.47	0.085-0.107
II					
Holding[b]	17.0-19.0	0.5-1.5	7.0-8.1	--	--
Exposure	18.5-19.5	1.9-3.0	6.0-8.9	8.19-8.33	0.047-0.085

[a]Larvae obtained from hatchery at one day of age; held at CBL for 12 days.

[b]Larvae obtained from hatchery at 12 days of age; held at CBL for 4 days.

concentrations of TBT plus a control. Dilution water was a mixture of well water and 5 μm filtered Chesapeake Bay water. Newly hatched *Artemia* nauplii (2000 nauplii/L) were added to the tanks three times daily. Survival was assessed daily while the tanks were being cleaned of dead fish and debris.

Water samples were collected from tanks at each concentration on days 0 and 4 for Experiment I, and on days 0, 4, and 7 for Experiment II. Di- and tributyltin concentrations (Table 2) were determined according to the atomic absorption hydride derivatization method of Valkirs *et al.* (11). A Perkin-Elmer 403 spectrometer equipped with an electrodeless discharge lamp (λ=286.3 nm) was used.

At the end of the experiments, half of the fish from each tank were stored at -70°C for RNA and DNA determinations. Four fish from each tank were placed in scintillation vials in 5% formalin buffered with $CaCO_3$ for one week and then stored in 2.5% $CaCO_3$-buffered formalin for morphometry and dry weight (DW) determinations. RNA and DNA determinations were performed on aqueous homogenates of two larvae from Experiment I and of single larvae from Experiment II, according to methods described in Wright & Martin (12).

Table 2. Measured TBT^+ and DBT^{++} concentrations (mean ± standard deviation and mortality data for Experiments I and II.

Experiment	TBT^+ (μg/L)	DBT^{++} (μg/L)	Mean % Survival
I[a]	<0.030 (n=7)	0.015±0.005 (n=7)	81.8 (A)[b]
	0.067±0.026 (n=7)	0.023±0.008 (n=7)	64.2 (A)
	0.766±0.220 (n=6)	0.158±0.085 (n=6)	59.8 (B)
	2.284 (n=1)	0.295 (n=1)	0[c] (C)
II[d]	<0.030 (n=8)	0.018±0.010 (n=8)	98.1 (A)
	0.052±0.019 (n=8)	0.025±0.025 (n=8)	92.2 (A)
	0.444±0.077 (n=9)	0.080±0.021 (n=7)	98.5 (A)
	1.498±0.252 (n=7)	0.219±0.086 (n=5)	0[e] (B)

[a]Samples collected on days 0 and 4 except for the highest concentration (day 0 only).

[b]Duncan grouping; groups with different letters are significantly different ($p<0.05$).

[c]All larvae died by day 5.

[d]Samples collected on days 0, 4, and 7.

[e]All larvae died by day 6.

The morphometry procedures of Martin & Malloy (13) were followed. Preserved fish were measured for: 1) notochord length (NL), 2) head length (HL), 3) eye diameter (ED), 4) head depth (HD), 5) body depth at the base of the pectoral fin (BDP), and 6) body depth at anus (BDA). Measurements were made on 16 fish/group with a dissecting microscope and ocular micrometer at

7 X. Afterwards, the fish were dried in a 60°C oven for five days and weighed to the nearest μg on a Cahn electrobalance. The condition factor (CF) was determined by the formula $CF=(DW/NL^4) \times 10^5$ [based on data of Houde & Lubbers, (14)].

The arc sin transformation was used for the analysis of survival data. Data were analyzed as randomized block designs with replicate tanks as blocks. Significance testing was performed by one way ANOVA followed by Duncan's Multiple Range Test (15, 16). For the morphometry, weight, condition factor and RNA-DNA data, ANOVA was performed with tanks nested within each concentration (15). Duncan's Multiple Range Test was performed to analyze for differences between groups (16). For all procedures, the p value of 0.05 was used for significance testing.

RESULTS

Survival data are shown in Table 2. In Experiment I, there were significant ($p<0.05$) reductions in survival for larvae exposed at 0.766 μg TBT/L (59.8%) and 2.284 μg TBT/L (all larvae dead by day 5). In Experiment II, larval survival was significantly decreased at the 1.498 μg TBT/L concentration (all larvae dead by day 6). In Experiments I and II, there were few deaths over the first 48 hours of exposure. The sequence of behavioral toxic signs was similar in the fish that died in the highest concentration tanks in Experiments I and II. The first sign was slowed swimming. Later, larvae lost equilibrium and remained motionless on the bottom. If prodded, such larvae would swim erratically, sometimes in spirals, and then fall to the bottom again. Fish often remained motionless on the bottom for up to 24 hours before dying. No signs of toxicity were observed in the larvae exposed to 0.766 μg TBT/L in Experiment I.

Morphometry, dry weight, condition factor, and RNA-DNA data for Experiment I are given in Table 3. At the 0.067 μg TBT/L concentration, there were significant decreases in the two body depth measurements. BDP decreased by 4.8% while BDA decreased by 8.6%. Significant decreases in BDP (-11.0%), BDA (-16.3%), HL (-10.0%) and DW (-20.7%) occurred in the larvae exposed to 0.766 μg TBT/L. No significant differences were found in morphometry, dry weight, condition factor, and RNA-DNA data in control vs. exposed larvae in Experiment II (Table 4).

DISCUSSION

Concentrations ≥1.498 μg TBT/L caused 100% lethality in larval striped bass in 5-6 days. Striped bass appear to be in the same range of sensitivity to TBT as other larval fish. Ninety-six-hour LC50s of 2 μg TBTO/L (nominal concentration) for sole (*Solea solea*) (17) and 3.0 μg TBT/L for inland silverside (*Menidia beryllina*) (6) have been reported.

At concentrations ≥0.766 μg TBT/L, larval survival was significantly reduced. Hall *et al.* (18) reported maximum water column concentrations of 1.801 and 1.171 μg TBT/L in Chesapeake Bay marinas in June samples. The laboratory mortality data of this study indicate that exposure of striped bass larvae to those marina concentrations would be likely to result in increased mortality.

Several morphometric parameters and larval dry weight were reduced in 13 day old larvae exposed to 0.766 μg TBT/L in Experiment I. These data should be viewed with caution, however, since there was a significant decrease in survival at this concentration. The lack of growth in these fish may therefore be a prelude to the imminent death of the larvae. Bushong *et al.* (6) reported a decrease in wet weight (-20.6%) of larval *Menidia beryllina* exposed to 0.490 μg/L for 28 days. These data suggest that TBT concentrations in the 0.5-0.8 μg/L range, which have been reported in marinas of the Chesapeake (18), may be detrimental to the survival and growth of larval fish.

Table 3. Mean ± standard error of morphometry, dry weight, condition factor and RNA/DNA data for Experiment I.[a]

	TBT+ (μg/L)		
Parameter	<0.030	0.067	0.766
NL (mm)	13.66±0.16	13.39±0.22	13.05±0.28
HL (mm)	3.42±0.06 (A)[b]	3.26±0.09 (A,B)	3.08±0.09 (B)
ED (mm)	1.08±0.01	1.07±0.06	0.99±0.02
HD (mm)	2.62±0.03	2.61±0.08	2.43±0.05
BDP (mm)	2.74±0.04 (A)	2.61±0.07 (B)	2.44±0.06 (C)
BDA (mm)	2.45±0.05 (A)	2.24±0.08 (B)	2.05±0.08 (C)
DW (mg)	0.82±0.04 (A)	0.76±0.05 (A)	0.65±0.04 (B)
CF	2.33±0.05	2.32±0.05	2.23±0.10
RNA/DNA	2.30±0.12[c]	2.29±0.19[d]	2.15±0.07[d]

[a]Nested ANOVA based on 4 larvae/tank, 4 tanks/-concentration.

[b]Duncan grouping; groups with different letters are significantly different ($p<0.05$).

[c]Based on 2-4 larvae/tank; 4 tanks/concentration.

[d]Based on 1-4 larvae/tank; 4 tanks/concentration.

Table 4. Mean ± standard error of morphometry, dry weight, condition factor and RNA/DNA data for Experiment II.[a]

Parameter	TBT+ (μg/L) <0.030	0.052	0.444
NL (mm)	14.72±0.21	14.96±0.16	14.98±0.20
HL (mm)	3.76±0.08	3.74±0.06	3.65±0.09
ED (mm)	1.13±0.02	1.16±0.02	1.15±0.02
HD (mm)	2.87±0.05	2.86±0.05	2.93±0.05
BDP (mm)	2.97±0.05	2.87±0.06	2.96±0.06
BDA (mm)	2.88±0.08	2.85±0.10	2.81±0.08
DW (mg)	1.12±0.06	1.12±0.05	1.09±0.08
CF	2.34±0.40	2.22±0.05	2.13±0.13
RNA/DNA	2.21±0.10[b]	2.24±0.08	2.40±0.11[c]

[a]Nested ANOVA based on 4 larvae/tank; 4 tanks/-concentration.

[b]Based on 4-7 larvae/tank; 3 tanks/concentration.

[c]Based on 3-5 larvae/tank; 4 tanks/concentration.

The decreases in the body depth parameters (BDA and BDP) in 13 day old larvae exposed to 0.067 μg TBT/L in Experiment I may be indicative of sublethal growth effects, although there were no significant changes in dry weight. These results are comparable with those of Bushong et al. (6) who reported decreased wet weight in larval M. beryllina exposed to 0.093 μg TBT/L for 28 days but no changes in any morphometry parameters. However, the decreases observed in 13 day old larvae in Experiment I were not observed in 16 day larvae exposed to similar concentrations in Experiment II. These contrasting results may reflect differences in the sensitivities of the different batches of larvae or an increased sensitivity of the younger larvae.

TBT can be a slow-acting toxicant, either as a neurotoxic agent or by interfering with energy metabolism (19, 20). There are few data on the sublethal effects of TBT on larval fish. In addition to decreased growth, Seinen et al. (5) also reported liver hyperplasia, decreased liver glycogen content, decreased hemoglobin content, and a diminished erythrocyte count after chronic exposure of yolk sac fry rainbow trout at nominal concentrations of 0.2 and 1.0 μg TBT chloride/L. Long-term exposures of larval fish should be performed at measured concentrations of <0.050 μg TBT/L, which may be representative of habitat concentrations. Survival, growth, and morphometry are suitable endpoints. Mechanistic studies should focus on possible effects on the nervous system, energy metabolism, liver histology, and hematology.

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INTERNATIONAL OIL SPILL LIABILITY AND COMPENSATION

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ABSTRACT

United States ratification of two international treaties relating to liability and compensation from seagoing tanker oil spills is long overdue. These international instruments are the 1984 Protocols to The International Convention on Civil Liability for Oil Pollution Damage of1969 and The International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage of1971. Until the U.S. ratifies these Protocols its citizens will likely be deprived of speed, certainty and adequacy of payment for damages resulting from tanker oil spills..

INTRODUCTION

Oil spills, which foul our beaches, kill our wildlife, disrupt both recreational and commercial activities, and have the potential for seriously damaging our natural resources are events which our citizens should not have to endure. But as long as we are an oil consuming nation and import by tanker such vast quantities of oil, it is inevitable that these dirty and emotional events will continue to occur. It is vital, then, that we plan for and properly respond to these accidents when they happen.

Response means not only quickly and effectively removing the oil from the environment, but providing an effective mechanism which compensats those who suffer damage and reinstates natural resources when that can be done.

THE PROTOCOLS

With respect to seagoing tankers, the 1984 Protocols to the international conventions on civil liability for oil pollution damage (CLC) and the establishment of an international fund for compensation for oil pollution damge (FUND) offer just such a regime.

A clear, internationally recognized standard of high liability for tanker owners, mandatory insurance and an oil industry supported back-up fund are embodied in this system which would provide our citizens with speedy and certain compensation for damages caused by oil spills from tankers. Gone would be the days of searching half way around the world for a tanker owner only to find that he has no resources, no insurance and the courts in his jurisdiction are not willing to honor United States judgments.

The geographic scope of the Protocols includes not only the territory and territorial sea of a contracting state but extends to its exclusive economic zone as well. Also, both laden and unladen tankers are covered unless, in the case of the latter, it is proved that no residues of bulk oil carriage are aboard.

Unfortunately, the definition of oil within the Protocols does not include lighter oils such as gasoline. Rather, damage caused by "persistent" oil is covered. However, the domestic regime, considered by many to be an essential companion to the Protocols to cover sources other than tankers, would most certainly fill this gap.

The definition of "pollution damage" is best left to the precise words of the Protocols, "(a) loss or damage caused outside the ship by contamination resulting from the escape or discharge of oil from the ship, wherever such escape or discharge may

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occur, provided that compensation for impairment of the environment other than loss of profit from such impairment shall be limited to costs of reasonable measures of reinstatement actually undertaken or to be undertaken; (b) the costs of preventive measures and furthur loss of damage caused by preventive measures." This definition will protect the international fund from claims based on abstract quantifications while providing compensation for loss of profit experienced by such persons as hotel owners, even though the spilled oil may not have directly impacted the property of the hotel.

The President, on 5 November 1985, transmitted the treaty instruments to the Senate recommending that it "give early and favorable consideration to the 1984 Protocols.....and give its advice and consent to ratification." However, advice and consent has not been forthcoming, the Protocols are not yet ratified by the United States, and implementing legislation advanced by the House of Representatives has not survived.

THE NEED

The fact is that tanker accidents continue to occur. Since March 1984, seven large tanker spills have dumped about three and a half million gallons of oil into U. S. waters. The potential damage was even greater. Spills occurred in the Columbia and Delaware rivers, and near Savannah, Georgia. The Texas/Louisiana beaches were fouled, the logging industry in Washingon disrupted, and the salmon catches in Alaska seriously threatened. Wildlife and natural resources were damaged and threatened, livelihoods were placed in jeopardy, and personal and real property damaged.

BENEFITS AND COSTS

How would the Protocols provide relief from these events? First and foremost, the Protocols would establish tanker owner liability at $78 million for cleanup costs, third party damages and natural resource reinstatement, and back this up with a fund to a per incident limit of $260 million (at July 1988 exchange rates). The costs of preventive measures would be covered, insurance would be mandatory and, just as important as the high monetary values, the Protocols would provide for speed and certainty of recovery and jurisdiction in U. S. courts. Our judgments would have to be enforced by the tanker owner's flag state.

And what would this cost us? Following the diplomatic conference that developed the Protocols, Temple, Barker and Sloane, Inc. concluded that adoption of the Protocols would cost only one tenth of one cent per barrel of seaborne oil received at our ports and terminals. TBS has also concluded that the insurance coverage offered by the Protocols is a real bargain. For instance, figures developed in 1987 show that if the U. S. experienced only one major oil spill ($150 million) in 17 years, a net economic benefit to the U. S. would have occurred from Protocol ratification.

STATE PREEMPTION

Some argue that preemption of state oil spill liability law (required by U. S. ratification) and which in many cases is unlimited, is a feature of the international regime which demands evaluation. That is true. However, the Protocols offer a number of advantages not afforded by state courts and would preempt state (and Federal) law only to the extent that certain claim actions are barred under the Protocols. State oil spill funds would not, as some have thought, be preempted.

OUTLOOK

The outlook for adoption of the 1984 Protocols to CLC and FUND is not clear. Two bills before the Congress as of this writing (July 1988), S. 1802 and H. R. 1632, would implement the Protocols when ratified. Another, S. 2643, would not do so with the question of state oil spill liability law preemption a major concern.

The Senate Foreign Relations Committee is not likely to hold hearings until both the Senate and House have given clear signals that the Protocols can become a reality for the United States.

However, the nations governors recently recommended that "Congress should approve legislation establishing a comprehensive oil spill liability and compensation system.....and Senate consent to ratification of the 1984 International Protocols on oil spill liability and compensation". It would appear that the governors have in mind the practical advantages of the Protocols over the theoretical rewards of unlimited liability, and this might indeed influence the Congress to proceed with ratification as part of a domestic package to cover spills not addressed by the Protocols.

NOTE: The author will provide a legislative update during Oceans 88.

OCEAN RESOURCE MANAGEMENT IN OREGON: PUSHING OPEN THE WINDOW OF OPPORTUNITY

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ABSTRACT

The Oregon Ocean Resources Management Program is an unprecedented effort by a state to protect the long-term values and benefits of renewable ocean resources and activities. The Program extends the state's coastal management program seaward to provide a coordinated, comprehensive management framework for state and federal agencies. Its objective is to produce a framework for decisions that recognizes both the environmental links between coastal and ocean resources and the economic importance of ocean uses to coastal communities.

Oregon's initiative attempts to redefine the relationship between the federal and the state governments with respect to resource management within the U.S. Exclusive Economic Zone. The Oregon program asserts the state's right and responsibility to plan for and jointly manage the resources and uses which affect the state. The first part of this paper discusses the state/federal partnership development process, and the second part focusses on regional coordination efforts.

INTRODUCTION

Oregon has not yet placed its ocean resource planning and management house in good order. Oregonians set themselves apart from other states, however, with their tendency to feel guilt over such organizational disorder. In the grip of this guilt, they will set in motion an atonement process to redeem themselves by establishing order, openness, and predictability. In short, they seek procedural salvation. The present catalyst for Oregonians' redemption is the management and use of its offshore resources.

Despite the current emphasis nationally on job creation in the the field of electronics and related industries, Oregonians never completely forget that they live in a natural resource-based economy. Oregon's long-term economic health requires conservation, management, and wise utilization of forests, agricultural lands, water, fisheries, tourism, and recreation resources. In short, the goal is to keep Oregon Oregon, as the late Governor Tom McCall used to say.

The Pacific Ocean permeates the economy and social fabric of the Oregon Coast and indeed much of Oregon. Traditional uses of the ocean and its resources such as fishing, transportation, recreation, and national defense are so obvious and accepted that it is sometimes hard to realize just how critically dependent they are on existing ocean conditions. Expectations for a high quality environment and existing economic values of the ocean, coupled with the unknown dynamics of the ocean, call for caution and care in the management of these resources.

Both private sector interest in nearshore marine mineral development and inclusion of the Oregon-Washington Planning Area in Interior's 1987-1992 Five Year OCS Oil and Gas Leasing Program make it clear that in order to keep Oregon Oregon in and beyond the 1980s, Oregonians must address the use of its broad range of ocean resources. However, the intricate balance of the environmental, economic, and social forces that provide Oregonians with a way of life, must be understood and considered.

I. BUILDING A STATE/FEDERAL PARTNERSHIP

SEIZING THE INITIATIVE

Knecht, Cicin-Sain and Archer, in their paper "National Ocean Policy: A Window of Opportunity" (Ocean Development and International Law, Vol.II, pp.113-142, 1988), believe a "window of opportunity" for changes in ocean policy opens when developments in the "problem", "politics", and "policy" streams converge. Such convergence occurred in Oregon in 1987 when both an overwhelming majority of the Oregon Legislature and Governor Goldschmidt reaffirmed and extended Oregon's historic commitment to conservation and development of its natural resources by enacting The Oregon Ocean Resources Management Act (SB 630). The Act itself establishes an Ocean Resources Management Program for Oregon.

Oregon's program is an attempt to open "the window of opportunity" before federal government or industry initiatives compel Oregon's natural resource agencies to utilize scarce resources in response to ocean development proposals. The program's first target audience must necessarily be Oregonians themselves. Unless Oregon's citizenry, legislature, and agencies have a clear idea of how agency programs interrelate, it will

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be nearly impossible to link them together into a smoothly-functioning team to accomplish the state's ocean resource management objectives.

A comprehensive and coordinated ocean resources management plan and program may appear to establish a new policy framework for ocean governance. To Oregonians, however, the approach is a logical extension of the state's comprehensive land use planning program created in 1973. A preliminary analysis of the existing ocean management regime was completed July 1, 1988; it suggests that there are several shortcomings in the status quo. The next phase of Oregon's ocean planning experiment will be to construct adaptive management systems that establish priorities and resolve conflicts among both ocean users and government agencies at all levels by developing alternatives to expensive lawsuits and moratoria. The plan will also serve to guide the efficient use of scarce agency resources.

SIGNIFICANCE OF THE PROGRAM

Oregon's ocean resources management program is significant for two reasons. First, it is an unprecedented attempt by a state to develop a comprehensive management program for ocean resources within its jurisdiction. Many states, pursuant to the 1972 Coastal Zone Management Act, have coastal management programs for shorelines, estuaries, and other coastal resources, but none has extended their programs to ocean resources in any comprehensive manner. Second, Oregon's initiative is a clear step by a coastal state toward redefining the relationship between the federal and state governments with respect to managing ocean resources within the U.S. Exclusive Economic Zone. Naturally, Oregon neither claims ownership of the seabed nor legal jurisdiction over resources beyond three miles. However, it does assert its right and responsibility to plan for joint management of resources and uses of the ocean which affect the state and its citizens.

Oregon 's program is designed to encourage local governments, state agencies, ocean users, and citizens to do their homework regarding ocean resource allocation in advance of important development decisions, and to insist that federal agencies do the same.

THE OREGON OCEAN RESOURCES MANAGEMENT ACT

The Oregon Ocean Resources Management Act is more than a mere legislative directive to take some action. It sets the stage for a future program by clearly stating the Legislature's policies on ocean resource management. In addition, the bill establishes clear priorities among potentially competing ocean uses and activities.

Findings

The Act's findings give a "real world" context for the state's development of an ocean management program. Among the findings are:

- The recognition of the fluid, dynamic nature of the ocean and the migration of its living resources;
- The absence of a comprehensive state management system in Oregon;
- Existing federal laws already give states a role in ocean resource management;
- Additional scientific understanding of the offshore environment is needed.

Policies

The Act includes policies to guide planning for management of ocean resources. Those policies:

- Give priority to the use of renewable marine resources.
- Encourage environmentally sound, economically beneficial ocean development.
- Incorporate the ocean management program into Oregon's Coastal Management Program.
- Assert Oregon's interests as a partner in ocean management within the U.S. Exclusive Economic Zone.
- Promote marine research and scientific understanding.
- Encourage marine technology research.

The means to accomplish these objectives and policies are discussed below.

MANAGEMENT PLANS

Implementation of SB 630 will result in a two plans to guide state and federal authorities and decisions concerning offshore activities.

PLAN 1: The Oregon Ocean Resources Management Plan

An overall management plan for ocean resources and uses within the 200-mile U.S. Exclusive Economic Zone, including the Oregon Territorial Sea, must be completed by June 1990, and approved by Oregon's Land Conservation and Development Commission by December 1990. The Oregon Ocean Resources Management Plan will have four major elements:

1. An analysis of state and federal laws, programs, and regulations affecting ocean resources within the planning area, including gaps, overlaps and conflicts.

2. A study of present and future ocean uses off Oregon, and an analysis of the state's management regime for such uses.

3. Maps and other information about ocean conditions, uses, and resources, computerized so as to provide a basis for plan decisions.

4. Recommendations to develop or improve state agency programs for managing ocean resources. Recommendations are to address:

- Oil and gas development, including exclusion areas, pipelines, onshore facilities, and its relationship to local comprehensive plans.
- Oil spill response, damage assessment, and compensation.
- Marine water quality, including ocean outfalls, chemical runoff, water quality standards, and monitoring programs.
- Air quality impacts from offshore development.
- Nonenergy hard mineral exploration and development.
- Environmental studies and other research.
- Ocean technology research.
- Private investment in ocean resources.
- Alternative methods of dispute resolution.
- A permanent management structure and process to keep the plan up to date.

This list results from a preliminary assessment of the states ability to manage activities that are expected to occur in Oregon's offshore area in the near future. These elements, and the issues with which they are concerned, will be developed further in an open, public forum.

PLAN 2: The Territorial Sea Management Plan

A more detailed plan for managing resources in Oregon's Territorial Sea, building on the Oregon Ocean Management Plan, will be completed and adopted by the State Land Board by July 1991.

PLANNING PARTICIPANTS

Preparation of the Ocean Resources Management Plan is the responsibility of an 18-member Task Force, chaired by the Governor's Assistant for Natural Resources. Membership on the Task Force presently includes seven natural resource agency directors; one representative from each of five private sector ocean user groups: recreational fisheries, commercial fisheries, oil and gas development, marine mineral development, and ocean navigation; two coastal local government representatives; and three citizens at-large.

The Task Force has been substantially supported in its work by a Scientific and Technical Advisory Committee. Staff from several state and federal agencies that have ocean resource management interests and authorities, local government planners, Indian tribal representatives, oceanographers, biologists, geologists, economists, ocean law experts, representatives from environmental groups, and Oregon citizens constitute the advisory committee.

The Task Force formed six subcommittees (Ocean Management Systems, Special Management Areas, Research Needs, User Conflicts, Onshore Impacts, and Coastal Economics) to assist in the investigation of various offshore resource development issues. The subcommittees prepared reports and recommendations to the Task Force which provide the basis for work on several ocean resources plan elements.

The Task Force met nine times from fall 1987 through summer 1988. During the meetings, reports from subcommittees and staff briefings were presented. The Task Force also heard presentations from ocean users and neighboring states either formally as part of the agenda, or informally during the Public Forum period at each meeting. Based on information presented during the Task Force meetings, an interim report was prepared and submitted to the state legislature in July 1988.

WHAT WE HAVE LEARNED

Certain themes have emerged from the first year of effort. The following is a summary of those themes:

1. Reserves of known resources and the promise of resources yet to be discovered lie within Oregon's Territorial Sea and the adjacent EEZ. Development of the full economic and social benefit of these resources requires an appropriate management scheme which builds on existing regimes that manage oil, gas, marine minerals, and fisheries, and which builds toward a process of co-management with federal agencies.

2. Sound planning will help bring an optimal economic return to Oregon's ocean resources by ensuring a collaborative, efficient, and balanced decision-making process. Resource allocation decisions are best made in advance of development decisions. Confrontational and litigative decision making is properly the technique of last resort.

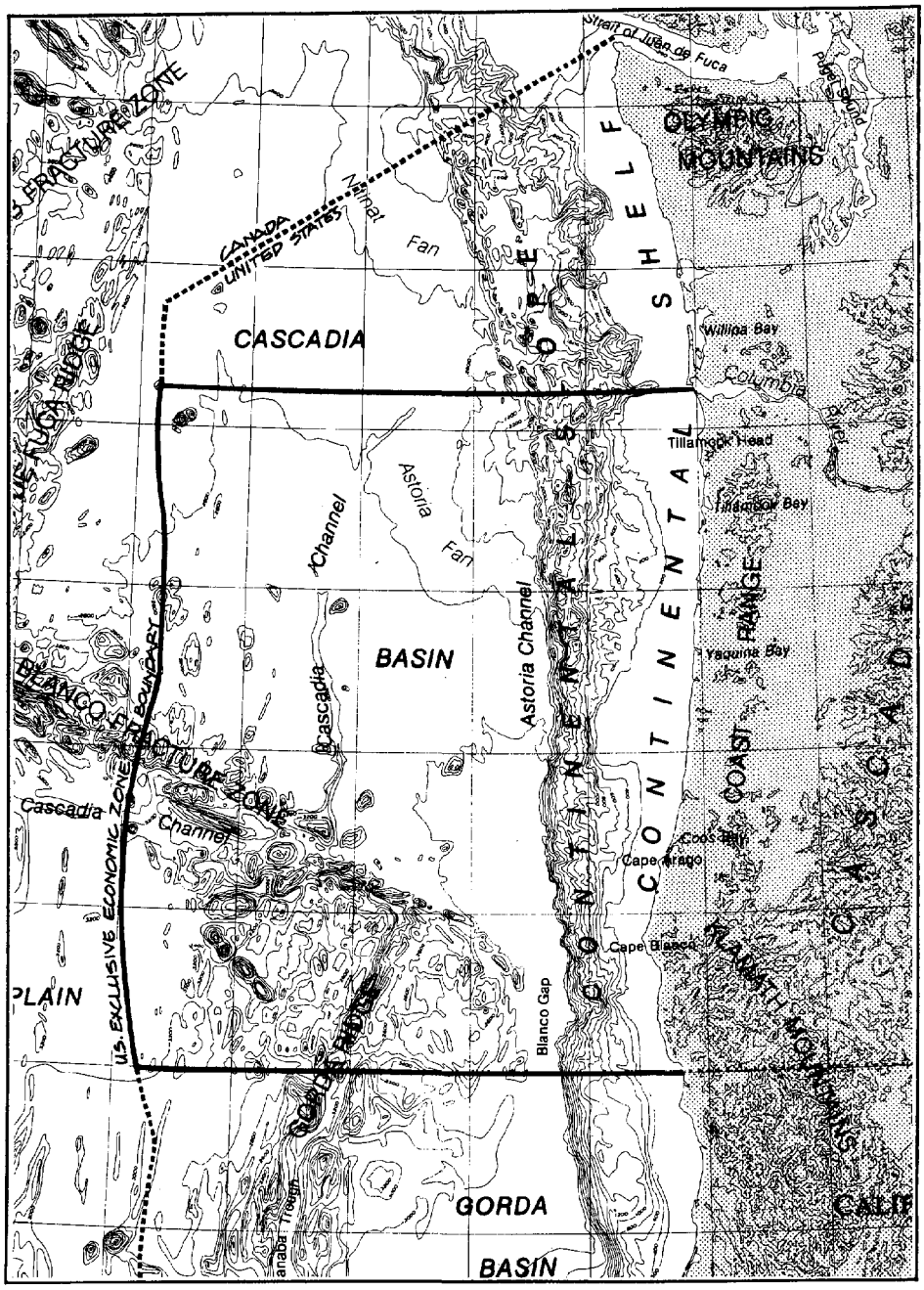
3. The private sector is often the prime mover in ocean resource development. What does or does not happen offshore and at what pace usually depends on market conditions and the judgement of ocean users.

4. New offshore uses may represent economic trade-offs that diminish existing ocean uses rather than simply adding to existing levels of income now derived from ocean resources.

5. Oregon is willing to experiment in a creative federalism, which is a true local-state-federal partnership, allowing close coordination with Indian tribes, adjacent states (see "Associated Efforts", below), and the private sector.

6. Oregonians will continue to assert their right to participate in ocean resource allocation decisions which impact their way of life, coastal communities and economy, both within the territorial sea and the EEZ.

7. Sound management of Oregon's ocean resources in state waters, and effective coordination with federal agencies in federal waters, requires a new state/local budget strategy with a commitment of resources commensurate with the state's ocean management responsibilities.



Oregon's Ocean Planning Area

II. ASSOCIATED EFFORTS: A REGIONAL APPROACH

A glance at a map of the coastline and continental shelf of the Pacific Northwest shows that Oregon and Washington share a common biogeographic region. From Cape Flattery, at the tip of Washington's Olympic Peninsula, to Cape Blanco on the southern Oregon coast, the coastline sweeps along a single continuous arc. The Columbia River estuary breaks, but does not interrupt, this single arc, and the fresh water discharge of this river strongly influences ocean conditions for miles both north and south of the estuary, depending on the season.

The Columbia River is only a political boundary between the states of Oregon and Washington. As well as an oceanographic setting, the two states share many social and political values. If these factors don't provide sufficient rationale, the trans-boundary dynamics of ocean resources compels the two states' cooperation and consultation in the management of their ocean resources.

For years, the Department of the Interior has designated a single planning area for Oregon and Washington. Because the two states are treated as one area by Interior, staff from the two states have collaborated at informal levels. Their collaboration is now growing toward a more formal mechanism for regional co-management with federal agencies.

The coastal management agencies of both states have developed considerable ability to participate in the Department of the Interior's OCS program. Oregon's coastal management agency is the Department of Land Conservation and Development (DLCD), and Washington's is the Shorelands Division of the Department of Ecology (DOE). Although the two states' agency and program structures are very different, their collaboration at the staff level has continued over the past six years.

Collaboration and coordination has grown, particularly with respect to the Minerals Management Service's (MMS) Environmental Studies Program. Discussions now involve staff from other affected state agencies, expertise from the states' universities, and staff from other federal agencies. In fall 1987, an ad hoc Environmental Studies Technical Advisory Committee convened to review and comment on MMS's FY 89 Environmental Studies Program. The Committee, which continued to meet through spring 1988, has attempted to establish what long-term studies are needed in the Pacific Northwest, and those which should be conducted prior to OCS leasing off Washington and Oregon.

On a related but separate track, the states have long argued that the OCS lease sale planning process for Oregon and Washington should be separated from the issues and emotions surrounding California OCS leasing. They have also maintained that lease sale planning in the Pacific Northwest requires a special state-federal effort for legitimacy. So although a Pacific Northwest planning group was suggested by Oregon's Governor in 1985, action to establish it was deferred by the Secretary of the Interior. In late summer 1986, Oregon and Washington OCS staffs met with the Director and the Pacific Regional Manager of Minerals Management Service to discuss the idea of a Pacific Northwest Regional Technical Working Group. This time there was interest in a reviewing a state proposal.

By mid-1987, state staff had agreed on the basics of such a state-federal group. In meeting with MMS Pacific Region staff to discuss these concepts, there appeared to be general agreement by MMS that the state's proposed structure and focus was constructive. However, it was not clear that MMS staff fully appreciated the political significance of an Oregon-Washington group. The state's proposal will be the first time a state has taken the initiative to restructure the framework within which discussions and decisions concerning offshore resources take place. The states continued to remind MMS of the importance of the issue through their Congressional delegation's actions on the House and Senate Appropriations Committees.

In October 1987, the recently-appointed Deputy Director of MMS met with Oregon and Washington staff members to discuss the composition and scope of work of a Pacific Northwest group. Discussions included the role of northwest treaty Indian tribes in the working group. Following this meeting, the states drafted a Cooperative Agreement, obtained their respective Governors' approval, orchestrated a letter to the Secretary of the Interior from the Governors of Oregon and Washington, and prepared a press release concerning the proposal. In February 1988, the proposal was submitted to the Department of the Interior.

As proposed, the Northwest Regional Task Force is intended to "facilitate efforts to reach consensus regarding issues related to the OCS program...." The Task Force's work would result in coordinated program and policy recommendations to submit to the Secretary of the Interior. Initially, the Task Force would focus on environmental studies and analysis required in advance of proposed Lease Sale #132.

As proposed by the states, the Task Force would be composed of two committees. A Steering Committee would be comprised of policy specialists from the states, the Department of the Interior, and treaty Tribes, and a Technical Committee would be appointed to provide expertise to the Steering Committee.

It is now late October 1988. The last of several volleys and return shots concerning the Agreement may be over soon; a Pacific Northwest OCS Task Force may, in fact, become a reality. When that occurs, Oregon and Washington will have a much better opportunity to influence the OCS process. In fact, a new opportunity for regional co-management of a wide variety of ocean resources may eventually devolve from this new state-federal-tribal structure.

CONCLUSION

When the Ocean Resources Management Plan is completed, Oregon will have a strategy and a plan of action to use in advance of important development decisions. The plan will be based on sound accessible information that ocean users need, agencies require, and the public expects. The plan will be implemented through a coordinated network linking local, state and federal agencies. It is highly likely that no new agency will be needed for its ongoing implementation, although new coordination mechanisms may be recommended.

The Task Force is committed to establishing an effective joint participatory process with the federal government that recognizes the legitimate interests of Oregon and its citizens. Oregon's example can help open the ocean policy "window of opportunity" at the national level by constructing an integrated regime for ocean resource management. Like its land use planning process, Oregon's ocean planning process is open to all, comprehensive in scope, and characteristically highly ambitious.

OVERVIEW AND ANALYSIS OF COASTAL ZONE MANAGEMENT IN THE ATLANTIC PROVINCES, CANADA

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ABSTRACT

This paper is an attempt to examine all of the coastal resources of the Atlantic Provinces in a comprehensive fashion on the basis of readily available information. The resources are identified in order to facilitate in establishing priorities for future investigation and to aid in the design of policies and procedures for making resource use decisions for the varied types of situations encountered along the coastline.

The coastline with its complex environement often governed by a varied body of laws and regulations which are administered by local, provincial and federal agencies. With the onset of urbanization, concentration, exploitation of resources and inherent uses and abuses of the coastal zone, the role of the local bodies has increased for proper understanding in the development of management strategies of the coastal resources. This work envisages the importance of developing suitable evaluation information for different policy issues and implementing tasks basing on research programmes.

Socio-economic and administrative structure has a great responsibility in determining the future for the "harvest of coastal riches". This study presents some examples of socio-economic conflicts and interests of the Atlantic Coastal Zone to impress the importance for the development of alternate strategies.

1. INTRODUCTION

The coastline of Canada is a valuable national asset. A large portion of this (nearly 40,000 km long) is along the Atlantic Seaboard, extending from the Arctic to the Gulf of Maine, the Canada-U.S. border. The continental shelf of the Canadian Atlantic Coast is about 200 km wide off Nova Scotia, reaches out 500 km on the Grand Banks southeast of Newfoundland, and then narrows to less than 100 km along the coast of Labrador. The depths, in general, are less than 200 m, with the exception of the Laurentian channel, which connects with the Gulf of St. Lawrence and Hudson Strait. The coastal zone supports over 2.285000 people of Newfoundland-Labrador (Nfld. & Labd.), Nova Scotia (N. S.), New Brunswick (N. B.) and Prince Edward Island (P.E.I.). Many estuaries, marshes, bays, barrier islands, mark this important coastal zone. Many current systems and upwellings are found on the shelf and in the estuaries.

Maritimers enjoy continental to maritime climate. The northern N.B. exhibit characteristics of a modified continental climate. In the coastal areas, the climate is influenced by the ocean. Precipitation is the highest in winter and the shore areas receive increased precipitation and they are mostly foggy in late spring and early summer. The yearly coastal invasion of ice makes the fishing and fish-processing operations limited to the open-water seasons. In winter the wave energy, along the Canadian Atlantic coast and over the continental shelf, was five to six times greater than during the summer and the energy concentration on the Grand Banks and Labrador was three to four times that over the Scotian Shelf(1).

The early inhabitants have depended upon the land for growing crops. Their forest woodlots provided fuel and often a small cash income from lumber and pulp wood. Man of the Atlantic Provinces drew support for his livelihood traditionally from the coastal waters which are used for power generation, shipping and trade, transportation, manufacturing and other industries, for municipal requirements, commercial and sports fishing, wildlife and recreation and in the disposal of residential, commercial and industrial wastes. There is an increasing trend towards the exploitation of this natural resource. This creates a challenge to plan for the future uses of the resources of the Coastal Zone (C.Z.) area. The continued use of C.Z. created problems like pollution of estuaries, loss of marshlands, deterioration of recreation areas, loss of soil aggregates, siltation, sediment displacement followed by competing and conflicting interests.

Generally the coastal zone (C.Z.) brings into focus the interface between land and water resources. C.Z. may coincide with high-tide coastline in a rocky cliff coastline, which has no backshore or the boundary may be a mile from the high-water line because the backshore consists of a broad plain or an extensive marsh-meadow shorescape or they could be frequently shifting (river meander progression, foredune storm

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ablation, sand-split growth or bluff recession). The foreshore and the backshore of the riverine, lacustrine, estuarine and marine waters are affected by the prevailing geohydraulic system. This region is called as the coastal zone or the shore-process corridor and these could cover vast areas as in the case of broad plains and marshes or very limited and narrow regions near rocky and mountainous coasts[2]. The broad plains shorelines shift from time to time depending upon the geohydraulic and other environmental influences. Erosion and accretion play an important part in the maintenance of the shore-process corridor. This is influenced by the quality of water received from the surrounding land, sea, the ground water and the atmosphere[3].

The estuarine and C.Z. environment is intimately integrated with the nutrient inputs and outputs along with the changes in water levels and their quality. Man is responsible for the imbalance in the natural shore-process systems by use and abuse without proper understanding of the principles of coastal or shore management. It is time, though not late, to understand these dynamic zones and systems to respect and maintain the integrity of this heritage resource. Establishement of priorities and preferences of the use of coastal resources with a view to protect and control the ecological, environmental and other characteristics of the coastal zone in consultation with the local users and planners of the region along with government authorities concerned will help to preserve this natural heritage to posterity. Orderly understanding, participation and co-ordination lead to the logical and impartial management policies in the interest of public. These will result in laws, guide-lines and other protective measures for the management of the coastal resources for the benifit of man. The resources should be used equitably for the functional recreational, economic and aesthetic values. C.Z. management implies development and utilization of all resources in a way that is compatible with one another and with the environment. This article tries to present a general classification of the coastal resources, their representative areas, evaluation of the alternate use of the resources and of the existing institutional arrangements.

2. COASTAL ZONE RESOURCES CLASSIFICATION

The historic shoreline uses[4] were for settlement, agriculture, trade, transport and defence. The current uses increased urbanization, industrialization, harbour developments, dredging, energy exploitation, reclamation of marshes and tidal flats for city developments, recreation and transport. The environment is being used in various aspects by man:

Physical and chemical aspect:

Coastal land: capability, type, geology, erosion, use and misuse, urban growth.

Air : Quality, climate, noise, radiation, microclimate

Water : Quality and urban runoff

Biological aspect:

Plants -- Forests, grasslands, bottomlands

Animals -- Wildlife, fish, micro-biota

Social and cultural apsect:

Population -- Urban and rural, employment, demography

Land use -- Urban, agriculture, rangeland, forestry, water, wetland, barren land,
Recreation - (sports, fishing, skiing, nature study)
Transport
Conservation - (parks, rare & scenic areas, wildlife)

Economic aspect: Agriculture, aquaculture, fishery, mining, forestry, construction, recreation & tourism, manufacture, utilities, finance and trade, urbanization, public administration, energy, resource development, conservation & preservation, transport.

3. COASTAL ZONE USE AND ABUSE

Canadian exports of fish and fish products amounted to about $2.2 billion in 1987. Coastal fishery usually fall into three categories, namely Fresh-water, Estuarine and Immediate Coastal Waters. Anadromous (spawn in the fresh-water and move to the sea for adult life - eg. Atlantic Salmon, Speckled Trout, Rainbow Trout, Brown Trout, Shad, Smelt, Striped Bass) catadromous (spawn in the sea and move to fresh-water for adult life - American Eel) and resident (live in fresh-water - landlocked Atlantic Salmon, Trout, Alewife, Landlocked Smelt) are the three types that could be distinguished, although the same types are present in Estuarine waters also. Tomcod is one of the anadromous estuarine fishes of Atlantic Coastal Estuaries. The important resident estuarine molluscan species are Oysters, soft-shell Clams, Quahaug, Whelks, Periwinkles, and Blue Mussel. Immediate and important coastal fishes include Atlantic herring, Bluefin tuna, Mackerel, Lobster and Crab for domestic consumption in the Atlantic Provinces and the dependency of fishing industry has become multi-species oriented. This economic dependency on water has lead to several conflicts and ultimately contributed to the deterioration of water quality by pollution, eutrophication, contamination of the

shallow and protected estuarine waters of the Southern Gulf, for example Miramichi Bay, Malpeque Bay and Caraquet Bay, where proper coastal conditions for oysters naturally exits. Deterioration of water quality has already, directly or indirectly affected the people, their interests in commercial and sports fishing, recreation, tourism and water related industries like fish-processing[5].

Some of the C.Z. areas are heavily exposed to pollution and have become dumping grounds for domestic and industrial effluents and solid wastes. Rivers discharge contaminants to the estuaries and between 1978 and 1983 alone there were 637 significant oil and petroleum product spills from ships and other sources[6]. Major hazards to canadian fisheries are the disposable sites, diffuse sources of contamination, pesticide contamination, recycling of chemicals already present in the environment, oil spills, deficiencies in technology and scientific understanding of chemical contaminants, regulatory and administrative deficiencies and ineffective endorcement of regulations and public perceptions regarding contaminated fish and toxic chemicals[7]. Contaminated dredge spoils (Baie Comeau, Gaspé, Chandler, Cap-aux-Meules), mercury in Saguenay, Mirex in eels, pulp mill discharges (Exploits River), mining (Belledune), pesticide spraying of forests, PAH contamination at Sydney, N.S., coal wash plant discharges at Cape Breton Island, Hydrocarbon exploitation (Scotian Shelf, Georges Bank, Hibernia), Potash mining, Pesticides use in agriculture), aquaculture developments, acid rain, organochemicals are some of the Atlantic C.Z. regional problems[8,9]. The biological and chemical factors are difficult to interpret and often add complexity to jurisdictional and regulatory measures for fishery management[7].

The protection of coastal waters from fecal coliform pollution is mandatory as it has significant impact on the economy and health of the people. Côté et al.[10] stated that there are nearly 310 bays and estuaries in the Maritime Provinces which are contaminated by fecal coliform bacteria and in recent years contamination of shellfish growing areas are in great increase due to point and non-point sources of pollution[11]. The uncontrollable dumping of shellfish and fish wastes on private lands in some coastal areas of N.B. resulted in the contamination of waters, creation of odour and vermin problems.

East coast blooms, occuring during summer and fall, are caused by Gonyaulax excavata (tamarensis) and appear in the Southern Bay of Fundy and in the area of the St. Lawrence River Estuary. Red-tides are known to occur frequently with increased eutrophication. The consequences of these blooms to Canadian Fisheries Resources is connected with the problem of paralytic shellfish poisoning (PSP), caused by accumulation of paralytic, dinoflagellate toxins by benthic filter-feeding molluscs. However, a herring kill in 1976 in the Bay of Fundy was linked to dinoflagellate toxins[12]. The mortality probably resulted through a series of planktonic food chain events. This raises the question of the extent of the consequences to fish of Gonyaulax toxins in the plankton community and the planktonic food chains could affect year-class strenghts of certain fishes. The PSP problem is increasing world-wide and the C.Z. of the Atlantic Region is no exception. The recent major toxic element present in P.E.I. mussels early last winter was domoic acid and the diatom, Nitzschia seriata was the prime suspect. A better knowledge and understanding of the phytoplankton populations of the coastal and marine waters is essential for the development of control and management strategies for the hazardous phytoplankton blooms.

The habitat destruction is frequent in the C.Z. of the Atlantic Provinces. Dams, impoundments have contributed in rapid erosion of the shorelines. Many wetlands were lost due to encroachment of urban development and extension of highways. Peatlands of Nfld., N. B. and N. S. are continuously being depleted. Sand mining and coastal erosion is very common. Drift of sand at the harbours' mouth is a frequent entrance problem for inshore fishermen. Dredging of the coastal channels, often a necessity, results in fish habitat destruction.

Barrier islands, long and sandy, with beautiful beaches, are common in the northern Gulf of St. Lawrence, like the north shore of P.E.I. which are the popular recreational areas. The best examples are Tabusintac, Tracadie, Pokemouche and Point Escuminac. These are long barriers or sand reefs backed by lagoons and estuaries dominating the shorline. There are also more detached fragments of sand reefs, like Portage and Fox Islands, at the mouth of the Miramichi. Even before these are discovered by the general public, they are faced with increased erosion due intense sand dredging to maintain navigable routes for small crafts. The common recreational activities ares swimming, boating, sport fishing, cottaging and camping, or space for more passive appreciation of aesthitic, scientific and ecological values, water-skiing, hunting fish, waterfowl, sight-seeing, picnic, and walking or hiking. Sport fishing (tuna and salmon or trout), boating and hunting are a major source of revenue.

Aquaculture, growing salmon, mussels and oysters, is an expanding industry. Often the ideal sites are located near fishing ports which require periodic dredging and this has led to conflicts between the siting of aquaculture and oceans disposal sites[13].

Renewed interest in Hibernia oil development, building a fixed crossing between P.E.I. and N. B. and Fundy Tidal Power plant have once again generated the question of impact on the C.Z. and the environment. Often topics like synergestic effects amongst multiple inputs on the C.Z., cumulative effects on marine organisms due to

hazardous chemicals or ecotoxicological effects on fish and other biota, and influnce of sediments on phytoplankton and microalgal benthic production of the dredged channels and surrounding areas remains untouched. The strategic roles of ecotoxicology in protecting marine environmenal quality from land-based pollutants was discussed in detail by Wells et al.[14].

4. RESOURCES AND CONFLICTS OF THE COASTAL ZONE

A variety of existing resource use conflicts require mediations of a comprehensive management plan. Some examples are:

- navigation or recreational boating vs. fishing activities (nets, buoys, rafts);
- beach mining vs. recreational use;
- water oriented recreational activities vs. environmental capacity of the National Parks;
- commercial development vs. aesthetic uses;
- public access vs. aquaculture;
- public access vs. cottagers privacy;
- disposal of domestic wastes by shore populations or boats vs. shellfish harvesting;
- shoreline protection vs. cottage developers;
- increased siltation due to road construction, land clearing, agricultural practices vs. estuary ageing and production of desirable species;
- input of nutrients vs. stability of estuarine communities and aesthetic or recreational use;
- runoff of pesticides and other contaminants vs. existence of some components in the estuarine web;
- bacteriological contamination from agricultural runoff vs. shellfish harvesting and recreational uses;
- energy production vs. quality of environment (water, air & land); and,
- disposal of pulp mill and other industrial wastes vs. water quality, fishery conservation and protection.

Interactions in the C.Z. environment commonly met in the Atlantic Provinces are shown in Fig. 1. An evaluation of the existing C.Z. demands by man and interaction between the demands in the C.Z. for proper environmental impact assessments is very difficult.

5. COASTAL ZONE MANAGEMENT NEEDS

At present there are about forty Federal and Provincial Acts administered in the coastal Provinces of Atlantic Region. Mixed jurisdiction, limited legislation and ineffective enforcement have prevented from direct action on a variety of chemical contamination incidients which have affected the canadian fisheries[7]. Legislatior must be amended or developed to increase the collaboration among agencies and between levels of government. Social, economic, institutional and legal considerations must receive greater attention to protect the coastal waters[10]. It is desirable to create a central organizational body with Intra-Jurisdicational Powers for the Atlantic Provinces (Fig. 2). This envisages examination and evaluation of decision processes for each representative area, basing on the recommendations of the scientific advisory bodies for each resource. The respective governments will implement the decisions. There must be constant collaboration from Public, Industrial, Private, University, Provincial and Federal Government Organizations.

The present federal-provincial split in resource management does not permit the recognition of the importance of the coastal zone from the functional point of view. The most important thing is to recongnize the coastal zones as the foundation for offshore and land developments. This can be carried out by declaring coastal zone as a national protected area.

Several improvements to the management of C.Z. are needed. We do require sufficient allocation of funds to foster and promote research on freshwater and coastal marine ecosystems. A basic understanding of these is required, particularly the primary producers and their interplay with the secondary production. For example emerging issues like dioxins in marine sediments; Phytoplankton distruction, blooms and their metabolism; ecotoxicological studies in relation to chemical hazards to fish and fisheries deserve immediate attention. Improvements in the areas of information systems, research, monitoring and evaluation, and institutional coordination as suggested by Morgan et al[15] for the marine environmental quality of management in British Columbia are also equally applicable to the C.Z. of the Atlantic Provinces.

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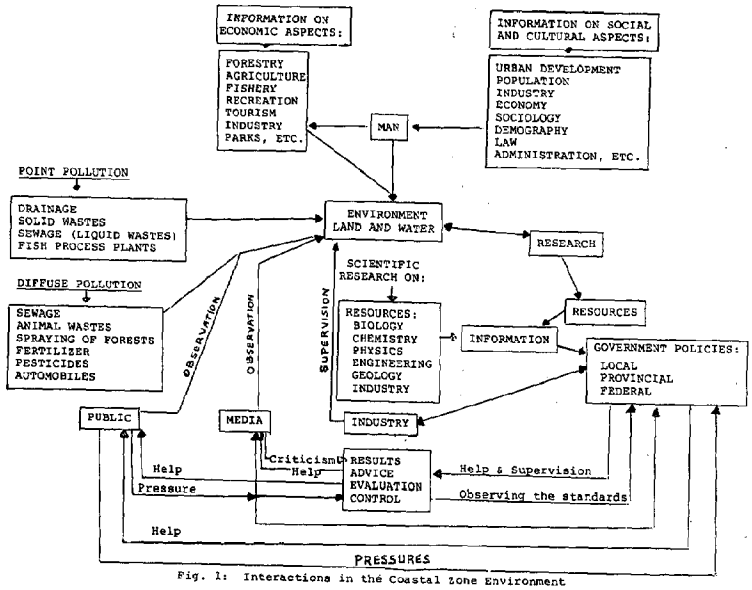

Fig. 1: Interactions in the Coastal Zone Environment

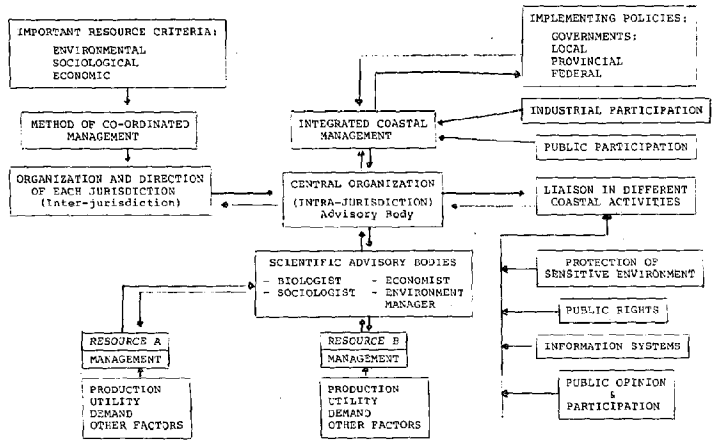

Fig. 2: Organizational structure for coastal zone management

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COASTAL STATES AND MARINE RESOURCE DEVELOPMENT within the UNITED STATES EXCLUSIVE ECONOMIC ZONE

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Abstract

In 1983 the United States established a 200 nautical mile Exclusive Economic Zone (U.S. EEZ). The U.S. EEZ is the newest, and perhaps last, playing field for a tug-of-war the states and the federal government have been playing since the Constitution was ratified -- Federalism. In terms of managing the resources within the U.S. EEZ, the coastal States define "federalism" as being "full partners" with the federal government. It is stateside where there must be port, processing, transport, and housing facilities to accomodate ocean resource development, and where the air, water, land or visual environmental affects are felt. States will have to generate increased revenues to pay for the new demands on their social infrastructures. Thus, it is only just that the states be "full partners" with the federal government in managing ocean resource development. Only changing the existing legal status quo will make this possible, a step that must be carefully weighed and considered before executing. The best way to do this is to establish a National Ocean Policy Commission.

Introduction

The oceans, long viewed as the great commons of the world, must now be seen in a fundamentally different light. Over 60 nations have proclaimed 200 nautical mile exclusive economic zones off of their shores. Within these zones, coastal nations have sweeping powers, including "sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or nonliving, of the seabed and the subsoil, and the superjacent waters, with regard to other activities for the economic exploitation of the zone, such as the production of energy from the water, currents and winds,"[1] as well as jurisdiction with regard to artificial islands, marine research and environmental protection. In 1983, the United States established, by presidential proclamation, the United States Exclusive Economic Zone (U.S. EEZ). Within this maritime zone the United States has internationally recognized authority to control its domestic resource management, and to regulate, or prohibit outright, foreign activities, such as fishing, oil and gas development, mining ocean minerals, or doing any other "economic" activity.

Collectively, the world's EEZs cover one third of the total ocean surface -- an area that was historically considered "high seas." Eighty five to 95 percent of the worlds commercial marine fishing, all of the worlds offshore oil and gas production, and most marine research occurs in these EEZs. But more is at stake in this new zone than resource management.

Federalism and the U.S. EEZ

The U.S. EEZ is the newest, and perhaps last, playing field for a tug-of-war the states and the federal government have been playing since the Constitution was ratified -- Federalism. Indeed, the coastal States are aggresively pursuing a much greater role in ocean resource management, that of being a "full partner" with the federal government.

The Coastal States Organization, representing the Governors of the 35 coastal States, Territories and Commonwealths, and several other organizations, has adopted a proclamation asserting "on behalf of their citizens, direct and inherent rights and responsibilities pertaining to the protection, conservation, and development of the living and nonliving resources" in the U.S. EEZ. Further, in recognition of these rights and responsibilities, the coastal States have resolved to be "full partners in the management of U.S. Exclusive Economic Zone resources and share in an equitable division of benefits derived from their development."

In terms of managing these ocean resources, the coastal states define "federalism" as being "full partners" with the federal government. The U.S. EEZ, however, is a fundamentally different playing field than the terrestrial United States. It is an "extraterritorial" region of the Nation, or "territories" of the U.S, or even the 3-mile belt of State ocean waters. The EEZ itself is not "owned" by the United States. Rather, the United States only has exclusive management authority over the resources in the U.S. EEZ. International uses, such as navigation, overflight, the laying of pipelines and cables, and other high seas freedoms, must not be infringed upon by the United States. U.S. duty and customs laws do not apply throughout the EEZ.

Given the broad scope of the "Commerce Power" vested in the federal government by the Constitution, it is arguable that the federal government

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would be constitutionally sanctioned to exert full and complete resource management authority in the EEZ, allowing no participation by the coastal States in the exercise of this authority. But the coastal States do have clear and direct responsibilities in how these resources are managed. It is stateside where there must be port, processing, transport, and housing facilities to accomodate the resource development. Environmental affects, whether they be air, water, land or visual, will burden the states. States may have to generate increased revenues (raise taxes) to pay for the new demands on social infrastructures: roads, police and fire departments, hospitals, etc.

Obviously, some form of partnership is required between the states and the federal government. But whenever any two entities cooperate, it is the stronger member of the combination that usually calls the shots. Because the national government has always been of superior fiscal size, to the extent of dwarfing any individual state, "federalism" is generally "a short expression for a constantly increasing concentration of power at Washington in the stimulation and supervision of local policies."[2]

Nonetheless, the assertion of "full partnership" federalism in the U.S. EEZ by the states comes at a time of opportunity and challenge. The opportunity exists because constitutional barriers no longer bar full state partnership participation. The challenge, however, is that a sizable body of federal ocean resource management law is in place that does not allow the states to be "full partners."

The U.S. EEZ Proclamation
A Frame Around the Picture

Much adieu has been made over the establishment of the 200 nautical mile U.S. EEZ. But in terms of providing a future source of natural resources for the country, the United States already had a wide array of statutes asserting exclusive jurisdiction and control for the exploration, exploitation, conservation and management of living and non-living resources in the waters that are now within the EEZ, as well as a host of other statutues affecting U.S. activities in the 200 mile zone. Indeed, with the possible exception of minerals within the EEZ that exist in deep ocean waters not traditionally recognized as the continental shelf[3], it may be fair to say that the United States could have continued what it was doing in our 200 mile zone forever without the Proclamation. And it is arguable that the United States actually did possess resource jurisdiction over these minerals prior to the Proclamation[4], although industry has not been willing to invest vast sums of money on such shakey legal ground, or seabed, as the case may be.

The Proclamation spoke more to the international community of nations than it did to the country itself. In fact, the Proclamation is silent as to what role the States are to play in this new domestic ocean area. But because the EEZ Proclamation was crafted in amazingly strict conformance with the LOS Articles on Exclusive Economic Zones, it squared up the United States' international ocean policy in a time when much of the world was deploring our refusal to sign the 1982 United Nations Convention on the Law of the Sea (LOS Convention). The Proclamation, however, added little to domestic authority or jurisdiction. The Proclamation, in essence, put an internation- ally recognized legal frame around the existing body of U.S. law pertaining to this 200 mile ocean zone.

A Sea Change for the Coastal States

Of great potential importance for the coastal States, however, is that the Proclamation fundamentally altered the legal character of the 200 mile zone around the United States. Prior to the Proclamation, the body of U.S. law pertaining to this zone, while asserting exclusive U.S. management jurisdiction in piecemeal fashion over select resources, continued to operate in the internationally recognized regime of "high seas." After the Proclamation, however, it became internationally recognized that the United States has exclusive jurisdiciton over not only fish, oil, or marine mammals, but "sovereign rights" to manage all living and non-living resources within the U.S. EEZ, and to protect and preserve the marine environment.

In other words, prior to the Proclamation the United States asserted certain rights over select resources in the high seas. After the Proclamation the United States now has sovereign rights over management of <u>all</u> resources (except tuna) in an area no longer characterized, in terms of international resource management law, as high seas. Although the pure concept of high seas had eroded bit-by-bit within 200 miles of this country, and others, the status of all resources in this zone did not unequivocably change to something other than high seas resources until the issuance of the Proclamation.

Now that the United States has sovereign rights over the living and non-living resources in the U.S. EEZ, how to exercise them is clearly a sovereign, i.e. domestic, question. In terms of international law, this is a fundamental change with a potentially profound domestic affect.

For decades the U.S. Supreme Court has consistently ruled that the federal government possessed full and paramount authority to manage the natural resources outside of the three mile territorial sea. In fact, until Congress passed the Submerged Lands Act in 1953, the Court ruled that even within the three miles the federal government had full and paramount natural resource management authority.[5]

In part, the present relationship for ocean resource management between the federal government and the States stems from the 1945 Truman Proclamation on the "Natural Resources of the Subsoil and Sea Bed of the Continental Shelf." President Truman declared that the United States

had "jurisdiction and control" over the natural resources of the continental shelf "appertaining to the United States." It was expressly noted that the character of the waters above the U.S. Continental Shelf remained "high seas."[6]

Two years later, in United States v. California, the Supreme Court ruled against California's claim that it had "dominion" over the submerged lands within the three English mile zone of state waters, and thus "owned" the natural resources therein. In rejecting California's arguments, the Court relied upon the rational that:

> whatever any nation does in the open sea, which detracts from its common usefulness to the nations, or which another nation may charge detracts from it, is a question for consideration among nations as such, and not their separate governmental units."[7]

As a result, the Court ruled that the "Federal Government rather than the State has paramount rights in and power over that belt, an incident to which is full dominion over the resources of the soil under that water area."[8]

Three years later, in 1950, the Supreme Court ruled in United States v. Louisiana that:

> The [three mile] marginal sea is a national, not a State, concern. National interests, national responsibilities, national concerns are involved. The problems of commerce, national defense, relations with other powers, war and peace focus there. National rights must therefore be paramount in the area.[9]

Looking beyond the three mile marginal sea, the Court was even more adamant that the federal government had paramount authority. Having ruled the the "three-mile belt is in the domain of the nation rather than that of the separate States" the Court went on to say that:

> ... it follows a fortiori that the ocean beyond that limit also is. The ocean seaward of the marginal belt is perhaps even more directly related to the national defense, the conduct of foreign affairs, and world commerce than is the marginal sea. Certainly it is not less so.[10]

In the same year Texas challenged the supremacy of the Federal Government over the marginal sea. Texas argued that because it was an independent Republic prior to admission to the Union it exercised both Dominion (ownership) and Imperium (governmental power) over the marginal sea, which in the case of Texas extends nine nautical miles. The Court held, however, that upon entering the Union Texas was placed on an "equal footing" with all the other States. As a result, Texas relinquished some of her sovereignty and

> "[t]he United States then took her place as respects foreign commerce, the waging of war, the making of treaties, defense of the shores, and the like. In external affairs the United States became the sole and exclusive spokesman for the nation."[11]

Congress reacted to this series of Supreme Court cases by enacting the Submerged Lands Act of 1953, granting the States title to the seabed of the marginal sea. Later that same year Congress passed a companion act, the Outer Continental Shelf Lands Act (OCSLA), establishing exclusive federal jurisdiction over the continental shelf seaward of the territorial limit of the States. The OCSLA expressly recognizes the nature of the superjacent waters as high seas.[12] As for the submerged lands, however, the OCSLA clearly provides that, on the continental shelf beyond State waters, the federal government has "exclusive jurisdiction and control over the seabed and subsoil of all submerged lands ... which appertain to the United States and are subject to its jurisdiction."[13]

Nonetheless, in 1969, thirteen Atlantic States challenged the federal government's paramount rights over the submerged lands beyond State waters. The States claimed that they had acquired, as successors to the Crown of England (or the Crown of Holland in the case of New York), exclusive dominion and control over the seabed beyond the three mile State waters. The Supreme Court, in rejecting this argument, reaffirmed the holdings in the California, Louisiana and Texas cases, holding that although Congress had vested full title and authority in the three mile zone to the States, the federal government retained full dominion over the seabed of the Atlantic Ocean beyond the three mile line, as set forth in the OCSLA.

These Supreme Court rulings, whether before or after the Submerged Lands Act and the OCSLA, were based on the view that, because the ocean area beyond territory clearly vested to the States was international in character, resource management decisions could affect foreign affairs. Because the U.S Constitution expressly grants to the federal government all powers to conduct foreign affairs, the States had no role to play in marine resource management decisions.

This has changed. With the U.S. EEZ Proclamation, resource management within the EEZ is no longer international in character, but rather is a purely domestic matter. The basis of the California case -- that "whatever any nation does in the open sea, which detracts from its common usefulness to the nations, or which another nation may charge detracts from it, is a question for consideration among nations as such, and not their separate governmental units" -- simply no longer applies.

First of all, the EEZ is no longer an "open sea." Second, no other nation can charge that a resource management decision by the United States detracts from the "common usefulness" of this zone. This is precisely what changed by force and effect of the EEZ Proclamation. The resources of the U.S. EEZ are not to be managed for

their international "common usefulness", but rather for the domestic usefulness of the United States. No other nation can now claim otherwise.

In terms of national defense, foreign affairs, and world commerce, the Supreme Court's reasoning -- beyond the three mile line the ocean area "is perhaps even more directly related to the national defense, the conduct of foreign affairs, and world commerce than is the marginal sea -- remains sound even after the Proclamation. But domestic resource management is not the conduct of foreign affairs, nor, after the Proclamation, does marine resource management pertain to national defense or world commerce any more than does the management of natural resources on land.

Likewise, in the Texas case, he Court held that "[i]n external affairs the United States became the sole and exclusive spokesman for the nation." But again, domestic resource management is not an "external affair." Thus, the federal government need not be the "sole and exclusive spokesman for the nation" on how the EEZ resources should be managed.

Given the clear stateside impacts of offshore development, it is only logical that the domestic management of the resources in the U.S. EEZ is now a legitimate question for consideration of the "separate governmental units," i.e. the coastal States.

CHALLENGES AND OPPORTUNITIES FOR STATE EEZ RESOURCE REGULATORY AUTHORITY

The EEZ Proclamation did not grant any authority to the States, but it did remove the constitutional barriers to full State participation in U.S. EEZ resource management. However, legislative barriers remain to be overcome. The challenge for the States, is how to become "full partners" in light of the existing federal legislation managing these resources.

Options Available Within the Legal Status Quo

1. State Assertion of Regulatory Authority

Under the OCSLA and the FCMA, regulations have been enacted for the exploitation of oil, gas, sulphur, and some commercial fishery stocks. However, regulations have not been enacted for any other marine mineral, or for all of the commercial stocks of fish, let alone for "all forms of marine plant and animal life." Thus many EEZ resources remain unregulated. Of course, these unregulated resources are the less commercially attractive ones.

Living resources: The FCMA is the principle federal law governing the management of commercial and recreational fishing in waters beyond state territory out to 200 nautical miles. Under this act, the United States asserts "exclusive fishery management authority" throughout the U.S. EEZ.

The FCMA establishes eight Regional Fishery Management Councils, composed of varying numbers of members, ranging from 7 (Carribean Council) to 19 (Mid-Atlantic Council). In each council, a majority of the members are appointed by the Secretary of Commerce from lists prepared by the governors of that Council's representative states. The remaining members are chosen solely by the governors, with the exception that the regional director of the National Marine Fisheries Service for the geographic area concerned is a member of that area's council.

The FCMA does allow a State to regulate fishery resources beyond its territorial waters, even if there exists a federal fishery management plan. However, the FCMA limits this regulatory authority by providing that "A state may not directly or indirectly regulate any fishing vessel outside its boundaries, unless the vessel is registered under the law of that State."[14]

The FCMA has actually been found to encourage State regulation of fishing by its citizens in adjacent waters, if the regulation is not in conflict with federal law, and there exists a legitimate and demonstrable State interest served by the State regulation.[15] In fact, when no federal regulations exist, State regulations should be assumed not to be preempted; a finding of preemption absent federal regulation would defeat the purpose of the FCMA, i.e. the conservation of fishery resources.[16]

The limitations to State regulatory authority are apparent, however, whether or not a federal Fishery Management Plan is in effect:

- o State authority can be asserted only over vessels registered in its State, or over its citizens;
- o State authority can be asserted only where there is a legitimate and demonstrable State interest served by the regulation;
- o State regulations cannot conflict with any federal law or regulation.

Non-living resources: The OCSLA is the central federal statute pertaining to the submerged lands beyond state territorial waters, asserting U.S. "jurisdiction, control, and power of disposition"[17] over the seabed of the continental shelf. The OCSLA recognizes that "exploration, development, and production of the minerals of the outer Continental Shelf will have significant impacts on coastal and non-coastal areas of the coastal States."[18] In view of these impacts, "such States [and] ... affected local governments are entitled to an opportunity to participate, to the extent consistent with the national interest, in the policy and planning decisions made by the Federal Government relating to the exploration for, and development and production of, minerals of the outer Continental Shelf."[19]

Thus, a partnership role for the coastal states is envisioned in the OCSLA. But it is not a "full partnership," nor can this role any longer be considered appropriate in view of recent

federal judicial rulings. The OCSLA provides for a relationship of "coordination and consultation." That is, a Governor of an "affected State ... may submit recommendations to the Secretary (of the Interior) regarding the size, timing, or location of a proposed lease sale or with respect to a proposed development and production plan."[20] If the Secretary determines that the Governors recommendations "provide for a reasonable balance between the national interest and the well-being of the citizens of the affected State" then the Secretary "shall" adopt them.[21]

One can easily conclude from these provisions that the Governor's role is quite a contolling one. But because of the great flexibility given the Secretary by this statutory language, the result over the years is that the Secretary is anything but mandated to defer to a Governor's recommendations.

First, the Secretary, not the Governor, determines what is "the well-being of the citizens of the affected State." That is, the Secretary determines the weight to be given to the "national interest" and the "well-being of the affected State." Further, the Secretary's determination will stand unless it is found to be "arbitrary and capricious" -- a legal standard next to impossible to overcome.

Second, federal court rulings have judicially gutted this provision of the OCSLA by ruling that no deference to the Governor by the Secretary is required. The Secretary need not evaluate the range of "reasonable balances or of whether the Secretary, beyond merely explaining an alternative balance, had shown the governor's balance to be outside such a range. It [is] enough that the Secretary touch on the relevant factors in setting forth his own, differing view of the state and national interests."[22]

Thus, the Governor has little, if any, leverage to alter the course of federal oil and gas leasing, no matter how reasonable the Governor's recommendations are. In other words, the word "shall" -- as in "the Secretary shall adopt" -- has been judicially contorted into really meaning "may."

Further, the OCSLA grants the Federal Government exclusive rights to sell leases and collect rents and royalties from OCS mineral development. Without authority to sell leases, or collect rents and royalties, and with an advisory role that has been relegated by the courts to nearly the same level as the public-at-large, States, under the OCSLA and federal agency interpretations of the OCSLA, have very little regulatory authority or control over non-living resource management on the OCS within the U.S. EEZ.

Non-OCS lands within the EEZ are another matter, however. Contrary to legal assertions Interior Department, vast areas of the U.S. EEZ are geographically not continental shelf. Strong arguments can be made that in these deepwater areas of the U.S. EEZ, the OCSLA does not apply.

This category of hard minerals is potentially a subject for State assertion of regulatory authority. However, unilateral assertion of State regulatory authority over these minerals easily result in litigation.

If the assertion of State regulatory authority included the selling of leases or the collection of rents or royalties, the State would also have to overcome challenges based on the California decision that the States do not have dominium (ownership) over these resources and therefor have no authority to lease, rent or tax them.

b. Options by Changing the Legal Status Quo

Amend Existing Statutes

On an individual basis statutes such as the OCSLA could be amended to provide a greater role for the coastal States in EEZ resource management. Such amendments could go far to resolve the inadequacy of the statutory role provided for the States. Nonetheless, the resource by resource approach taken by federal legislation does not lend itself to resolution of multi-use conflicts over ocean resources.

To address both the role of the States in EEZ resource management, and the worsening problem of multi-use conflicts over these resources, an umbrella-type law would be needed. An "EEZ Resource Management Act" that would not repeal other marine resource acts outright, but rather only select provisions in those laws, could implement a new role for the States, provide a mechanism for resolving conflicts in lieu of litigation, and establish the national policies and priorities for managing the resources of the U.S. EEZ.

Conclusion

Clearly the coastal States do not have a great deal of leverage for becoming "full partners" with the federal government for U.S. EEZ resource management under the current legal status quo. Narrow channels exist for the states to exercise regulatory control. But for the most part the States must react to the federal government's resource development plans, rather than participate at an equal level in the planning and conduct of any EEZ resource development.

The EEZ Proclamation did act to clear the path towards "full partnership" with the federal government, but it was not self-effecting in granting the States any additional authority or control over ocean resource management. The only real route for the States to become "full partners" is through amending the existing framework of ocean resource legislation. This would involve amending a whole realm of federal laws. Such a step cannot simply or lightly be taken. A great deal of consideration, balancing and research must be done to effectively implement a "full partnership" for the coastal States. In order to do this job correctly and completely, an oceans policy commission, or

something equivalent, seems mandatory.

The U.S. House of Representatives has passed a bill that would establish a National Ocean Policy Commission charged with reviewing the body of U.S ocean law and policy, the respective roles of the federal, State and local governments in ocean resource management, and developing recommendations to the Congress and the President on domestic ocean laws that will need revision.

With the issuance of the EEZ Proclamation, a Proclamation that has not yet been legislatively implemented, the need for such a Commission is justifiable. In the event of any other major ocean iniative, either by the President or the Congress, such as extending the U.S. Territorial Sea from 3 to 12 nautical miles, the need for a National Ocean Policy Commission becomes much stronger.

Given that is stateside where there must be port, processing, transport, and housing facilities to accomodate ocean resource development, and that it is stateside where the environmental affects, whether they be air, water, land or visual, are felt, and given that States will have to generate increased revenues to pay for the new demands on social infrastructures, such as roads, police and fire departments, and hospitals, due to ocean resource development, it is only just that the states be "full partners" with the federal government in managing ocean resource development. The only feasible way for the states to attain "full partnership" is to change the existing legal status quo, a step that must be carefully weighed and considered before executing. The best way to do this is to establish a blue ribbon reviewing panel, such as a National Ocean Policy Commission.

FOOTNOTES

1. U.N Convention on the Law of the Sea, Article 56.

2. The Constitution of the United States, pg. xxi. Library of Congress publication, 1972.

3. See, EEZ Proclamation, March 10, 1983.

4. See, Opinion of the Solicitor, Dept. of the Interior, M-36952, May 30, 1985.

5. See, United States v. California, 332 U.S. 19 (1947).

6. Proclamation 2667, Sept. 28, 1945.

7. 332 U.S. 19, 35.

8. Id.

9. U.S. v. Louisiana, 339 U.S. 669, 704 (1950).

10. Id. at 705.

11. U.S. v. Texas, 339 U.S. 707, 718 (1950).

12. See, 43 U.S.C. 1332(2).

13. Id., at 1331(a).

14. 16 U.S.C. 1856(a).

15. People v. Weeren, 607 P.2d 1279; 163 Cal. Rptr. 255 (Ca. 1980). See also, Fidell, Enforcement of the Fishery Conservation and Management Act of 1976: The Policeman's Lot (1977) 52 Wash.L.Rev. 513, 593-597, and fn. 467; cf. Northwest Trollers Ass'n v. Moors, 89 Wash. 2d 1, 568 P.2d 793, 795 (1977)).

16. See Anderson Seafoods, Inc. v. Grahm 529 F.Supp 512 (N.D.Fla. 1982) upholding state statute prohibiting use of purse seine within or without the waters of the state as applied to fishermen with vessels registered in the state operating beyond state territorial boundary.

17. 43 U.S.C. 1332(1).

18. 43 U.S.C. 1332(4).

19. 43 U.S.C. 1332 (4)(B). (Emphasis added).

20. 43 U.S.C. 1345(a)

21. 43 U.S.C. 1345(c).

22. The Tribal Village of Akutan, et al. v. Hodel et al. (D.C. AK, 1988). See also, California v. Watt, 683 F. 2d 1253 (9th Cir. 1982), rev'd in part on other grounds, 464 U.S. 312 (1984).

COLLECTION AND QUALITY CONTROL OF MARINE GEOLOGICAL DATA BY THE OCEAN DRILLING PROGRAM

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ABSTRACT

A computerized database is being used within the Ocean Drilling Program to archive geological data generated from shipboard and shorebased analyses of core samples from beneath the sea floor. These data include geophysical, geochemical, paleontologic, paleomagnetic, petrologic and physical properties determinations.

Data collection on paper forms are often incomplete, illegible, and incorrectly filled out. To overcome these problems, standardized data collection procedures are being implemented. Computerized data entry forms with standard error checks have been designed for shipboard data collection. Error checks include restrictions on values, checks on missing values, and sample identification.

Computerization onboard the drillship JOIDES Resolution, the organization of the database, and the benefits of the system to the scientific community as they apply to shipboard and shore-based studies are discussed.

INTRODUCTION

The Ocean Drilling Program (ODP) is a basic research program primarily directed at exploring the earth's history by retrieving and analyzing core samples from beneath the floors of the world's ocean basins. The sediment and hard rock samples are collected during cruises aboard the drilling vessel JOIDES Resolution (Figure 1). The retrieved core samples are described and analyzed by the shipboard scientific party in the laboratories listed below. Samples are further distributed for shore based measurements.

Each cruise of the JOIDES Resolution, approximately 2 months in duration, departs with a multi-national scientific crew and technical support staff 50 persons. A 12,000 sq. ft., seven-story shipboard laboratory contains state-of-the-art scientific equipment. The laboratories (Figure 2) include sedimentology, paleomagnetics, physical properties, petrology, thin section, paleontology, chemistry, X-Ray diffraction and fluorescence, downhole logging and underway geophysics, as well as modern facilities for photography, electronics, and refrigerated core storage. Two DEC VAX 11/750 (the VAX 11/750 is a trademark of Digital Equipment Corporation) computers onboard assist with scientific bookkeeping, routine clerical work, data collection and data retrieval. IBM personal computers (pc's) and pc clones are located throughout the labs for stand alone capability and to act as terminals to the VAX[1]. For an overview of the drilling program, including science plans, drilling vessel, shipboard laboratories, engineering development, logging, etc., the reader is referred to the Proceedings of the Oceans '85 Conference[2-6].

The ODP Database Group is responsible for archiving the data generated from core samples curated by the ODP. This includes data collected onboard the ship and data generated from ODP core samples by investigators working in their home laboratories. Computerized data from the Deep Sea Drilling Project (DSDP), which operated from 1968-1983, are also incorporated in the ODP database.

Three important concerns of the Database Group are the subject of this paper: 1) the organization of the ODP database which facilitates the storage and retrieval of the data; 2) the computerization of shipboard data collection which improves the quality of the data; and 3) the services we are able to provide to the international scientific community. Both the organization of the databases and success of the shipboard collection scheme affect the ODP Database Group's responsiveness to the data users.

ODP DATABASE ORGANIZATION

The ODP database is stored in System 1032 or S1032 (System 1032 is a trademark of CompuServe), a relational, general-purpose database management system that runs on the VAX computer family. The organization of the data in S1032 reflects the analyses that are being conducted in the labs on the ship. For example, smearslide descriptions are stored in one datafile, while calcium carbonate data are in another. A standardized sample identifier is part of each record in the database facilitating searches and retrievals. A datafile can be searched individually or all the files can be cross referenced to allow reports containing information from more than one file. Figure 3

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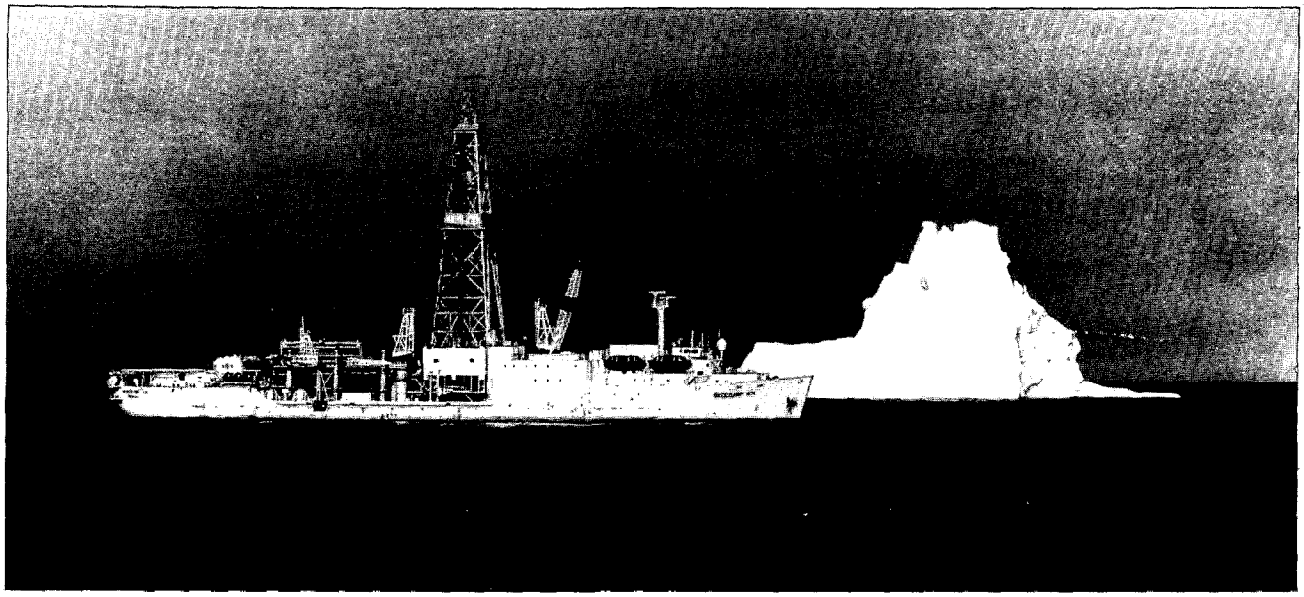

Figure 1. The JOIDES RESOLUTION (registered name SEDCO/BP 471) during Leg 105 in Baffin Bay

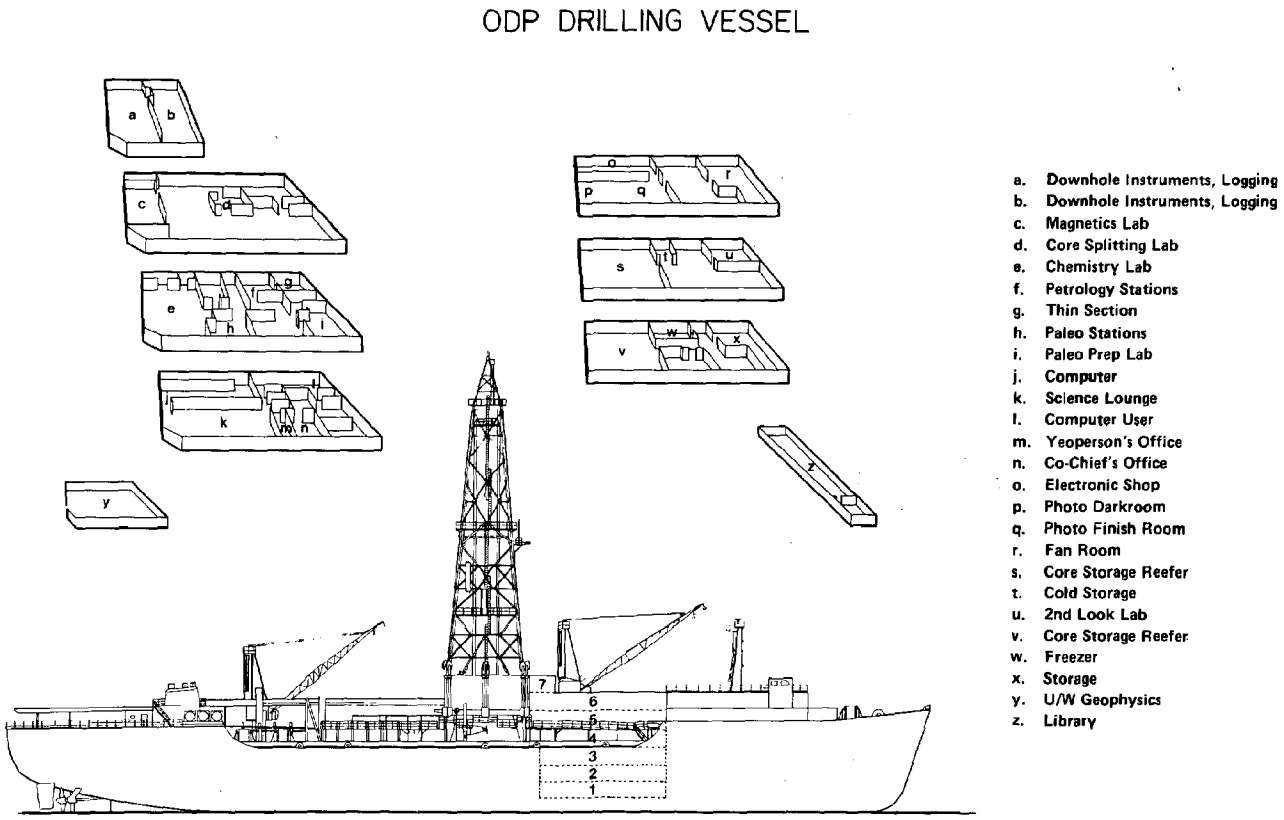

Figure 2. Scientific work spaces onboard D/V JOIDES RESOLUTION.

DATAFILE	DESCRIPTION
1 LITHOLOGIC AND STRATIGRAPHIC DATA	
Visual Core Descriptions	Core color, sedimentary structures, disturbance, large minerals and fossils
Smearslide Descriptions	Nature and abundance of sediment components
Thin Section Descriptions	Nature and abundance of hard rock thin section components
Paleontology	Abundance, preservation and location of fossils
2. PHYSICAL PROPERTIES	
G.R.A.P.E. (gamma ray attenuation porosity evaluation)	Whole core density measurements
Index Properties	Water content, porosity, bulk density and grain density
Thermal conductivity	
Shear Strength Measurement	
Liquid and Plastic Limits	
Velocity Measurements	
P-wave Logger	
Downhole Tool Measurements	Pressure and temperature insitu
3. SEDIMENT CHEMICAL ANALYSES	
Carbonate	% by weight of calcium carbonate content of a sample
Carbon, Hydrogen and Nitrogen	% by weight of a sample
Interstitial Water	ion measurements on pore water samples squeezed from the sediments
Gas Chromatography	Hydrocarbon levels in core gases
Rock Evaluation	Hydrocarbon content of a sample
4. HARDROCK CHEMICAL ANALYSIS	
X-ray Fluorescence	Major and minor mineral components
5. PALEOMAGNETICS	
Discrete Sample Analyses	By the Spinner or Cryogenic Magnetometer
Whole Round Continuous Analyses	By the Cryogenic Magnetometer
6. SPECIAL REFERENCE FILES	
Leg, Site and Hole Summaries	Information on general leg, site and hole characteristics (ex. location, water depth, sediment nature, drilling statistics, etc.)
Corelog	Depth of each core for determination of the depth of a particular sample
7. UNDERWAY GEOPHYSICAL DATA	
	Includes bathymetry, magnetics, navigation, and seismics

Figure 3. The organization and content of the ODP Database

outlines the organization of the database with a brief description of the contents.

COMPUTERIZATION OF DATA COLLECTION ONBOARD SHIP

Currently onboard JOIDES Resolution, data are collected by three methods, with overlap between these methods: 1) scientists and technicians record the data on pre-printed, multi-part NCR paper forms; 2) computerized data entry screens are utilized to enter data directly into the appropriate S1032 datafile, and; 3) data are captured directly by the computer from a machine conducting an analysis. All data are returned to the Database Group after the cruise. Computerized data are easily reviewed and merged with preexisting computerized data. Data on paper forms must be reviewed, edited and then key entered into the computer.

One of the major activities of the Database Group and the ODP Computer Services Group has been to reduce the use of paper forms, as much as possible, because of their many disadvantages, including:

a. Inability of shore personnel to read the handwriting of the scientists and technicians.
b. Forms are often incorrectly or incompletely filled out.
c. Mistakes can be made during key entry onshore, such as a misplaced decimal point, incorrect spelling, etc. The long lag time before entry of the data usually precludes recovery from such errors.
d. Extra time and personnel are required onshore to edit and enter the data.
e. The availability of the database is delayed while key entry onshore is being performed.

Collecting data using computerized data entry

forms or direct data capture greatly improves the quality of the data by removing the disadvantages listed above. While entering data into the computer on the ship, queries on possible errors can be made immediately after computerized cross-checks. The scientist is immediately able to take advantage of other software packages on the VAX computer. He is able to produce important charts and graphs for data interpretation. He is able to compare data from different datafiles in real time, in order to better understand the geological environment.

Shipboard computerization is a challenge because each two month cruise includes a new group of scientists from around the world, who must learn to use the ODP computer system quickly. Computerized data entry must be simple, even for someone unfamiliar with computers or with the English language, as are many of the shipboard scientists. Computerized entry forms must be carefully designed to capture all data pertinent to the database yet allow scientists to include their own personal comments. The success of computerized data collection systems already implemented onboard ship has encouraged us to continue our efforts.

The following is a discussion of the computerized shipboard data entry methods used on the ship. The two methods described are the use of computerized data entry screens for key entry of data and the capture of data from a computer-driven analytical device. Both speed up data collection and help to maintain quality control over the data.

Computerized Data Entry Screens for Key Entry Onboard Ship

Computerized data entry screens are currently being used with 11 of the 25 ODP datafiles, including both analytical and descriptive data. The screen forms are very simple in design, easing the task of teaching their use to the constantly changing personnel. Edit checks are built into the screen forms to verify data quality while the scientist is still at the terminal. Routine checks include:

a. All data required by the datafile must be entered before the record is accepted into the datafile.

b. Data which are outside a predefined range and field for a particular data parameter are not accepted by the form and an error message results.

c. Data parameters that are coded are matched against valid codes listed in a table. Error messages indicate an invalid entry.

d. Each sample identifier is checked to be sure it is from a valid core section. If not an error message results.

e. Built-in cross checks among data parameters result in error messages or warnings for incorrect form entries (Figure 4).

Online "help" menus are available to supplement the user error messages and to explain what the permissible ranges and fields are for a particular data parameter. "Key word"

```
-------------------C A C O 3 _ C A R B O N-------------------
SAM CODE  LEG  S  SITE  HOLE  CORE  T  SECTION  TOP  BOTTOM
  BRO     101  _  621   A     4     R   04      100    98

                    ____4 % INORGANIC CARBON
                    33.3 % CaCO3

                    ____ % TOTAL CARBON
                    ____ % ORGANIC CARBON

                                    C CaCO3 Method (C/B)
                                  ____ BOMB Pressure (psi)

COMMENTS_____________________________________________________
_____________________________________________________________

ERROR: Bottom interval must be greater than or equal to top interval
```

Figure 4. Example of a computer entry form with an error message.

tables are provided for forms used to collect descriptive data. This standardizes the datafile and helps the scientists, with their varied backgrounds and expertise, to include all data pertinent to the datafile. Comment fields are present to enter items of a personal interest to the scientist or help clarify the data. A printer connected to the computer terminal generates a paper copy of each entry, thus providing a backup record of the data in case of computer failure.

Once the data have been entered into the S1032 datafile on the VAX, the scientists are immediately able to access the data. Standardized print menus are built into the data entry system so that scientists can easily display the data. For more sophisticated users, the software packages on the VAX are available. Also, the other datafiles in S1032 can be accessed for comparison.

The sediment smearslide description shipboard application will serve as an example of data entry screens for key entry. Smearslide descriptions are descriptions of small amounts of recovered sediments examined under a microscope to derive information about the nature and abundance of the sediment components. A trained scientist indicates the abundances of the various components he or she is able to identify using percentages which should sum to 100. Before the computerized application was installed on the ship, the scientist recorded the data on paper forms. He or she was able to record anything, everything, or nothing, with no control over whether percentages summed to 100.

The computerized application allows the scientist to enter what he or she feels is important, yet requires that the information for the datafile be entered correctly. A large comments field is available for the scientist to enter pertinent descriptive information. The edit checks listed earlier are performed before each record can be added to the datafile. Checks specific to the smearslide application are also performed. For example, the data entry screen form supplies an error message if the total abundance of the components is greater than 100%. The component names are stored as codes in the datafile. An online list of

component names and codes is available. The component codes entered by the scientist are automatically compared against the code list in the computer to ensure correctly spelled, valid components.

The success of the smearslide application is its ability to meet the needs of the shipboard scientists and the requirements of the Database Group. The scientist is able to directly enter his or her data into a computer datafile without having to fill out a paper form. He or she is then able to display the data immediately using the standardized report formats built into the application. The data returned to the Database Group are already entered into the computer with all the appropriate edit checks. Thus the data need only be quickly reviewed and merged with the rest of the ODP database.

Data Captured Directly from Computer-Driven Analytical Devices

Data are currently being captured directly from 5 different computer-driven analytical devices on the ship. The resulting datafiles contain the sample identifier for each record and the data generated by the device. The scientist or technician must key enter the sample identifier which is merged with the analytical results. For several of these applications the computer queries the scientist or technician to enter that part of the sample identifier common to all the samples being run at one time. The computer then generates the rest of the identifier based on the depth within the core that the analysis was performed. For the rest of these applications, screen forms are utilized to key enter the entire sample identifier which is then merged with the analytical results.

Direct capture is the ideal data collection method for data generated from computer-driven analytical devices. It eliminates all the disadvantages of using paper forms mentioned earlier. It frees the scientist and technicians from the chore of rewriting computer generated data onto a paper form or typing them onto a computerized entry screen. Again the scientist is able to retrieve the data easily, print the data, and produce plots and graphs.

SERVICES PROVIDED TO THE INTERNATIONAL SCIENTIFIC COMMUNITY

One of the most important functions of the ODP Database Group is to answer data requests from the international scientific community in a complete and timely fashion. The use of S1032 to organize and store the data on the computer and the computerization of data collection on the ship facilitates this task. Requestors are able to receive data from Leg 1 through the most current ODP Leg. (A one year moratorium following the end of a Leg is placed on all data.) One or more data parameters in a datafile can be searched quickly, and since all the datafiles are linked by the sample identifier and sub-bottom depth, a data request can include information from more than one file. Documentation is provided for each datafile. The documents designed to accompany the data collected by DSDP are available as ODP Technical Note #9, "Deep Sea Drilling Project Data File Documents". Data can be provided as hard copies, on tape or diskettes, or through the various computer networks. To obtain data, contact the Data Librarian at ODP. As more of the data are entered into the computer on the ship, the Database Group will continue to spend less time editing and keying the data onshore. This will allow more time for designing guides and references to the database, thus making the ODP database more useful to the public.

The responsiveness of the Database Group to the shipboard scientific party has greatly improved as a result of computerized shipboard data collection. As already mentioned, scientists are able to create plots, graphs, and charts while onboard to help with the geological interpretation of an area. They are able to leave with these materials in hand to complete their interpretations for later publication. Currently all the computerized DSDP data are available on the ship. Eventually, any data collected at sites similar to or near the site being studied will be available on the ship. This can be a very important tool to the shipboard scientists as they try to understand the structure and history of a region.

CONCLUSIONS

The Ocean Drilling Program database is generated from both shipboard and shorebased analyses of samples retrieved by the Ocean Drilling Program and the Deep Sea Drilling Project. The database is computerized in System 1032 which operates on a VAX computer. The organization of the datafiles is based on the analyses that are conducted on the ship.

Computerized shipboard data collection includes direct data capture from computer-driven analytical devices and the use of computerized data entry screens for key entry. Edit checks built into computerized forms prevent capturing incorrect or incomplete data. Computerization eliminates the need for paper data collection and the many disadvantages associated with it. Also, it helps to insure data quality, consistency and accuracy.

The computerized data collection applications are designed to be simple in order to facilitate their use by the international shipboard scientific party. Comment fields are included to help the scientist provide extra information. Graphs and plots can be produced while still on the ship. Less time is spent recording numbers, providing more time for the scientist to complete his or her work.

The ODP Database Group is able to respond quickly to the scientific community due to the organization of the database and the computerization of data entry onboard the ship. As more data are computerized on the ship, the

burden of extensive editing and key entry of the data onshore is lessened. This makes it possible for us to concentrate on individual requests as well as preparing guides to the data for the international community.

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SHIPBOARD LABORATORY SUPPORT: OCEAN DRILLING PROGRAM

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ABSTRACT

The Ocean Drilling Program (ODP) is dedicated to providing a state-of-the-art research environment for the study of deep ocean marine geology. JOIDES Resolution, the scientific drillship of ODP, contains over 12,000 sq. ft. of laboratory space in a seven-story modular structure designed to meet the needs of modern marine geological research. This laboratory complex allows for investigation of sedimentology, physical properties, paleomagnetics, chemistry, petrography, and paleontology through the examination and analysis of core material recovered from the ocean bottom. This floating laboratory supports a team of about 25 international research scientists on each two month cruise. A group of 17 technicians operates, maintains, and trains scientists in the use of the scientific equipment aboard the JOIDES Resolution. This paper discusses the equipment, purchased and built, that supports the above investigations.

INTRODUCTION

The Ocean Drilling Program (ODP) is a long term basic research program primarily directed to studying the evolution of the solid earth and its environment through the recovery of samples from beneath the floors of the world's oceans (1-4). These samples are described and analyzed at sea in the laboratory space (Figure 1) aboard the research drillship JOIDES Resolution (a.k.a. SEDCO/BP 471) (5-6). We list below the laboratory spaces and describe the state-of-the-art equipment used for shipboard analyses of the cores.

CORE LABORATORY

The core lab is a core entry lab, core splitting room, sampling area, and description area (sedimentology lab).

The core entry lab is divided into an outside core receiving area and an interior core holding area. The equipment used in the core entry lab includes core liner cutters, a core extruder, a core inscriber, a core-logging computer with a core label printer, and basic hand tools. The core is received from the rig floor in a thirty foot long by two and a half inch diameter cylindrical plastic liner. This liner is cut into five foot sections using a specially designed stainless steel cutter. This cutter clamps around the liner and cuts the liner with an exacto-type razor blade as the cutter circumscribes the liner. The core extruder is an hydraulic ram with a piston head that is used to remove compacted sediment in the core catcher, the lowermost section of the steel core barrel. Once inside the core lab, each five foot core section is inscribed using a high speed rotary drill with a grinding bit (much like a dentist's drill).

The core splitting room is isolated from the rest of the core lab due to the noise and contamination produced during the longitudinal splitting of the core sections. The core splitter was designed to split core in two ways. If the sediment is unconsolidated the section is split by cutting only the plastic liner with two razor blades mounted opposite each other on a block with the core section in the middle. The block is equipped with ball bushings that glide on two hardened stainless steel rails the length of the section. A rope is attached to the block and the block is moved with the help of an electrically driven capstan winch. The core material is cut with a piano wire that follows the block as the plastic liner is cut. If the core material is consolidated sediment (for example limestone) a specially designed rock cutting saw is employed. The rock saw is mounted on a block which, like the razor blades, glides over hardened stainless rails. A ten inch diamond-tooth blade is used to cut both the liner and core material simultaneously. Basalt and other basement rocks are hand cut on a Felker rock saw to preserve the orientation of rock material from piece to piece. Chert is not cut with a rock saw; because of its extreme hardness it is split using a hammer and chisel.

The sedimentology lab contains separate description and photography tables, as well as bench space and microscope stations. Smear slides are prepared using ovens and hot plates under benchtop fume adsorbers. Most standard chemicals and lab equipment are available, as well as stains, dyes, and mounting media. The optical equipment in the sedimentology lab includes two Zeiss standard WL microscopes and two Zeiss SR stereomicroscopes. Oculars,

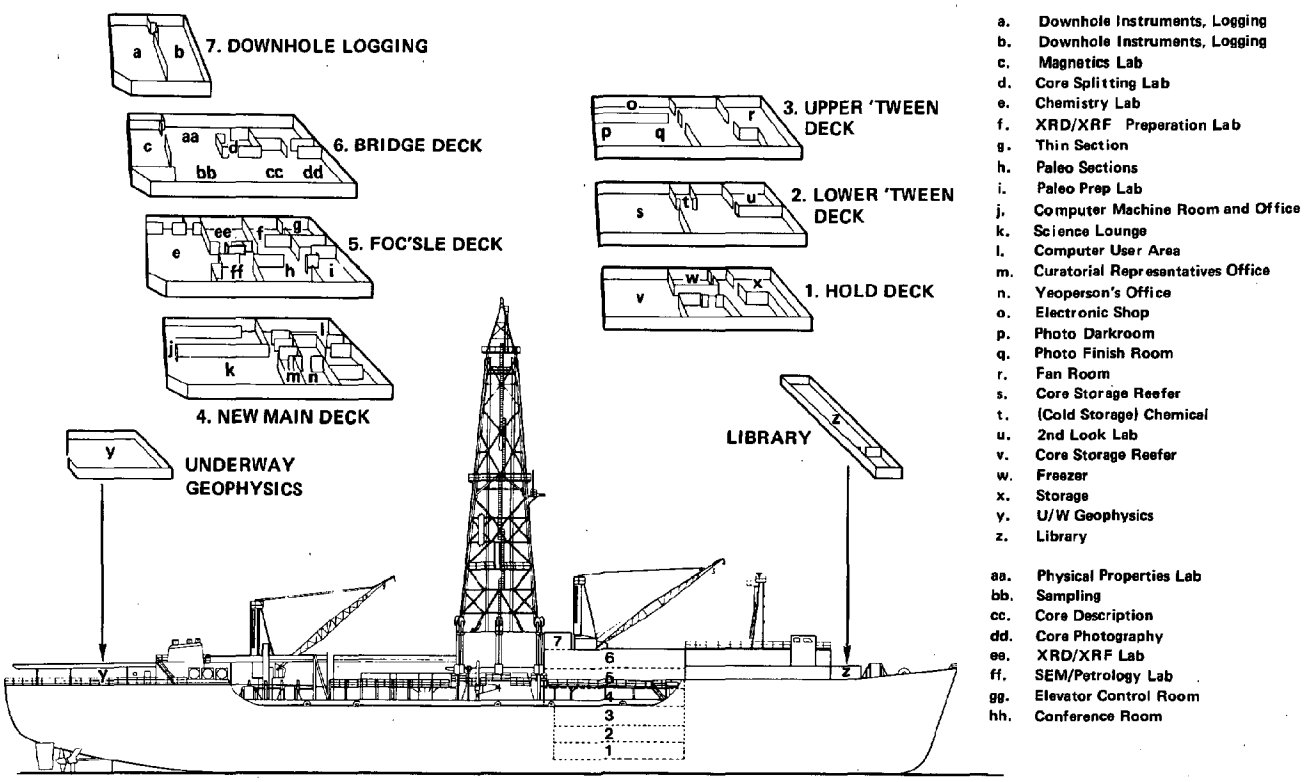

Figure 1. Laboratory spaces aboard the JOIDES Resolution.

objectives, micrometers, and filters for these microscopes are inter-changeable among all the Zeiss microscopes on board. Each microscope is supported by a vibration isolation system. Grain size is measured with an optical particle size analyzer. An area is set up to photograph the archive halves of each core. This table is equipped with a 4x5 overhead-mounted view camera for black-and-white and color sheet film. The table is mounted on a scissor-lift table that facilitates core handling. There is also an MP4 copystand with 4x5 and 35mm cameras for core closeups.

Core sampling equipment includes Felker radial arm saws, a drill press with diamond coring bits and minicorer, heat guns, and heat sealers. Computer terminals are conveniently located for direct input of sampling data and to print sample labels.

PALEOMAGNETICS LABORATORY

The shipboard paleomagnetics lab is located at the aft end of the core lab. This lab is equipped for measurement of magnetic remanence (using spinner and cryogenic magnetometers) and volume magnetic susceptibility of whole (or split) cores of sediment and discrete samples of sediment and rock. Discrete samples may be demagnetized using alternating magnetic field (AF) or thermal demagnetizers. Split sections may be AF-demagnetized using in-line demagnetization coils built into the cryogenic magnetometer. Cores may be geographically oriented as they are taken, using a Multishot core orientation tool. The results of these analyses are thus available for immediate integration with other shipboard data. Shipboard measurements help to reduce the effects on data of alterations such as oxidation, mechanical disturbances, and exposure to high magnetic fields that occur between coring and shorebased sampling.

The Molspin Minispin spinner magnetometer is a basic field unit interfaced with a PRO-350 computer for control and data acquisition. The BASIC program for the Minispin executes spin sequences and, using the data from each spin, calculates declination, inclination, and intensity in mA/m corrected for sample volume. A series of measurements is made on each sample as it is run through a demagnetization sequence. The Minispin can measure both rock and sediment samples up to 2.54 cm (1") cubed in size, with intensities ranging from 0.05 to 105 mA/m. Ordinarily, six separate spin orientations are required to produce an accurate measurement. In general, the processing rate varies with NRM intensity and response to demagnetization of the samples from a particular lithologic unit.

A Schonstedt alternating field demagnetizer is used for demagnetization of discrete samples

of rock or sediment. The user can select a range of peak fields from 0-999 Oe and a decay rate of 1-50 mOe/half cycle.

A Schonstedt thermal demagnetizer is used for thermal demagnetization of dry rock samples with a temperature range of 0-800°C.

A Schonstedt portable fluxgate magnetometer is available to measure ambient fields, with a range of ±2000 milligauss and a sensitivity of 0.01 milligauss (1 gamma). The sensor is small enough (1.3 X 7 cm cylinder) to fit into small spaces such as the sample access tube of the cryogenic magnetometer.

The shipboard Bartington magnetic susceptibility meter has two sensors: one for discrete samples and a loop for whole core pass-through measurements. The meter has two measurement modes for different sensitivities. An accuracy of 1.0×10^{-6} cgs can be obtained with a 1-second measurement cycle and accuracy of 0.1×10^{-6} cgs with the 10-second cycle using either sensor. An automated core conveyor and data acquisition system for the susceptibility meter is being developed to facilitate whole core pass-through measurements. This new system will use a new 80mm dual frequency loop (0.47 and 4.70 kHz.)

The 2G 760-R superconducting (cryogenic) magnetometer is used primarily for whole core continuous NRM measurements on half sections of cores, though these cores may be uniformly demagnetized (up to 90 Oe) inside the mumetal shielding of the cryomag and subsequently measured by the magnetometer. It is calibrated in units of magnetic flux (phi_0) and measures in units of 10^{-6} emu. The cryomag may also be used to measure and demagnetize (to a level of 90 Oe) discrete samples; a control program facilitates these measurements.

The best-shielded instrument is the cryogenic magnetometer, which resides inside three concentric mumetal cylinders. Its AF coil assembly is also contained within these shields. A superconducting lead shield surrounds the sensing region and maintains an absolutely stable field within. The cryogenic magnetometer has a liquid helium capacity of 100 liters which lasts approximately six months.

Using an Eastman multishot core orientation tool, cores may be oriented in situ with respect to the downhole ambient field. This tool requires a special nonmagnetic drill collar as part of the drill string.

PHYSICAL PROPERTIES LABORATORY

The shipboard physical properties program is aimed at monitoring variations and values of physical and mechanical properties of recovered lithologies. Since the properties of sediments change with time after they are recovered, a complete shipboard physical properties program represents the best opportunity to obtain reliable physical properties data from the cores. Results from this lab are valuable for correlating drilled sequences to seismic reflection and refraction profiles and downhole logging results, and for defining the nature of lithologies derived from distinct geologic settings.

A number of physical property tests require whole-round lengths of core sections and therefore must be performed prior to having the core sections split. These tests include whole-section logging for density, porosity, and velocity, thermal conductivity, and vane shear measurements made perpendicular to bedding. Density, porosity, velocity, and magnetic susceptibility of a core section are measured on a recently designed "multi-sensor track". A computer controlled stepping motor drives a fiberglass core boat through the sensing devices. Bulk density and porosity are determined by measuring the attenuation of a gamma beam through the sample. Compressional-wave (P-wave) velocity is measured while the core section passes between two 500-kHz transducers. Magnetic susceptibility is measured as the core stops in a sensing loop. The multi-sensor track was designed to accommodate up to eight sensors, each controlled by its own microcomputer. A master microcomputer controls track movement and coordinates data acquisition of the individual sensor computers and data transfer to the main shipboard Vax computer complex. Thermal conductivity measurements, necessary for studies of heat flow through the oceanic crust, are made by drilling a small hole in the plastic liner of a whole-round core section and inserting a needle probe connected to a heater current. The resistance data obtained can be reduced to values of thermal conductivity.

In addition, other physical property tests are performed after the core sections are split. These tests include compressional velocities, index properties (bulk density, water content, grain density, porosity, and void ratio), vane shear strength and other conventional tests such as Atterburg limits. The shipboard laboratory is equipped with a Hamilton frame velocimeter to measure velocities parallel and perpendicular to bedding. A dual-blade trim saw is used for cutting parallel faces of firm to hard rocks. All index measurements are made by noting gravimetric-volumetric relationships on wet and dry samples using a computer controlled electronic balance that automatically compensates for the ship's motion, automatic Quantachrome Pentapycnometer (volume), and freeze-drier. Wet samples are weighed and measured for volume as quickly as possible to prevent desiccation. Then the samples are freeze-dried, re-weighed, and the volume determined. All index properties are calculated from these raw data. A Wykeham-Farrance spring-type device and a torque transducer/X-Y plotter system are the two motorized vane-shear strength apparatuses available on board. Hand-held torvanes are also available for vane shear strength determinations.

CHEMISTRY LABORATORY

The chemistry lab is equipped for both organic and inorganic geochemical measurements.

The primary function of the organic lab is hydrocarbon monitoring. Elemental analysis of sediment and interstitial water is the primary function of the inorganic lab.

Gas monitoring equipment in the chemistry lab includes two Hewlett Packard 5890 Gas Chromatographs and a Carle model 101 GC. The Carle is used for rapid analysis (less than 5 minutes) of methane/ethane ratios. One of the 5890s is configured as a natural gas analyzer with three chromatographic columns which enable hydrocarbon separations as well as analyzing elemental gases. These gases include oxygen, nitrogen, carbon dioxide hydrogen sulfide, and hydrocarbons through C14. The second 5890 is fitted with a split/splitless 50-m fused quartz small-bore capillary column. This gas chromatograph is used primarily for hydrocarbon analysis of liquid extractions. Both 5890s are equipped with a thermal conductivity detector and a flame ionization detector in series, and the Carle has an FID. The GC's are connected to a Lab Automation System (LAS) via an HPIB loop. The LAS stores, converts, and integrates data output, and generates a customized report for each analysis. Three HP3393 Integrators are used to integrate each analysis. The LAS is an HP1000 minicomputer and consists of a 600+ CPU and a 28-megabyte Winchester disk.

The Delsi Nermag Rock-Eval II Plus TOC is a microprocessor-based instrument for whole-rock pyrolysis, used to evaluate type and maturity of organic carbon, calculate petroleum potential, and detect oil shows. It has a printing recorder and an automatic sampler that holds 24 samples.

Two Coulometrics analyzers are available which produce accurate colorimetric measurements of total carbon and carbonate constituents in sediments. The inorganic coulometer uses hydrochloric acid to convert carbonate to carbon dioxide which is then back-titrated to a colorimetric endpoint. In the total carbon analysis, sample is heated to about 1000°C and the resulting CO_2 is back-titrated to a colorimetric endpoint.

Interstitial water core samples are scraped of contamination and placed in a Manheim squeezer apparatus. The squeezer is then placed in one of two Carver hydraulic presses that are capable of 25 tons constant pressure, and squeezed until a sufficient quantity of water is extracted usually 30ml from a 500 cubic centimeter sample. The resultant pore water is filtered into a syringe and prepared for analysis.

First, the water is titrated for a PH/alkalinity determination. This analysis is automated by interfacing a Metrohm 655 Dosimat, a Metrohm 605 pH meter, and an HP86B microprocessor.

Titrations of calcium, magnesium, and chlorinity are performed using a Metrohm 655 Dosimat, which is capable of dispensing titrant in microliter amounts.

Colorimetric measurements of ionic concentrations in pore water samples are conducted on a Bausch & Lomb Model 1001 Spectrophotometer. With a wavelength range from 190 to 950 nm, analyses can be made of ionic concentrations of nitrate, silica, ammonia, nitrite, phosphate, bromide, and other common pore-water constituents. The spectrophotometer can accommodate a variety of cell types and sizes, facilitating precise analysis of small (microliter) sample volumes.

A Varian Atomic Absorbtion Spectrometer (AA) will be added to the chemistry lab in the near future. The AA will be supplied initially with lamps for analysis of calcium, iron, potassium, magnesium, strontium, sodium, manganese, and lithium.

A Dionex Ion Chromatograph (IC) produces sulfate and potassium data with the possibility of automated calcium and magnesium in the future. The IC uses the patented Dionex system of two-column chemical suppression. It is microprocessor-controlled and is coupled to the LAS. Its autosampler can hold 56 samples.

Two balance systems are available in the chemistry lab. A Cahn 29 balance mounted on a gimbaled table is used to measure small sample sizes (from micrograms to 1250 mg). Twin Scientech balances are available for measuring larger size samples (1 mg to 40 g). By employing a method of differential counterbalancing with computer averaging these balance systems compensate for all but the roughest sea state.

A Labconco 39-port freeze drier is available for removing water from sediment samples. It can hold 39 individual samples of up to 15 cm^3 each, one at each port, or larger samples in the central manifold.

The ship's potable water is further purified by passing through a Barnstead ultra-pure water purifier, to produce both lab and reagent grade waters by osmotic pressure and filtration. There is a 100-liter reservoir.

Electric agate mortar/grinders and hardened steel ball Spex mill grinders for homogenizing dried sediment samples and a shatterbox for pulverizing basalt or hard-rock samples are all available. Various drying and ashing ovens are available, as are refrigerators and freezers. There are three fume hoods: one is for solvents, the other two for chemical reactions.

There are two hydrogen generators in the chemistry lab, which supply the GC FIDs. Bottled helium (GC carrier gas) and oxygen are kept aboard the ship. The ship's pressurized air system is available throughout the lab structure and is appropriately filtered.

The chemistry lab contains a complete set of standard lab chemicals: acids, bases, solvents, etc. An ample supply of laboratory glassware and support equipment is maintained aboard ship for use during the cruise.

PALEONTOLOGY PREPARATION AND MICROSCOPE LAB

There are separate rooms for sample preparation (paleo prep lab) and microscope study (microscope lab). The paleo prep lab contains equipment and supplies needed to process micropaleontological samples and make slides. This equipment includes fume hoods, hot

plates, sonic bath and probe, centrifuge, ovens, microsplitter, sieves, chemicals, stains, dyes, and mounting media. The microscope lab is equipped with research quality Zeiss stereo, binocular, and photo microscopes and accessories for the study of paleontological and petrographic preparations. The binocular and photo microscopes can be used for either transmitted or reflected light microscopy. Two video TV cameras are available that can be adapted to any of the Zeiss microscopes. Connected to the cameras are video printers that produce immediate hardcopies of microscopic images. A shipboard paleontology library is kept in the microscope lab. This collection of important texts, journals, and reprints is cataloged in a separate paleontology library catalog and cross-indexed in the main shipboard science library catalog.

THIN SECTION LAB

The thin section laboratory has been outfitted to make thin sections by traditional methods as well as to provide quantity output. When only one or two thin sections are required, they are made "by hand" using a Buehler Petro-Thin thin-sectioning system and thin-section grinder. When large batches of thin sections are requested, the Logitech LP-30 lapping machine can be used to produce approximately 200 high-quality thin sections in a 40-hour week, in batches of 40 at a time. The sections are polished on a Logitech WG-2 polishing system. Special support equipment in the thin section lab includes a Logitech CS-10 thin section cut-off saw and IU-20 impregnation unit used to impregnate porous or friable specimens with synthetic resins. Delicate or critical samples are cut on a Leco VC-50 Vari-speed diamond saw. A Zeiss standard WL binocular microscope is available in this lab for monitoring slide preparation.

XRF AND XRD LABORATORY

In the interests of safety and to minimize sample contamination, a separate lab was designed for geochemical determinations by X-ray analysis.

An Applied Research Laboratory 8400 hybrid spectrometer is used for X-ray fluorescence analysis. This instrument is fully microprocessor- controlled with auto-sample loading. It has an end-window Rhodium X-ray tube, a 60 kV generator, and two independent goniometers with scintillation, flow proportional (P-10), and sealed Kr detectors. The following analytical crystals are available: LiF 200, LiF 220, LiF 420, PET, TLAP, GE and a multi-layered crystal that optimizes for sodium and magnesium. A DEC Micro-11 computer with a 28-megabyte Winchester disk drive supports the ARL-8400. Software includes quantitative, qualitative, statistical analysis, and fundamental parameters (XRF-11) programs. The system is calibrated for both major and trace element analyses of sediment and rock.

A Philips ADP 3520 is used for X-ray diffraction analysis. The diffraction pattern detected as an X-ray enters a sediment sample identifies mineral composition. It is fully microprocessor-controlled with auto sample loading, and is configured with a Cu X-ray tube and monochromator. A second DEC Micro-11 computer with 28-megabyte Winchester disk drive supports this system. Software support includes quantitative, qualitative, search-match of JCPDS and user data bases, line profile analysis, and statistical analysis programs.

SHIPBOARD COMPUTER SYSTEM

JOIDES Resolution is equipped with a research-oriented computer system designed to perform routine clerical and arithmetical tasks in order to free scientists and technicians for more creative research activities.

The central computer system assists in performing such diverse functions as core-log entry, core sampling, data analysis, drill string engineering, presentation graphics, microscopy, chemistry, inventory control, office automation, and manuscript preparation. This is accomplished through conveniently located microcomputer workstations arranged in a distributed processing architecture. A central theme in the design of the shipboard system was the offloading of common tasks onto workstations for more efficient use of the central system. This type of computer system architecture minimizes the possibility that shipboard operations would ever be delayed by a central system failure. All major system components are backed up with redundant twins or a complete complement of spare parts. The result of this approach is a system which fails gently, with a gradual degradation of performance when individual components fail, in contrast to a system where the demise of any one piece of equipment creates a catastrophic failure.

The central VAX system is equipped with four million bytes of random access memory (RAM) and provides high-speed computational power for arithmetic processing. The system also offers archival storage of shipboard data on one gigabyte (about 1.6 million typed pages) of high-speed mass storage and three magnetic tape drives that function at 800 or 1600 bpi.

A networked satellite communications capability allows the shipboard host computer system to access a similar VAX system at ODP headquarters in College Station, Texas. This communications link operates at 2400 bits per second through the Marisat satellite communications system. Capabilities of the system include access to scientific data from past cruises, shipboard inventory control, and electronic mail.

The major components of the shipboard computer system include two VAX 11/750 super-minicomputers, 50 microcomputers (a combination of Lucky IBM-clones, DEC Pro350s, and an Apple Macintosh), laser printers, high speed printer plotters, and a 36 inch drum plotter. In the near future the VAX 11/750 computer will be

clustered with a VAX 3500. This will considerably speed the system response time and allow for expansion as the system grows.

SCIENCE LIBRARY

A collection of more than five hundred volumes contains basic reference works, ODP Proceedings volumes, a set of DSDP Initial Reports, geologic and bathymetric maps, and selected mono-graphs covering various aspects of geology and oceanography. In addition, at the beginning of each cruise, collected reprints relating to cruise objectives are added to the library. These materials are intended to provide the necessary resources for shipboard analysis of drilling results. The science lounge and library share a collection of paperback books and magazines for popular reading.

Other library facilities include ten study carrels, a large map/chart table, microfiche and microfilm readers, a computer terminal, a copying machine, and a portable light table.

PHOTOGRAPHIC LABORATORY

The primary function of the shipboard photographic lab is to document the cores while they are fresh. In addition, the Photographic Technician is responsible for core closeups meant for ODP publications, seismic profile copywork, documentation of equipment, and public relations photography. The processing of photomicrographs, X-radiographs, and cruise-related personal copywork is accomplished on a time-available basis.

The darkroom has facilities for black-and-white developing and printing (both manually and with the Kreonite Print Processor) and for E-6 Ektachrome color film developing using a Wing-Lynch Film Processor. There is an MP4 copystand for seismic profile and document copying. Public relations photographs and other special photographic projects are performed with still camera systems and a video camera.

ELECTRONICS SHOP

The electronics shop is operated by ODP Electronics Technicians who are responsible for maintaining and repairing all shipboard ODP electrical equipment. The shop is equipped with a comprehensive list of electronic test equipment to enable test and repair of both digital and analog instruments.

DOWNHOLE TOOLS LAB

An in situ pore water sampler and temperature/pressure measurement instrument is used to collect pore water samples from sediment in the bore hole as well as temperature and pressure data. The tool is a battery operated device employing remote electronic timers and recorders. It is lowered down the bore hole and pushed into the sediment. The tool decouples from the drill string to minimize motion disturbance. At a pre-selected time a valve opens, allowing pore water to enter a pressure chamber at sea level ambient pressure. A thermistor accurately detects sediment temperature and a pair of pressure transducers measures the differential between hydrostatic and overburden pressures.

Another type of temperature recorder is used during piston coring operations. This self-contained unit (5 x 2 x .5 inch) fits into the wall of the coring shoe at the lower end of a piston core. Temperature data are recorded throughout the core run including a five to ten minute record after the core barrel is shot into the sediment. On recovery the data is downloaded to the VAX system and plotted to show accurate in situ temperatures verses depth.

UNDERWAY GEOPHYSICS LABORATORY

Shipboard personnel use this laboratory to collect navigational and positional data, collect and display bathymetric data (12-kHz and 3.5-kHz echo sounder data), collect and display magnetic data, collect, process and display in real time both single channel digital and unprocessed analog seismic data, and to produce standard (SEG-Y) format seismic data tapes for further processing and post-cruise archiving.

A Magnavox 1107-GPS combination Transit and Global Positioning Satellite Navigator, equipped with a Rubidium frequency standard, allows navigation during selected time intervals using only two GPS satellites. A Magnavox MX 4400 GPS receiver is on the ship's bridge. Other navigational equipment on the bridge includes a Magnavox MX702A Transit Receiver, and Decca and Loran C positioning systems.

For collecting bathymetric data, both 3.5-KHz and 12-KHz Precision Depth Recorder (PDR) systems are available aboard ship. A Raytheon PTR105B transceiver and 12 Raytheon transducers are used to gather 3.5-kHz data; another PTR105B transceiver and an EDO 323B transducer are used to gather 12-kHz data. Two Raytheon LSR1807M recorders are used for display. The 3.5-kHz and 12-kHz systems normally operate with CESP-III Correlators that give approximately a 20 db signal-to-noise improvement over the standard system. Due to difficulties in obtaining a good bathymetric signal at speeds greater than eight knots, a sonar dome will be attached to the ship's hull. The sonar dome will contain two 12-KHz transducers and an array of 12 3.5-KHz transducer bottles. It is hoped that the sonar dome will extend far enough below the ship's hull to escape the noise created by air bubbles along the hull/seawater interface.

Magnetic data at a density of one reading per seismic shot are recorded in the header of seismic tapes. These data are collected using a Geometrics 801 proton precession magnetometer and displayed on a strip chart recorder.

The standard seismic sources used aboard JOIDES Resolution are two 80 cubic inch Seismic Systems, Inc. waterguns. One 400 cubic inch SSI watergun and the following airguns are also available: one Bolt 1500-C with chambers of 120

or 300 cubic inches and three Bolt 600-A with firing chambers that can be varied from 5 to 80 cubic inches.

Two Teledyne streamers are mounted on winches on the fantail. They each contain sixty hydrophones, are 330 feet long and can be towed up to 1600 feet behind the ship; the towing depth can be maintained by external depth depressors (birds). Streamer output is transformer coupled to the ship via the tow cable. The hydrophone elements are combined to produce a single signal. A 10-Hz low cut filter is inserted between the streamer and the rest of the electronics to reduce high-amplitude low-frequency noise which might overload the amplifier.

The seismic system operates independently from the main computer system (VAX), using a Masscomp 561 super-micro computer as the central unit to record, process, and display data. Data are displayed in real time on a 15-inch wide Printronix high resolution graphic printer (160 dots per inch). The raw data are recorded on tape; processed data can also be displayed on a 22-inch wide Versatec plotter that gives a higher resolution display (200 dots per inch).

Raw seismic data are also displayed in real time in analog format on and Khron-Hite filter. This analog mode would be the primary recording mode should irreparable equipment failure preclude digitizing.

CONCLUSION

Although much of the equipment purchased for JOIDES Resolution's science laboratory was off-the-shelf, in many instances technicians modified the equipment to meet the unusual demands of an ocean environment. Ship's motion, vibration, salt air, and electrical power irregularities are major considerations when purchasing and installing shipboard equipment. Equipment must also be rugged enough to survive multiple users. Shipboard inventories of supplies and spare parts are carefully maintained to ensure minimal down time. If a piece of equipment is returned for repair, it is possible the equipment will be off the ship for four months or longer considering repair time and shipping schedules. Critical equipment is duplicated to avoid unnecessary loss of science. The technical staff of the Ocean Drilling Program pride themselves on an excellent record of equipment operation. This excellent record is achieved through rigorous safety practices, frequent routine maintenance, and a professional staff of highly trained and experienced technicians.

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CORE CURATION: OCEAN DRILLING PROGRAM

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ABSTRACT

Cores are stored for future scientific investigation at three sites: the East Coast Repository at Lamont-Doherty Geological Observatory, the Gulf Coast Repository at Texas A&M University (TAMU), and the West Coast Repository at Scripps Institution of Oceanography.

Aboard our drilling vessel, the JOIDES Resolution, the cores are described, analyzed and sampled by an international shipboard scientific and technical staff of ~50 persons, which changes with each two month cruise. The cores are kept in refrigerated storage at all times (aboard the vessel, in transit and in the repositories).

This paper describes the cores' shipboard and shorebased environments, the sampling procedures, and curatorial policies, as well as innovative studies monitoring long term changes in the conditions of cores resulting from storage.

INTRODUCTION

How does glaciation affect ocean current circulation? Do worldwide anoxic events really occur? What factors contributed to the extinction of the dinosaurs? What is the nature of new oceanic crust?

Nineteen years, 445,000 nautical miles and 119 voyages ago, a converted oil rig sailed from Hoboken, New Jersey to drill into the Earth's ocean floor so that marine scientists might better address these and other far reaching questions. This voyage, Leg 1 of the drillship Glomar Challenger, initiated an era of scientific drilling in the deep oceans (1-5) and marked the start of the most elaborate deep sea core curation program ever.

The Curator's Office of the Ocean Drilling Program (ODP), as inheritor of the Deep Sea Drilling Project (DSDP) cores drilled by the Glomar Challenger and repository of cores recovered by ODP's one-of-a-kind drillship, the JOIDES Resolution, has devoted much effort not only to expedite sample requests submitted by members of the worldwide marine science community but to the preservation of its most valuable asset, the cores.

SHIPBOARD CURATORIAL ENVIRONMENT

The Curator staffs the JOIDES Resolution with a curatorial representative who maintains accurate sampling records. The shipboard curator is responsible for guiding the scientific and technical staff in the preferred method of core handling and sampling. He/she also gives advice to the Co-Chief Scientists regarding the NSF/JOIDES/ODP sampling policies (6).

The bulk of shipboard curatorial work takes place in the core lab. Stringent shipboard procedures insure the scientific integrity of ODP cores. Following these procedures, the cores are split lengthwise into halves: the sampling half ("work" half) and the description half ("archive" half).

Once the cores are described, photographed and sampled they are placed in labeled tubes and boxed in waxed cardboard cartons. The "work" and "archive" halves are boxed separately and stored in different areas. Once the sections are split, the two halves are rarely handled together again. Care is taken not to sample or otherwise alter the archive half.

In port, the cores are carefully offloaded and shipped in refrigerated ocean freight containers to minimize the evaporative effect of heat. If the cores must be shipped over land, refrigerated air cushion vans are used.

SHOREBASED CURATORIAL ENVIRONMENT

ODP cores are stored at three locations in the United States. The ODP repository system has a combined storage capacity of over 16,500 square feet and holds approximately 84 miles of core. Cores drilled by the JOIDES Resolution from the Pacific and Indian Oceans and the Red Sea are housed at the Gulf Coast Repository of Texas A&M University in College Station, Texas. Pacific and Indian Oceans and Red Sea cores drilled during DSDP are located in San Diego, California at the West Coast Repository on the campus of Scripps Institution of Oceanography. The East Coast Repository is located at Columbia University's Lamont-Doherty Geological

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Observatory in Palisades, New York. It houses all DSDP/ODP cores from the Atlantic and Southern Oceans, and from the Caribbean, Mediterranean and Black Seas.

Each repository provides an efficient work environment for visitors from the international scientific community (Figure 1). Scientist may request samples to study or may gain permission to visit a repository through the ODP/TAMU curator. Every effort is made to process sample requests within 8 to 10 weeks of receipt.

Figure 1. Visitors sampling cores at Gulf Coast Repository, Texas A&M University

Repository libraries contain full sets of ODP Proceedings and DSDP Initial Reports, reprints of articles resulting from analyses of ODP core material, photos and slides of cores and all thin sections and smear slides made onboard the drillships or in the repositories. The shore labs house microscopes, thin sectioning machines, close-up photography tables, and standard laboratory equipment to assist in choosing samples.

ARCHIVING

The initial methods of DSDP core storage were modeled on those used by various oceanographic institutions with long-standing piston core collections. However, several differences were established from the outset. Whereas piston cores taken prior to 1969 were often archived in unrefrigerated and uncovered metal trays, all DSDP cores were refrigerated and stored in sealed opaque plastic tubes. Originally designed as fluorescent light fixture covers, the tubes inhibit water loss, do not chemically react with the sediment and cut down on contamination from airborne particulates. A moistened sponge is placed inside each tube to provide further protection from water loss. The use of the sealed tubes, sponges and refrigeration is perhaps the drilling program's most significant contribution to the battle against degenerative processes that attack deep ocean cores during years of storage.

Core archiving policies of science and industry have contributed to other innovative storage methods used by ODP. Cores requiring special storage conditions are removed from the general collection.

ODP archives three special collections: halite/anhydrite cores, organic geochemistry core sections and sulfide-rich material. Halite/anhydrite cores are best stored in unrefrigerated dehumidified chambers to prevent dissolution of the salts. Sampling must be done with kerosene-cooled rock saws. Drilling in the Mediterranean Sea has resulted in recovery of cores of this type. The largest special collection maintained by the program is the organic geochemistry collection of core sections. The samples are taken aboard the ship without the use of organic solvents, and are immediately frozen in order to slow chemical reactions. Although the concept is not yet fully implemented, ODP plans to maintain a collection of sulfide-rich cores in oxygen-free storage. The sulfide-rich cores were recently recovered as the result of newly-developed bare-rock drilling technology in areas of hydrothermal activity along the Mid-Atlantic Ridge.

In an effort to conserve sample material and to encourage cooperative efforts among scientific contributors, the Curator requires the return of unused portions of samples requested by investigators, and instructs each repository to incorporate the returned samples into a refrigerated residue collection. Before approving requests for core samples, the Curator searches the residue inventory to determine whether appropriate materials are available for distribution.

INVENTORY

Information regarding ODP's general core collection, special core collection, residues, thin sections and smear slides is recorded on core history/inventory forms. The curatorial staff is in the process of transferring this information to a computerized database which, when accessed, will yield information on initial conditions of recovery, core storage environment and location, nature of special or critical intervals, and the state of preservation of cores. In addition, all critical boundary cores and rare or unusual layers are given color-coded labels for easy identification by repository personnel and visiting investigators.

The rules governing distribution of samples taken from ODP cores are determined by various scientific advisory committees and by the Curator. From the central office at TAMU, the Curator accesses a sample investigation database for up-to-date information on the status of sample requests, publications resulting from work done on ODP samples, sample identities and availability of returned samples. The Curator

then makes decisions on the distribution of samples.

SAMPLING

The ODP repositories receive a combined average of six visiting scientists and technicians a month. Repository personnel help investigators with sampling, description, photography and X-raying of cores. When not assisting visitors, repository staff process requests for samples.

ODP cores vary greatly in mineral composition, geochemistry, grain size, fossil content and degree of lithification. Core variability has given rise to a diversity of sampling techniques, which may be as simple as inserting a plastic tube into soft, moist sediment to obtain microfossils for an ecostratigraphic synthesis, or as involved as cutting an oriented cube from a well-compacted limestone for a magnetostratigraphic study.

Sampling tools include: toothpicks used to make smear slides for identification of mineral composition; pre-measured plastic tubes and cubes for use in soft mud; hammers and chisels for use on lithified sediment; and slow cutting diamond coated saws and drills for sampling hard igneous rock.

Sample data are collected in real-time at computer workstations located adjacent to sampling tables. The data are then loaded into a database stored on a mainframe computer located at ODP headquarters in Texas. Loaded sample data is corrected and samples are assigned values corresponding to depth below the sea floor. Sample location inventories and depth listings are included with sample shipments to scientific investigators.

CURATION

In an effort to minimize the effects of aging on the cores, the repositories are engaged in an active maintenance and restoration program, referred to as the Curation Program.

The handling of the cores over the years has taken its toll. Despite refrigeration, a certain amount of drying has occurred, and continued sampling has caused the core material to become displaced in spots. The Curator has established a policy of repairing cores whenever they are sampled, even if this may cause a delay in completing a sample request. In order to return the cores as nearly as possible to their original condition, the "work" half of the core is compared to its corresponding and unsampled "archive" half and to original core, descriptions and photographs. Special stabilizing baffles are installed when core material begins to shift from its original position.

Sponges, which are stored inside the tubes, are periodically re-wetted. When sampling of a core results in a void, the gaps are filled with foam inserts. Curation may also entail scraping mold and crystal growth from the cut face of core sections.

GERIATRIC STUDY

Currently the curatorial staff is conducting a systematic investigation of changes in physical and chemical properties of cores with time. The objective of this project is to refine our understanding of curatorial procedures and techniques as they affect the scientific integrity of cores during shipment and long-term storage. Cores taken during early DSDP legs, which now have been in storage for more than nineteen years, are still generating sample requests. An understanding of the scientific significance of changes which occur subsequent to core recovery is essential to the accurate interpretation of data resulting from analyses performed on samples taken from the repositories.

A two-fold approach has been designed: 1) to re-examine samples and residues in the existing core collection, looking for changes which have occurred since they were first described, and 2) to monitor a set of fresh cores from the time they reach the ship's deck through shipment and subsequent years of repository storage. Concurrently, all repositories will be monitoring temperature and humidity conditions in refrigerated and unrefrigerated storage areas.

In February 1988, the curatorial staff began processing and distributing samples from the first set of cores taken solely for the Geriatric Study. These newly-recovered cores are being monitored for pH, water content, physical properties, magnetic properties, organic and inorganic geochemistry, mineral composition, and the condition of microfossils. ODP Staff Scientists and other interested scientists are being encouraged to contribute in their fields of expertise. Additional Geriatric Study cores have been requested from upcoming legs.

By doing such a study, the Ocean Drilling Program hopes to understand how the cores age under the existing storage conditions. When the study is complete, the scientific community will be notified of the nature and degree of these changes, if any.

PUBLIC EDUCATION

The repositories serve an important educational role for students and local groups who tour the facilities. The repository staff uses photographs, slide shows, videotapes, core displays and demonstrations of drilling equipment to expand visitors' awareness of the environment, the geologic past and scientific methods of studying the oceanic crust.

ACKNOWLEDGEMENTS

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THE UNDERWATER ELECTRIC KITE
EAST RIVER DEPLOYMENT

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ABSTRACT

The UEK is an efficient Kinetic Hydro Energy Conversion System (KHECS) that utilizes river or tidal water current without need of impoundment behind dams. In the UEK system an artificial head is actually created within the machine. A very sophisticated "draw tube" arrangement that utilizes the outside housing like a venturi tube combined with the rotating hollow blade of the first-stage turbine, which acts like a centrifugal pump, are the heart of this innovation. The power turbine, or second-stage turbine, is much smaller and directly drives a conventional generator through the mechanical pitch control and small step-up gearing. If a variable speed isosynchronous generator is used, no pitch control is necessary.

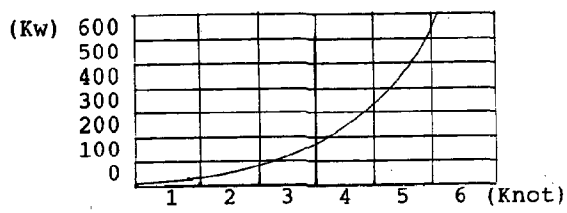

Fig. 1.

Power output of a 20 ft/diameter UEK as a function of current speed. (Diameter does not include skirt)

PROPOSED MOUNTING SUPPORT OPTION:

Three sorts of support can be used depending on the prime water current characteristics and depth:

A. Rivers: On a tower, or suspended from an existing fixed or floating structure.

B. Tidal current: On a tower with a 180-degree controlled rotation, or suspended from a fixed or floating structure and activated by the current like a "wind sock."

C. Ocean current: The UEK, tethered by an electromechanical cable to the bottom, can dive, search for the optimum current, or surface by microprocessor program commands. (1.2-meter diameter model reached a 76-degree total lateral sweep and perfectly performed dive and retrieval functions in a test executed in Maryland in 1981).

Operation of the UEK in any of the described modes is dependent on the velocity of the water current as shown in Fig. 1.

THE CHOICE OF ENERGY OUTPUT FROM UEK'S

Electrical:

1. Alternative electrical power with frequency accuracy at +/- 2% by a governed pitch or gate control at the power turbine stage.

2. Alternative electricity delivered by a variable speed isosynchronous generator that perfectly matches the voltage and frequency of the grid to which it is connected.

3. Electricity in a direct current mode where it is used for surrounding industries'needs. (For example, production of oxygen and hydrogen by electrolysis, aluminum processing, smelting, drying in mining operation and, to some extent, for lightening purposes).

4. Electricity in a HVDC mode, 1 conductor and return by the sea, followed up by thyristor/SCR controls situated in the switchgear station on the shore.

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Water Head:

1. Irrigation from rivers by substituting the generator with a water pump.

2. Filling up reservoir during tide time with water to be utilized on demand by a conventional "low head hydro-electric system".

3. Water source for transport of coal and other minerals in "slurry" trough pipelines.

Compressed Air:

1. Compressed air from UEK's devices used through PVC piping scheme on the bottom of a bay or river in order to supply oxygen to anoxic water and therefore restore life-supporting quality in the environment.

2. Compressed air to be used as a commodity for industries'needs.

DEVICE & TESTING EQUIPMENT

During 1986 a 12-foot UEK was built to test the concept and serve as the basis for the final design to be implemented in our East River site in New York City. This UEK turbine is the largest model built to date and was tested during 1987 and 1988 under many different situations for theoretical data confirmation of basic feature and added improvements. Many small, three foot diameter UEKs were built to address specific questions concerning the blade design of the first stage turbine.

To support the testing, two small vessels also were specially built to permit the deployment and retrieval of the test models, while being towed behind a tug boat in the Chesapeake Bay or set at anchor in a fast flowing current.

The 12-foot diameter UEK turbine data are:

Overall diameter, augmentor ring 12 Ft.
Diameter of the first stage turbine 9 Ft.
Three blades (fixed 14 degree pitch)
Diameter second stage turbine 46"
Five runner blades adjustable pitch
Electric pitch control & remote control
General Electric Generator rated at 60 Kw
(Three phases-240 volt induction type)
RPM sensors, first turbine & Generator
Temperature & Vibration sensors
Drag at 5 knots: over 5,000 pounds
Dead weight 3,600 pounds
Displacement apr. 3,450 pounds (- buoyant)
Internal pressurization, Nitrogen at 14psi
Sumitomo speed increaser: 4/1 ratio
Fiberglass, first stage turbine
Carbon fiber, power turbine & gen. housing

External controls and instrumentation:

The UEK turbine is suspended by a frame mounted on the deck of the supporting vessel and can be lowered in the water over the stern of the vessel. The deployment of the device is operated with two electric winches (4,000 pound capacity) and two back-up hand operated winches. Two 5/8 stainless steel cables are connected to the end of the transversal arm of the supporting frame and meet together 50 feet in front of "Wide Load" (below). A cable from the bow to the the same meeting point serves to some extent as a depth control means. Further, in front of this point, the main anchorage line is connected to its anchor, if the test is conducted in a river, or is attached to the towing tug if the test is simulated. Usually we use 600 feet of 1.25 diameter nylon line to avoid the propeller wash of the tug. In a river, we may use the full 1,000 feet of line which provides not only an excellent holding force with a relatively light anchor but also permits lateral drifting at will in different current velocity.

THE SUPPORT VESSELS

"WIDE LOAD"

"Wide Load" is a barge like platform boat 12'x 24' built in aluminum and designed for the sole purpose of testing the UEK turbine. A 240 hp Volvo engine can push the boat without the turbine at approximately 18 knots. The vessel is equipped with a small forward cabin which contains three voltmeters, three ampmeters, one pitch control two way switch and position indicator, one 24 switch box (tripper fuses), one main power switch, hydraulic steering station with engine control and instruments, depth finder and safety equipment, oscilloscope station for monitoring RPM's of all rotating items etc.

Other equipment includes a load box composed of many water heater elements of 4,500 watts and 1,500 watts respectively to be lowered into the water at the stern of the boat , a small 5 kw gas generator to activate the pitch actuator rod for the second stage power turbine blades and three compressed cylinders of nitrogen with regulator to pressurize the 60 kw generator housing. The boat is also equipped with trim tanks, bow & stern, serviced by a transfer pump.

"SPARKY"

"Sparky" is a catamaran, 20' x 7' over-all dimension powered up to 8 knots by a 7.5 hp outboard engine. Between the hulls is a marine plywood working platform of 16'x 4' with a 40" diameter hole cut in it.

A lever with a half inch stainless steel shaft mounted at 90 degrees to its end can swing a three-foot diameter UEK model through the platform hole into the water between the hulls. This system permits the interchange of models and accessories within minutes. Small power turbines are tested with different first stage turbines at will. A shaft attached in front of the power turbine transmits the RPM and torque to a pony break installed at the front of the platform. We find it to be a good way to make a fast appraisal of our design. With "Sparky"'s configuration, it is also very practical to take flow readings near the augmentor ring of the first stage turbine and throat entrance of the second stage turbine with or without the runner installed. Those measurments are made with the sensor of a battery operated knot meter mounted at the end of an 8 foot handle This method of data gathering is of course fast and economical if we take into consideration the expenses of hiring a regular size tug boat. All of the promising improvments are transposed on the 12-foot diameter model, tested and verified again. Any data scale-up changes are also noted. This information is extremely important to determine economic viability of future sites.

Testing of the three foot model under tow has been conducted with "Wide Load" as the towing vessel.

SITE

Site-specific analyses are a natural step for regional resource development. The small-scale low and very low head hydro-generator became attractive to us in the Seventies'petroleum energy crisis. Innovative turbine technologies were developed to capture natural hydro resources which were untapped. Unfortunately, very low head also means very high cost per kilowatt, but without the civil work, penstocks, dams, etc., the figures are better. The economic assessment for UEKs, is therefore now very attractive. The time was right to take a good look at options that could not even have been considered 10 years ago. Because the technology was new, nobody really had a proven concept of how to install a free tidal turbine. However, by identifying the needs and looking at other more widely known technologies and processes, especially ocean oil rigs, one could develop and establish a general guideline.

Many factors are considered when choosing a site. The water current availability, the bottom quality for implementation and the close proximity of the end user are the principal site quality factors. Next, are the economic and political factors which generally influence greatly the avoided cost rate offered, acceptance by local utilities, understanding and quest for clean, economical and renewable energy by the people and elected officials.

The site chosen by UEK Corporation, which was the closest to the criterion disclosed above, was the East River in New York City.

NEW YORK CITY SITE
PROJECT NO. 10331-000

According to our preliminary permit filed February 24, 1987 under the Federal Power Act. 16 U.S.C. 791 (a) - 825 (r), UEK Corporation and its agent Kinetic Hydro Energy Corporation have conditional right to a portion of the East River in New York City. Our site is limited by Roosewelt Island on the West side, by the borough of Queens on the East side, the Queensboro Bridge on the South and Hell's Gate on the North. The depth is more than thirty feet over most of its entirety and we have measured a current speed of over 4.2 knot during our December 24, 1987 survey. When all the preliminary measurement and data collection are completed with the 12-foot diameter engineering model, we will proceed with the implementation of full size turbines for this site.

According to our present permit, the 2.1-megawatt electric-generating equipment to be installed consists of 7 (seven) double-stage kinetic hydro-electric turbines that develop, through isosynchronous generators, 300,000 volts-amperes at 60 hertz each.

The kinetic turbo-generators (UEKs) will be mounted, for this application, on pedestals anchored to the river bed and will be activated by the natural flow of the tide running between Long Island Sound and the Atlantic Ocean.

The UEK life expenctancy is twenty years with two weeks off line for maintenance each year.

UEK SPECIFICATIONS FOR THIS SITE

The overall diameter is 21 feet for the ducted first-stage turbine. The operating RPM is 18.78 to 31.00 (3-5 knots tidal current). Inducted by pumping action, the artificial head is 1.813 to 5.036 feet.

The second-stage turbine (power turbine, 73 inches in diameter) runs at 225 to 275 RPM and drives an isosynchronous generator through a small speed increaser bolted on the generator. The generator-speed increaser assembly is corrosion resistant, skin cooled and can operate in a two atmosphere environment.

The electricity generated at 23kv by each individual UEK turbine is delivered via underwater electric cable to the switching, metering and protective circuitry before reaching the client gride. (In this case, Consolidated Edison Vernon Substation in Queens, New York City).

Annual electric power for sale is calculated as follows: UEK generated kilowatt at average tide current velocity and running time is 198.75 Kwh, multiplied by yearly percent on line: 198.75 x 8,766 hours x 96% on line = 1,672,552.8 kilowatts per UEK. Therefore, the seven UEK units on the site are expected to produce a total of 11,708 megawatts annually.

If everything is progressing well and the first seven turbines are performing according to plan, we intend to install more units in this site. The implementation which would be the least controversial as we see it today is to use only twenty per cent of the width of the channel and space the rows of turbines by one hundred feet each.

This configuration implemented during a period of approximately five to seven years would yield a total of 426,500 Mw annually when completed to New York City Utility or perhaps the Subway system from only 255 UEK turbines. Clean renewable energy, all year long with compounded reliability.

BOTTOM SURVEY OF THE SITE

The survey of the bottom of our channel site is acomplished by using the following criteria:

A. Take bathymetric (depth) measurements in a grid pattern to allow development of a bathymetric chart showing bottom contours.

B. Maintain continuous definition of bottom morphology over the entire grid area via side scan sonar.

C. Indicate the collection of the bottom samples at the corners and center of the grid pattern.

D. Look for irregularities which could be used for submarine power cable installation without burial (dead water)

All fixed points of the grid pattern taken during the survey are located in terms of coordination from preliminary navigational reference points or landmarks.

A series of depth sounding and side scan sonar passes are run along the site and overlapping passes are made to assure adequate coverage of all the channel bed area. Once recorded, the data combined with flow velocity information collected by Endico type 110 current meter are assorted later by computer in a regular grid pattern, because at the time of the data aquisition it is almost impossible to follow a perfect straight line across a four to five knot current with the workboat.

AUXILIARY ANCHORAGE

The efficiency of the UEK system is based on the capture of kinetic energy by very well known hydrodynamic laws which are combined into a usefull device. The main consideration is the 4-5 knot current encountered in the site which resulting action on the setting of the supporting tower is comparable to the thrust of an extremely efficient sea anchor.

Since the bottom of the East River was cut in the same rock as Manhattan is built, an anchor such as sailors use is of no permanent value except to assist the deployment, therefore other means must be used.

The best and most economical holding device chosen for our needs is a simple pin buried in the rock.

Hardware must be stable, easy to install and economical to build and maintain. Tests on a small scale show that it is possible, helped with the proper anchorage system, to guide the pedestal of the turbine from the surface to the bottom, the same as oil riggers do at sea.

INSTALLATION OF TIDAL UEK

The two characteristics of a tidal UEK configuration support system are:

1) The base of the tower pedestal is diamond-shaped and is of two UEK-diameter width and five UEK-diameter length. The supporting tower is located in the center of the lozange.

2) The top of the pedestal has a pivot to accommodate a controlled 180-degree rotation.

The pedestal supporting the UEK is a hollow conical shell composed of welded streamlined sections. This tower is closed

on top by a hatch and has a guide rail section which will receive the fixed shaft of the UEK later and is surmounted by an opened, streamlined, temporary extention tower section. Inside the tower is a ladder from the top hatch to a bottom door that is parallel to the electric power cable harness and a drilling tube guide.

The streamlined tower is mounted on the center of the lozange shaped base constructed from pipe braced with other tubular structures to the main body. This assembly forms a semi-boyant pedestal that can be towed to the site with a small tug or workboat.

Installation scenario:

1) The workboat carries an anchor conforming to the characteristics of the bottom and sets it at the beginning of the site where the end of the shore power electrical cable is already installed and marked by a buoy.

2) The same marker is attached to the end of the anchorage cable and the boat can now bring the tower pedestal and tow it to the site.

3) The leading edge of the tower is attached to the end of the anchorage cable, the boat releases the cable tension, and the current pulls the assembly in a straight line downstream.

4) The next step is to let air escape in a controlled manner from the hollow tower and let it slowly sink to the bottom.

5) Using the preinstalled drilling tube guide, a cylindrical hole is drilled in the bed of the channel. Depending on the quality of the bottom, this hole may be anywhere from two to ten feet in depth.

6) A commercial expendable or explosive anchorage pin is introduced in the hole by divers, and secure holding is accomplished. (This operation is possible in very stong currents because the divers work inside the tower.)

7) Now, again, the workboat retrieves the UEK turbine and the assembling crew introduces the supporting guiding slide from the main shaft of the generator-turbine into the track rail from the trailing edge of the extension tower. The UEK slides downward to its operational position, passing the bottom of the extention tower, and rests on the top of the pedestal.

8) Divers go down inside the pedestal, secure the turbine and connect the power cable from the UEK to the preinstalled shore power cable reaching the tower via the pre-anchorage cable. (Connection of the electric and signal cable can be done in a small air-filled space in the tower for a perfectly dry splicing.)

9) The tower extension is then unlocked by towing it away against the current, (or at slack time) with the workboat and can be used again to install the next pedestal and UEK turbine.

In a multi-UEK site, the units are added to each other in column and row to fit the site and can be expanded from the first UEK turbine in any direction.

OTHER SITES

There are of course a multitude of sites available to this technology. Many of which we already are exploring for future uses in the continental U.S. and abroad.

In January 1987, UEK Corporation prepared, at the demand of China Hua Yang Technology & Trade Corporation and The State Economic Commission Council, State Bureau of Oceanographics P.R.C. an informal guide line to implement UEK turbine to be used for electric power generation and/or irrigation. Follow-up is actively pursued on this matter.

In April 1988, sites were informally surveyed on the Island of Hainan, People's Republic of China. Near the city of Wenchang in particular we have found a tidal site for UEK turbines which may yield up to two hundred megawatts of electric power. If the negotiations with the U.S. developer are successfully concluded, UEK Corporation will install fifteen megawatts of electric power rated at 10,500 volts and 50 hertz to be delivered into the grid of the Power Industry Company, Hainan Administrative District, City of Haikou.

Any sites can be procured with the proper size UEK turbine to suit the depth and the current velocity characteristics by introducing the site's data into the computer implementation program.

BRITISH OTEC PROGRAMMES 10MW FLOATING AND 0.5MW LAND BASED

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ABSTRACT.

For a decade the UK OTEC effort has been directed at the development of a closed cycle, floating, OTEC plant of 10MW size making use of 5MW power modules. Electricity production was the sole objective. Recently, a separate UK initiative has focussed on a small 0.5MW land based design, with the object of utilising the cold deep nutrient rich waters for aquaculture and for the production of potable water. For both projects island locations are preferred. The paper reviews progress to date.

1. INTRODUCTION.

OTEC has substantial potential to produce other outputs in addition to electricity. The association of some or all of these additional outputs with an OTEC plant can improve the economics and increase the usefulness of the overall process so as to extend the geographical market for such composite plants. This paper concentrates particularly on electricity production, aquaculture and, to a lesser extent, the production of potable water.

Regardless of the thermal feasibility of OTEC generated electricity, there must be a demand for it if the economics are attractive. For an OTEC plant producing electricity alone the economics, we believe, become attractive for plants of 10MW capacity or more. Some of the smaller islands cannot be candidates for a 10MW plant since their total demand is well short of that. However, the majority of island countries which do have an adequate demand rely on imported oil for generating power and, further, are frequently paying very high prices for this imported oil. In the short term, it is these islands which provide the most likely market for OTEC electrical generating plants.

The rate of growth of power demand in many of these developing countries is in turn dependent on the price of the power generated. The provision of a stable energy price is of the highest priority among economic objectives of those countries. OTEC, with only its operational and maintenance costs (no fuel costs), meets this requirement.

Potable water can be derived from the waste cold water from an OTEC plant using one of a number of alternative processes. In the case of an open cycle OTEC plant, some of the flash evaporated warm water vapour can be condensed in a separate condenser to produce potable water.

The deep cold water, which is very rich in nutrients, can be the basis for a food change resulting in fish, molluscs or crustacea. Work in Hawaii has shown that a considerable range of aquaculture products can be grown in this nutrient rich cold water.

An examination of the sites suitable for OTEC plants shows that a very large number are either short of drinking water or it is very expensive. Further, many of those sites would welcome the additional protein which fish production would bring. For a 10MW plant the potential for the production of fish in this way is so large that it could support an export industry in addition to providing for local consumption. The potential application of a combined OTEC desalination aquaculture (ODA) plant is therefore considerable and the economy of the combined system is at least equal to that of a simple OTEC plant, for certain specified location parameters (Eg. a suitable sized lagoon adjacent to a land based OTEC plant). The remaining development necessary to achieve satisfactory production of each of the products just mentioned is significant. OTEC technology is, at present, still in the demonstration stage. At this point therefore, there is much to commend separate development for the different products to minimise risk and this is essentially the British approach. Limitations on paper length precludes detailed descriptions, but some salient aspects are described.

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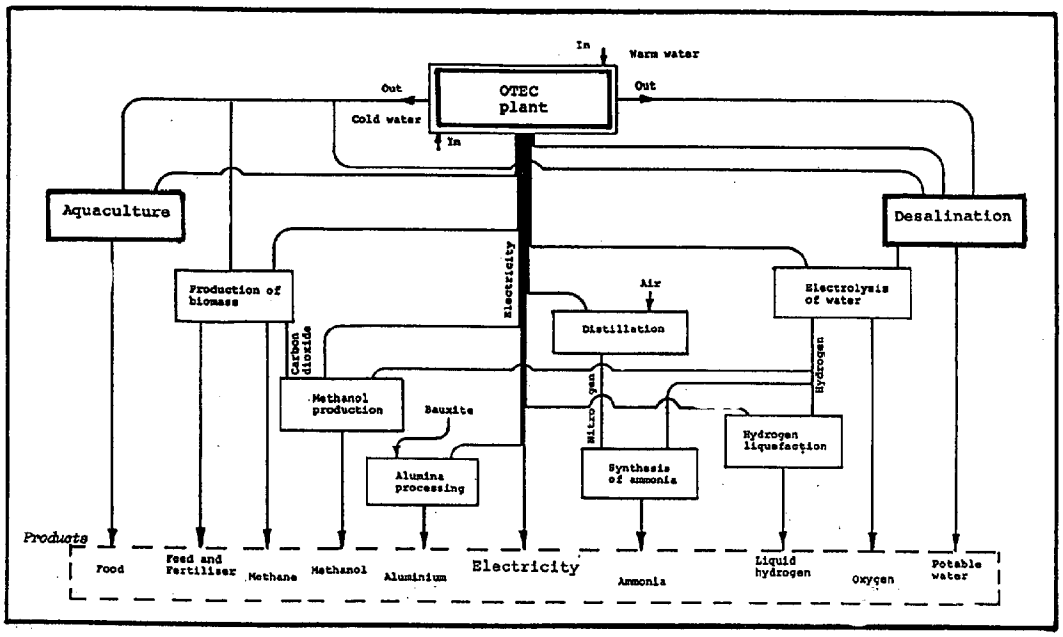

Figure 1. A range of products from an ocean thermal energy plant

2. ELECTRICITY/FLOATING.

The variant selected for electricity production after rigourous review of market opportunities is closed cycle, floating, and tethered with catenary moors shown diagrammatically in Figure 2.

A controversial decision was that to go for a floating plant design, rather than a land based one. In the view of Ocean Thermal Energy Conversion Systems Ltd. (OTECS), whilst the problems are very different on balance the floating variant where electricity is the only product has problems which are more tractable than the land based option and the Conference presentation will develop this point.

Evaluation of mooring options for the floating variant included thrusters (with a dynamic positioning system), hydrodynamic forces (making use of fluid flow past the OTEC plant) and tethers. Tethers were the preferred solution at this time, and single point, multi-point and tension leg options were evaluated. Of the preferred multi-point moor for the spar design of plant chosen, seabed terminations examined included piled, clump weight with anchor, intermediate stand off buoy plus anchor or pile, among others. Specific solutions were optimised for individual preferred sites (see below).

Developments in tension leg technology are now making this format very competitive to the catenary, although the ability readily to locate a catenary moored plant makes this attractive for the early development demonstration phase. As noted in the abstract the power modules are 5MW for the 10MW unit, and in the first plant 3 power pods are proposed, the third being for development work.

Estimated capital and generating cost for this type of plant are US$5300/kW and 12.7 cents/kWh these figures being calculated for the eighth production unit. The values are plotted on Figures 3 and 4 respectively which show the extreme values for all OTEC plants designed for electricity production since 1970. Independent Japanese calculations have resulted in virtually identical limit values.

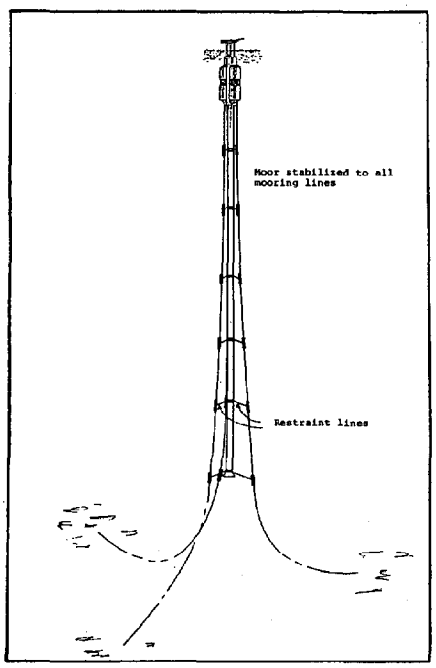

Figure 2. A catenary moor with stabilisation for the cold water pipe

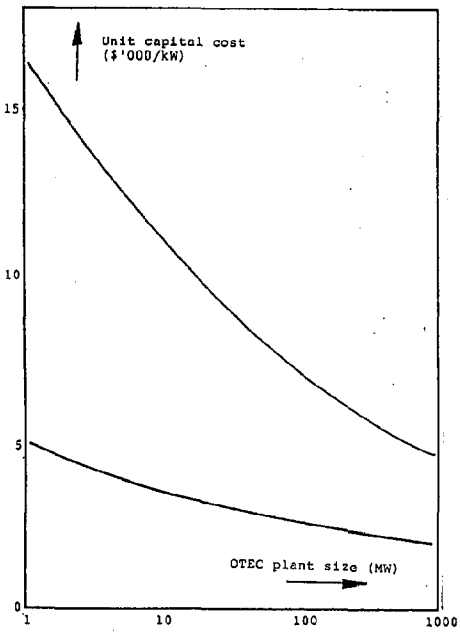

Figure 3. Range of capital cost/kW for all known OTEC schemes

The preferred sites for this 10MW floating OTEC are:

i. in the Caribbean: St. Lucia or Jamaica;
ii. in the Pacific: Fiji or Papua New Guinea;
iii. the Indian Ocean: the Seychelles or the Maldives.

The location for the quoted value in Figures 3 and 4 to be achieved is the "best site" found by OTECS, the evaluation taking note of the temperature difference available, distance from shore, economics of alternative power generation techniques, potential for funding, etc. It will be noted that all are island locations, with cold deep water close to shore.

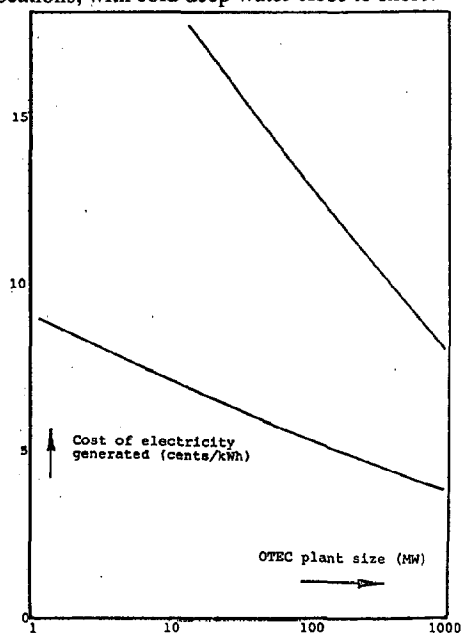

Figure 4. Range of cost/kWh for all known OTEC schemes

3. A SMALL LAND BASED PLANT.

GEC, England, has been considering the possibilities for a small 0.5MW (gross) closed cycle land based OTEC plant for the last three years. As a major producer of electrical generating equipment, covering a power range of some 8 orders of magnitude, we naturally keep a watching brief on all new possibilities. In our view the most impressive demonstration of OTEC technology to date was the plant built by the Tokyo Electric Power Services Company on the island of Naru. This plant produced a gross output of 120 KW and a nett output of some 31KW. Over a period of 9 months, during 1980, this plant was operational and achieved a maximum continuous period of operation of 10 days. However, to make an economic OTEC plant one would need to increase this

nett power to 10MW or more, increase the availability to about 80% or better and operate the plant for about 25 years or more. While this is a feasible objective it is a very large extrapolation from proven technology and consequently there is a high risk of meeting unforeseen problems which can prove to be very costly.

From a technical point of view what is needed, we believe, is a more modest scaling up of the previous Japanese work. What we had in mind was a closed cycle land based plant with a gross output of about 500 KW connected to a distribution grid and operating for a minimum of 5 years with a high availability. Such a plant should provide a very thorough test of the whole OTEC concept. The sea water pipes would need to be reliable, the sea water pumps would need some redundancy, control systems would need to be installed to match the output to the distribution grid, maintenance cycles would need to be planned and, in addition, the plant would need a monitoring package to check the correct working of all the key components. Such a demonstration would provide a sound basis on which to plan, design and finance larger installations.

However, one consequence of the second law of thermodynamics, is that a plant of this type would be doing well to produce an annual return on capital of 1%, scarcely enough to pay the staff and not the sort of proposition to appeal to managing directors or to venture capitalists. Thus our view was that, until such a demonstration became economically viable, OTEC would remain as just another interesting concept.

This view was considerably modified by the work done at the Natural Energy Laboratory of Hawaii. This had measured consistently high levels of nitrates and phosphates in sea water pumped up from the deep ocean around Hawaii. Further this deep sea water proved to be remarkably free from pathogens so was ideal for aquaculture. Subsequent work at this laboratory has demonstrated the value of this deep ocean sea water resource for aquaculture and two commercial enterprises have already started there. In my view this work demonstrated that the greatest resource in the oceans is the water itself. The combination of aquaculture with a small scale OTEC plant can dramatically alter the economics of such a combined operation.

This view was arrived at, quite independently, by ALCAN International, in particular by Nigel Fitzpatrick. As a result of a number of discussions ALCAN asked us if we would design such an OTEC plant for them and this we are now doing. The main team during this work is based at our Engineering Research Centre. The design aim is a plant that could provide a minimum of 13,000 US gallons of deep ocean sea water per minute for aquaculture and provide a nett output of 150KW of electricity into a local electricity supply grid. Our preferred site is close to the Natural Energy Laboratory at Keahole Point on the Big Island of Hawaii. This not only has excellent access to deep ocean water, a local grid system willing to buy all surplus electricity, a growing aquaculture industry based on pumped deep ocean water but also all the infra-structure needed for installing and maintaining the plant.

The design work falls into two distinct parts. The initial work is concerned with studying the various parameters such as flow rates, pipe sizes, heat exchanger types, working fluids, fabrication techniques etc. with a view to establishing a minimum cost option. This will then be followed by the detailed design of this chosen option. In the course of this detailed design there may well be some further changes in the key parameters as specific details are investigated in more detail.

The largest single expense in such a small land based OTEC plant is the sea water pipelines and the sea water pumps. Preliminary estimates indicate that we would probably need pipes of about 36 to 40 inches in diameter to cope with the flow rates without the need for excessive pumping power. We sub-contracted this part of the work to Makai Ocean Engineering, Inc. at Kailua, Oahu, Hawaii. They have designed three sea water pipelines of 12, 18 and 40 inches that have been installed at Keahole Point. All of these pipelines use polyethylene as the pipe material. The preliminary work indicates that we shall need a cold water pipeline of some 2300 to 2500 meters in length to reach down to a depth of 640 meters. The warm water pipeline will be about 300 to 380 meters long to reach an intake depth of 30 meters at a point some 10 meters above the bottom - this is to minimise bio-fouling problems. There can be problems with disposing of the discarded sea water from both the OTEC plant and the aquaculture facility. Here we are considering mixing these two outputs and discharging them through a sea water pipeline at a depth just below the mixing layer, ie at a depth of about 100 meters. To do this will require a third pipeline of approximately 850 to 900 meters in length. The greatest part of the cost of these sea water pipelines is the transition section from the shore to a point sufficiently deep to be free of surface wave loading.

We plan to site the sea water pumps off shore at a depth of about 10 meters. Following Makai's recommendations we also plan to use three pumps for each pipeline, two operating in parallel and the third as a standby. Stainless steel pumps are preferred but they are considerably more expensive than cast iron pumps. However, they have a considerably longer life. These sea water pumps will consume about 70% of the gross power output. Further, as the exhaust cold water is to be delivered to an adjacent aquaculture site one cannot use a siphon to reduce the pumping power needed. At Keahole Point the land is about 4 to 5 meters above mean sea level so this is a significant factor. Another consideration is that the cold water

supply to the aquaculture facility will need to be maintained during any plant shut-down for maintenance so suitable by-pass circuits need to be provided.

A crucially important input to the design work comes from ALCAN. They have been carrying out a long series of corrosion tests on a number of aluminium alloys in both deep and surface sea water - the chemistry is quite different in the two cases. In surface sea water the corrosion is uniform and regular but in deep sea water pitting corrosion is the primary result and this needs more care if one is to have a satisfactory life for the heat exchangers. ALCAN are currently carrying out a series of corrosion tests on various types of joined sections to test the suitability of various fabrication techniques.

Another important input from ALCAN has been their work on bio-fouling. In surface sea water regular small doses of chlorine produced by electrolysis can prevent the build up of bio-fouling. If the electrolysers malfunction, bio-fouling builds up quickly. After maintenance to the electrolyses the bio-fouling largely disappears but the thermal resistance falls to a value 10% higher than before the malfunction. It can only be reduced to its original value by mechanical cleaning so this will be an important aspect for both the design and maintenance of the warm water heat exchangers. Further, it had been generally assumed that bio-fouling would not be a problem for the cold water heat exchangers. ALCAN have found that this is not the case. Bio-fouling can occur in the cold water circuits but its build up is much slower. ALCAN is currently trying to establish a minimum chlorination regime for the cold water heat exchangers.

The heat exchangers will be fabricated from aluminium and the designs will incorporate a 10% margin against accidental bio-fouling. They will be modular so that individual sections can be replaced, if necessary, without needing to shut down the whole plant. This is not only a precaution against a defective component but also a means whereby we can inspect a component and check its actual corrosion rate - it will also make it easier to transport and erect the heat exchangers at the site. The heat exchangers will be designed for simple mechanical cleaning and for minimum cost. A number of different fabrication techniques are being studied. There is advantage in using components that enhance the transfer of heat between the sea water and the aluminium but this has to be balanced against any increase in cost. One particularly simple construction technique would be roll-bonding but a final decision has not been reached.

We will probably be using a Rotoflow turbine, gearbox and generator with all the regulation and power conditioning being done on the electrical side rather than by regulating the input pressure to the turbine. The actual form of the turbines and gearboxes varies considerably with the working fluid used. Ammonia produces much higher pressures that butane but either could produce the required electrical power. Lower pressures also ease the requirements on the strength of the heat exchangers. This is just another example of the highly interactive nature of all the differing considerations - in fact OTEC is all about compromises.

Considerable care will be needed in the design of the safety and protection equipment and procedures will need to be established for the start-up and shut-down of the plant. For example the cold water pipeline will contain some 2000 tonnes of sea water which will need to be accelerated to 1 meter per second during the start-up process - not something that can happen in a few seconds.

Another important aspect of this design will be the provision of a reasonably comprehensive instrumentation package. This is important since we will be accumulating a great deal of new data about the actual operation of a closed cycle OTEC plant. It will be important to measure not only the initial performance in order to compare it with the designed values but also to detect any slow drift in this performance away from the initial values and make an early assessment of the cause.

There is one additional item we are proposing to demonstrate namely the generation of potable water. Any shore based OTEC site will have a virtually unlimited supply of warm air with a dew point well above the exhaust temperature of the cold water discharge from the OTEC plant. Allowing for the latent heat of water vapour and assuming a 30% efficiency for an air condenser, one should be able to condense potable water at a rate of 0.043% of the cold water flow rate for each 1°C increase in the cold water temperature. This may sound very small but OTEC is all about exploiting small efficiencies. In our case we could increase the cold water exhaust temperatures by 5°C and still deliver cold water at a temperature of 14°C to the aquaculture facility. This would suggest that we could condense potable water at a rate of about 1700 US gallons per hour. We are currently planning a small scale test facility to produce somewhere in the region of 100 gallons per hour and this part of the work has been subcontracted to Dr P F Monaghan of the Department of Mechanical Engineering, University College, Galway, Republic of Ireland. He has been doing much design and testing work on external air heat exchangers for use with heat pumps.

The plan is to complete the detailed design work by the end of 1988 and then proceed with the installation of the sea water pipes and pumps and finally with the construction, commissioning and operation of the plant during 1989 and 1990. If all goes well we should then begin to see an OTEC plant demonstrating, in a very realistic way, its overall capability.

HYDRO POWER FROM THE OCEAN

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PATENT ABSTRACT

An apparatus is disclosed to generate electricity using ocean thermal and salinity gradients. An elongated chamber extends vertically downward from the surface of the ocean. Warm, high-salinity water from the ocean surface flowing by gravity down the apparatus is used to drive a turbine and electrical generator. Air bubbles are introduced into the flow at the upper opening of the apparatus. This air is subject to hydraulic compression as the water falls. The flow of sea water and air passes through a cooling tube near the bottom of the apparatus where it is cooled to the temperature of ambient sea water at that depth. The flow then enters a chamber where the air and water are allowed to separate. Because of its greater density than the ambient sea water at that depth, the water in the chamber tends to flow out exhaust ports located at the bottom of the chamber. Excess air pressure held in the chamber can be used to exhaust water from the separation chamber or be returned to the atmosphere.

INTRODUCTION

The new patented Hydro Well Invention falls into the classification of an Open Cycle - Ocean Thermo Energy Conversion (OTEC) device. All such devices use solar heat stored in the Ocean surface in contrast with the cold depth sump to create power from that temperature difference. The Hydro Well also uses this differential but adds gravity, salinity gradient, hydraulic air compression, osmosis, vacuum, weight and depth pressure to is work force.

The apparatus drops warm salt water entrained with air down a penstock to drive a Hydro Electric Turbine Generator. The salt water is cooled by the ocean sump and becomes heavier than the ambient water. The air is hydraulically compressed and is separated to create a second work force. The forces, together with salinity, work to exhaust the water.

There is no commercial operating OTEC in the world. However, The Department of Energy (DOE) estimates a mechanism of 2 MWE can be built at a cost of $7,200 per KWE.

Using the same cost basis, a 2 MWE Hydro Well could be built for $1,345 per KWE because it is only 1/3 as deep and handles 1/8 the amount of water. Hydro Wells can be built now with off the shelf equipment while DOE-OTEC must still develop larger turbines and cold water pipes.

U.S. PATENT # 4,703,626 NOV. 3, 1987

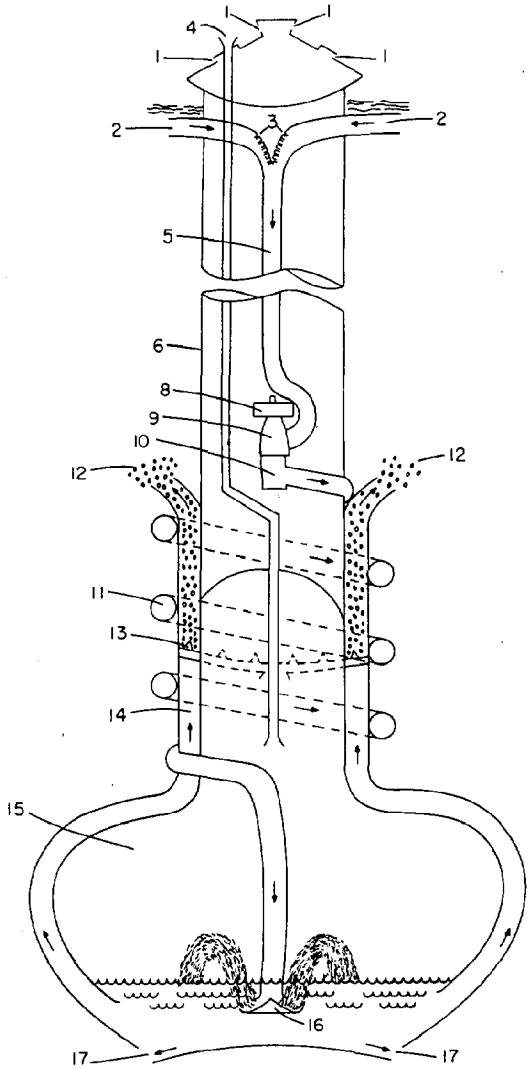


FIG. 1

The Basic Mechanism

An 8 ft. diameter 1000 ft. deep Hydro Well will produce electricity for 3200 people.

CH2585-8/88/0000- 1039 $1 ©1988 IEEE

WORLD ENERGY AND POLLUTION SOLUTIONS LIE IN THE OCEAN

Pollution now threatens our life style as we know it. Hopefully, there is an answer. Heat from different kinds of fuel is not the only source of power available to us, although it is the most convenient to use. It is also our main cause of pollution. I believe that the answer lies in the oceans of the world through renewable energy.

Man has looked to the sea for power since the first recorded Ocean Energy Device in 1881, with many different attempts to harness wind, wave, tide, heat, salt and water power. However, each attempt to date has used only one single force. Yet the complex ocean contains many different power sources and phenomena that have energy potential. I believe that if we are to tap this vast power, inventions must become as complex as the ocean. The ocean is a balanced wonder with off-setting pressures and many unknowns. One is its ability to correct itself when disturbed. The device upsets that balance and utilizes the ocean's power as it corrects itself.

This writer believes future off-shore stations will supply electricity, hydrogen, fresh water and food for the world without pollution or changing the natural balances of the ocean by combining the many available forces together.

The Hydro Well may be the first step toward this goal, in that it generates electricity from ocean phenomena. There is enough power available from the oceans of the world to supply all our energy needs without pollution, at less cost now!

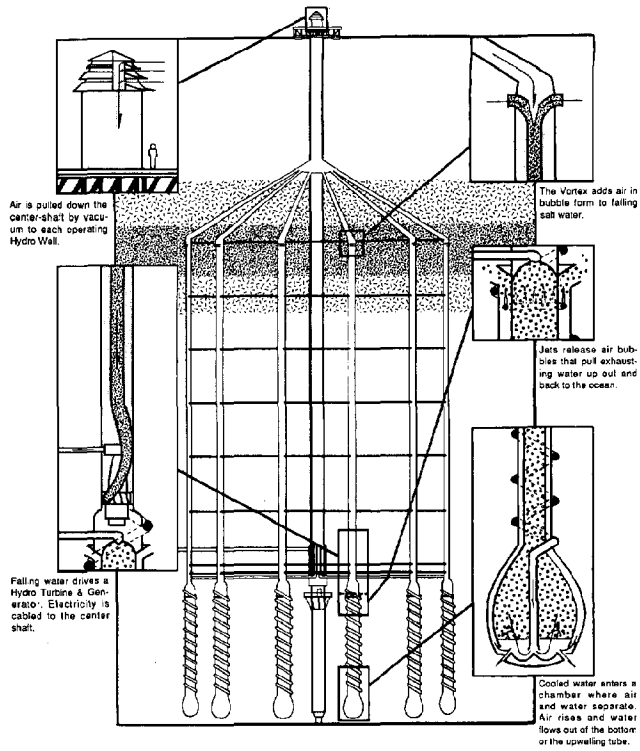


FIG. 3

Grouping wells together for strength makes mass production possible.

The Hydro Well starts below the surface where the highest salt content and temperature exists. This depth varies from site to site as do currents, tides, and storm frequency.

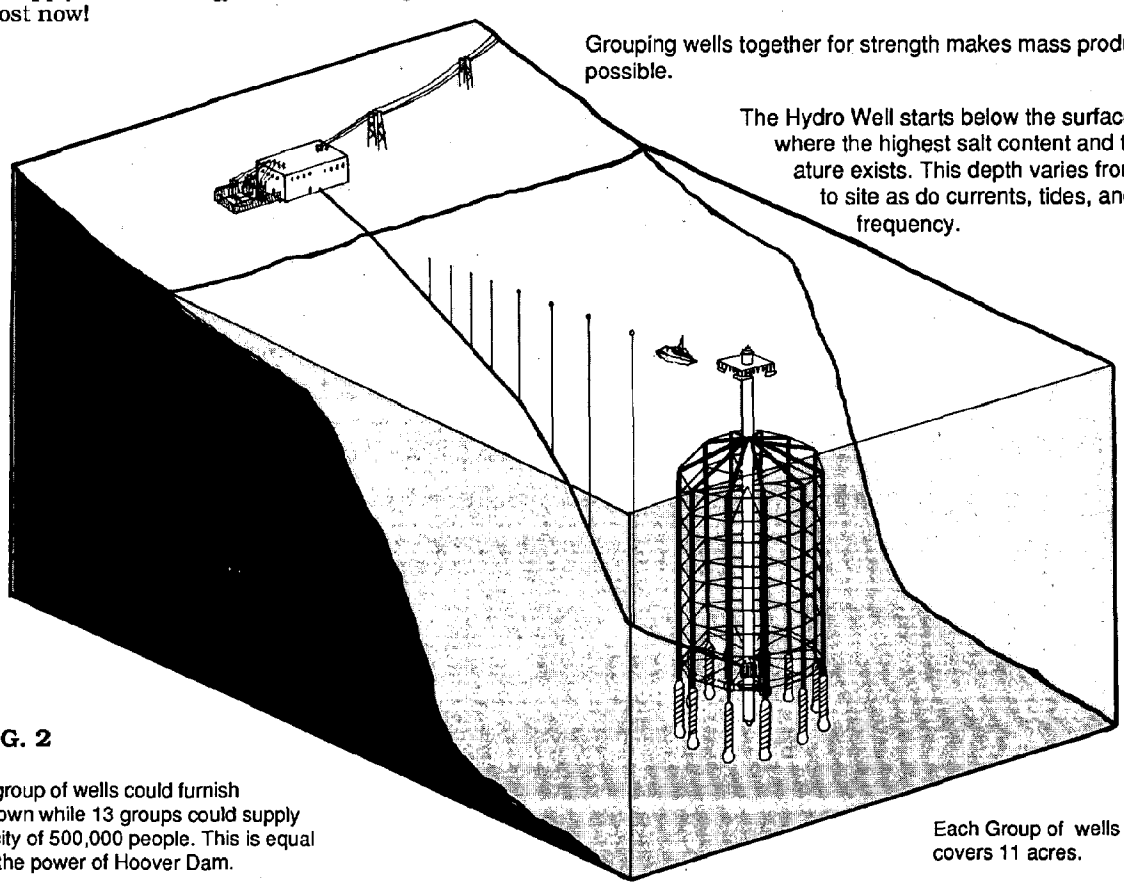


FIG. 2

A group of wells could furnish a town while 13 groups could supply a city of 500,000 people. This is equal to the power of Hoover Dam.

Each Group of wells covers 11 acres.

BACKGROUND OF THE INVENTION

In most oceanic locations around the world the water at depths greater than 130 meters is relatively fresh, dark, and cold in comparison with the surface water, which is warmer, and has a greater salinity, due to surface evaporation. Various OTEC inventions have been devised in the past to exploit these temperature and salinity gradients between the surface and the deep ocean acting as a sump to produce power, or to create an upwelling of nutrient-rich deep water to the ocean surface for mariculture. For example, one simple method involves placement of a long vertical cold water pipe into the ocean in such a manner that the bottom of the pipe is exposed to cold, relatively fresh water, while the top of the pipe is in warm saline water. A continuous flow of water up or down the pipe results, after the fountain is primed, due to an exchange of heat, but not salinity, with the ambient ocean. H. Stomel, A. B. Arons, and D. Blanchard, "An Oceanographical Curiosity; The Perpetual Salt Fountain," Deep Sea Research, Vol. 3 (1955), pp. 152-155. A similar system for surface water-deep water counterflow is disclosed by Johnson of SERI "Salinity-Driven Oceanographic Upwelling," U.S. Patent No. 4,597,360, issued July 1, 1986. A basic system for generation of power is disclosed by Claude, et al, "Method And Apparatus For Obtaining Power From Sea Water," U.S. Patent No. 2,006,985, issued July 2, 1935.

OTEC systems of this type have considerable appeal in that approximately sixty percent of the world's largest cities and two-thirds of the world's population live within 80 kilometers of the sea. However, existing systems have either been inefficient or not cost-effective due to a number of problems, such as, the length of the large cold water pipe required; the size of heat exchangers, turbines, evaporators, biofouling, corrosion, creation of salt water gases, and the difficulty of transmitting electricity under water.

In contrast, in the present invention, hydraulic compression of the entrained air is one of the methods used to assist in exhausting water at the bottom of the apparatus thus increasing the flow through the configuration. The present mechanism does not require extreme temperature differences, and therefore can be located close to shorelines near most major cities. This serves to minimize the length of electrical transmission lines. The present invention does not involve cold water pipes, evaporator, condensers, or steam turbines. The heat exchanger is an inexpensive cooling tube which serves to limit biofouling and corrosion.

HOW DID IT START

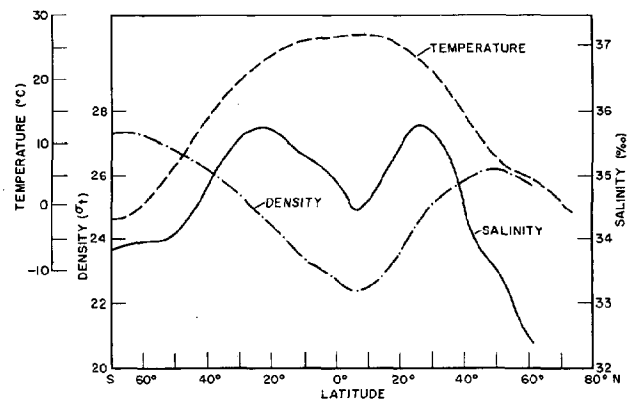
The most often asked question of the inventor is "Colorado doesn't have an ocean; how did you get the idea?"

In 1982, while fishing in Alaska, and after watching a new Hydro Electric Plant come on line, it dawned on me that if an empty tube were sunk vertically in the ocean, water would fall toward the center of the earth and could generate electricity. All I had to do was figure out how to get rid of the water as fast as it fell. A sixth subconscious mechanical sense told me there was a way.

Research revealed that this "hole in the ocean" had been used by professors teaching physics and engineering to illustrate the first and second laws of thermodynamics. Due to friction loss the falling water can't generate enough power to pump that same water back to the surface or out against the ocean's pressure at any depth.

Study also revealed that SERI located two miles from my home in Golden, Co., was the lead agency for our governments' DOE doing research into OTEC. This was better than a Colorado ocean! SERI was very helpful with information, the use of their library and scientific advice. Government engineers are working to perfect The Claude Cycle OTEC a 1932 invention that pulls steam from the ocean's warm water and uses the cold deep water as the sump. Many countries have worked on OTEC over the last fifty-five years, yet no one has a commercial model. There must be a better way.

Further research turned up some unusual phenomena that reminded me of my World War II machinist mate days on the U.S.S. Mississippi, where evaporators were not large enough to produce fresh water for both the crew and boilers. When they operated in tropical waters the crew showered and washed their clothes in salt water. Near the Equator more water evaporates from the ocean then returns by rain, leaving the upper ocean layer saltier. Why doesn't that saltier water sink? See salinity density verse latitude chart (fig. 4). Salinity exceeds density between 40° N and 40° S latitudes.



Average Surface Temperature, Salinity, and Density Variation with Latitude for all Oceans

FIG. 4

Salt water weighs 64 lbs. per cubic feet. Fresh water weighs 62.428 lbs. per cubic feet. Both weights are at maximum density (4° C = 39.2 F). A similar difference exists between the surface salinity and the salinity at a 1000 foot depth in the ocean. The three parts per thousand average difference is enough to change the ocean's balance of weight and pressure for a small area above and below the exhaust level without affecting the surface temperature or salinity content. (See Temp. vs. Weight charts Fig. 5 and 6.)

The device should have no effect on the environment. Some fish may seek a different level or may move away from the exhaust effected area. Persistent digging found the perpetual salt fountain. However, science labeled it a oceanographical curiosity because no one could figure how to benefit from its oozing slow flow. The Hydro Well had found its first tools, heat salinity and density as additional forces that would help to overcome the losses in the system, thus helping to exhaust part of the water.

Another lost discovery, dates back to the early 1900 when Hydraulic Air Compression (HAC) was invented and used to run mining equipment. Falling fresh water entrained with air bubbles compressed the air so that

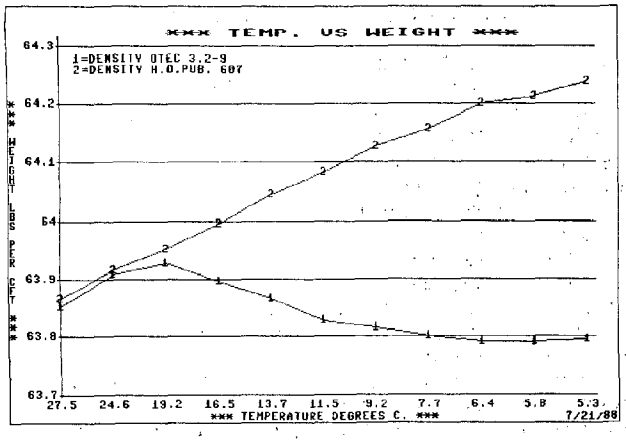


FIG. 5

Fig. 5 shows heat loss effect of salinity and density due to deletion 1 compared to penstock confined water 2.

-----TEMPERATURE VS SALINITY VS DENSITY COMPUTATIONS-----

REV. 1 5/30/88

--NOTE--DATA FOR TEMP. VS SALINITY FROM OTEC B-46 NEW ORLEANS
DATA FOR TEMP. VS DENSITY FROM H. O. PUB. 607

DEG C	DEG F	SALINITY NO	SALINITY DENSITY	SA=36.5 DENSITY	SALINITY WEIGHT	SA=36.5 WEIGHT	DELTA WEIGHT
30	86	36.38	1.0236	1.023	63.9027	63.8652	-.0375
27.5	81.5	36.3	1.0235	1.0238	63.8964	63.9152	.0188
25	77	36.3	1.0235	1.0244	63.8964	63.9526	.0562
22.5	72.5	36.3	1.0235	1.0251	63.8964	63.9963	.0999
20	68	36.3	1.0235	1.0259	63.8964	64.0463	.1499
17.5	63.5	36.24	1.0235	1.0265	63.8964	64.0837	.1873
15	59	35.99	1.0232	1.0272	63.8777	64.1274	.2497
12.5	54.5	35.6	1.0227	1.0277	63.8465	64.1586	.3121
10	50	35.2	1.0223	1.0284	63.8215	64.2023	.3808
7.5	45.5	35	1.022	1.0286	63.8028	64.2148	.412
5	41	34.68	1.0217	1.029	63.784	64.2398	.4558

NOTE WEIGHT IS IN LBS/CFT

FIG. 6

Fig. 6 shows the delta difference between ocean and Hydro Well water at varied degrees.

when separated at the bottom of a shaft the air could power pneumatic tools. Would salt water compress air the same as fresh water? More tools, gravity vacuum and air. I consider the air chamber as the source of still another force capable of lifting some of the water from the reservoir at the base of the Hydro Well through the air lift principal.

Ocean pressure decreases as you rise. However a vertical pressurized tank (the air chamber) has the same pressure at the top as at the bottom. The simple difference between air and water pressure is that air bubbles released from the tank could pull water up through the upper exhaust. Another tool, pressure and buoyancy.

Yet another phenomena that has been known since before Christ that is when fresh water and salt water are separated by a membrane the fresh water (lighter density) flows through the membrane, raising the salt water. Another tool osmosis.

Why does cold water move toward warmer water when the heat is moving in the opposite direction? Another tool thermo syphon.

Still solar heat is the main tool for all OTEC's. The Hydro Well should be no different! If the device could be designed to use all of the tools mentioned, would a hole in the ocean still violate the laws of thermodynamics? I doubt it.

DETAILED DESCRIPTION OF THE INVENTION

A generally cylindrical casing (6) housing the apparatus extends vertically from the surface down into the ocean. A depth of 1000 feet may be used as an average length for the apparatus based on other hydro electric plants. The apparatus may be held in place by moorings attached to the ocean bottom. Past research suggests that concrete or polyvinyl chloride may be the most cost-effective materials for the apparatus. A cone-shaped top extends from the upper end of the cylindrical casing, above the high tide and wave limits, to afford easy access to the equipment located inside the casing for servicing. Open-grate platforms located inside the casing add strength and support equipment where needed. The optimal diameter of the cylindrical casing and the water intakes (2) are determined by tide, current, and wave conditions. In particular, the screened water intake (2) must not allow warm surface water to enter faster than is available.

Prior to commencing operation of the apparatus, the separation chamber (15) must be pressurized with air before water is allowed to enter the water intake (2). Operation of the apparatus is commenced by allowing water to enter the water intake (2). The water is then drawn by gravity through the penstock (5) to drive the reaction type turbine (9) and electrical generator (8).

Air flows through the air intakes (1), and is added to the flow of surface water in the form of small bubbles by the venturi effect at the air induction vortex (3). The screened amount of air entering the vortex is regulated to equal the amount of air being exhausted from the apparatus. Only as much air is entrained as necessary to stabilize the water level in the separation chamber (15). When the jet of air bubbles is activated the air induction vortex allows the maximum amount of air to be entrained. The air trapped in the falling water is compressed as it is pulled downward by gravity through the penstock, as the air bubbles are isothermally compressed they become smaller and colder helping to cool the penstock water from the inside. The penstock below the turbine has an increased diameter to avoid back pressure in the turbine. The flow of water and air then enters the cooling tube (11) which spirals down and around the outside of the separation chamber (15). Heat flows from the warmer water and air in the cooling tube to the ambient ocean water, and to the water flowing upward through the upwelling tube (14) located between the cooling tube and the outside surface of the separation chamber (15). The flow of water and air then enters the separation chamber (15) over a separation cone (16). The compressed air in this flow then separates, rises, and pressurizes the separation chamber (15). This cold dry air has been compressed to the same pressure as the ocean depth pressure opposite the separating cone (16), less any unintentional losses.

The water in the separation chamber is essentially at the same temperature as the ocean at that depth, only denser because of its higher salt content. A density difference exists. The upper portion is continuously moving and releasing trapped air that didn't separate over the cone. This air rises to the surface while the water flows out of the lower exhaust manifold (17) because it is denser than the ambient sea water at that depth.

The upwelling tube (14) is also used to remove water from the separation chamber. When the salinity and temperature gradients are sufficiently large, most of the water in the separation chamber will flow out the lower

exhaust ports (17) with only a minimal flow through the upwelling tube, drawing from the top area of the air chamber. Due to heat exchange between the cooling tube (11) and the upwelling tube (14), the flow of water upward through the upwelling tube is gradually warmed, resulting in a thermo syphon effect. The flow through the upwelling tube can be accelerated by releasing a jet of air bubbles through orifices (13) into the upwelling tube, using a portion of the compressed air in the separation chamber. Air is always moving upward through the separation chamber at a constant pressure, but it is only near the top portion where it exceeds the water pressure in the upwelling tube. Varying the rate of flow in the upwelling tube provides another means of controlling the air pressure and water level in the separation chamber. This exhaust system would not be used during normal operating conditions. However, should the flow through the lower exhaust ports (17) or the upwelling tube (14) slow, the water level would rise within the separating chamber (15), triggering activation of the valves controlling the jet of air bubbles in the upwelling tube. Air not exhausted by the air jet orifices, as well as any excess compressed air vented from the separation chamber is released to the atmosphere through the air exhaust tube (4).

It will be apparent to those skilled in the art that many variations and modifications of the present invention may be made without departing from the spirit and scope of the invention. Legal claims have been omitted.

POWER

Horse-power is created by falling water. Volume X Head X Density. Chart (fig. 7) shows Power vs. Head. Given the power required, salinity, temperature, and ocean depth our computer model will size the Hydro Well or a group of wells for a location.

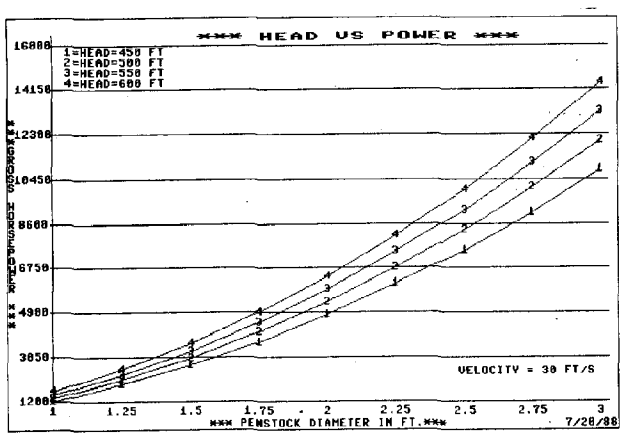


FIG. 7

Fig. 7 shows Horse-power vs. Penstock size.

FUTURE HYDRO WELL OPTIONS

The potential OTEC market consists partly of tropical islands that have no natural fuel or fresh water. After the first Hydro Well prototype is perfected, research and development R. & D. will be concentrated on producing fresh water as a by product. Heated surface water is already falling to a cold water sump. With the addition of a vacuum evaporator to extract steam and a condenser to convert the steam to fresh water. That water can then be pumped ashore, the engineering problems are believed solvable. Another potential market is for cold water and the nutrients present in the ocean bottom water for both fish and aqua culture. The Hydro Well upwelling exhaust system can be extended to the surface where the cold nutrient rich water would be pumped ashore. Osmotic power (another ocean phenomenon) that has not been used in the basic Hydro Well, would be used to mix the bottom water with surface water through osmosis. Again engineering problems appear to be solvable.

A third potential is the recovery of minerals from ocean water. A continuous flow of water opens the possibility that useable mineral can be trapped or extracted. The Hydro Well will explore all reasonable possibilities through continuous R. & D.

HYDROGEN

Hydrogen often called the perfect fuel can be produced from the ocean using electricity. It is thought that future offshore stations would include hydrogen making machinery to utilize the off-peak electricity available.

EQUATIONS

Research scientists, physicists, oceanographers, mechanical-electrical-hydrology and thermodynamic engineers have all written equations for the invention. About 50% are favorable. The one thing they all have in common is that none of them are conclusive! For this reason they have been omitted. Established methods of evaluating an energy device do not seem to fit the Hydro Well.

ANALYSIS

It is going to take a team of engineers with varied expertise, using computer modeling techniques, to prove the concept. After which conceptual design, prototype and deployment in the ocean will be the ultimate test.

SUMMARY

The invention consumes no fossil fuel, does not pollute and has the potential to furnish most of the Worlds' electric needs without subjecting people to radiation. Breaking the barrier of tradition with a invention is difficult. The Hydro Well will have to do just that to gain acceptance. Because traditionally heat is used to create power. The Hydro Well creates power through the cool-

ing of salt water (an opposite of the accepted science).

The turbine and generator are the only moving parts in a Hydro Well! The inventor used basic common knowledge that: (1) Gravity starts at the center of the earth; (2) Heat moves one way toward cold; (3) Salt water is heavier than fresh water; (4) Air changes temperature faster than water; (5) Ocean pressure increases with depth; (6) A pressurized air tank is constant.

The Hydro Well is the first invention to receive U.S. Patent Office approval using sun, gravity, water, air and salt to produce electricity without disturbing natural balances or confidences.

The 1978 Public Utilities Regulatory Policy Act assures cogeneration power producers a market for their electricity to the public utility companies. This Act changed the electric power industry! Private industry is now furnishing most of the growth required.

The 1980 OTEC Act allows developers of OTEC plants up to 87 1/2% government loan guarantees along with an accelerated approval system. To date no one has used it!

The 1986 Tax Reform Act established a 10% to 15% business tax credit for renewable energy cogeneration investors. With rates already set by utility commissions, no fuel or ground cost and the tax credit, investors should do well.

CONCLUSIONS AND RECOMMENDATIONS

The inventor believes he has found a better way! The Hydro Well produces its electricity below the surface of the ocean with only 10% of the water required for (OC) OTEC at a cost of less than 20%, but with all of the benefits associated with this renewable energy source. As a one-man force without the benefit of laboratory or ocean test site, the inventor recognizes the amount of work that will be required to confirm his concept and design, to bring the Hydro Well to model, prototype, and production. he believes the rewards are there and as every inventor dreams, the Hydro Well will make the world a better place to live. He is seeking the right U.S. company to model, design and test the prototype and market the Hydro Well world-wide.

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The inventor wishes to acknowledge and express his gratitude and appreciation, without their help the Hydro Well would not exist today.

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FIRST PRODUCTION OF POTABLE WATER BY OTEC AND ITS POTENTIAL APPLICATIONS*

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ABSTRACT

An experiment -- the Heat and Mass Transfer Scoping Test Apparatus -- was built to obtain design data for a larger test that will assess the technical feasibility of the open-cycle OTEC process. (The closed-cycle concept was successfully demonstrated in 1979.) The DOE-funded project is a joint effort between Argonne National Laboratory (ANL) and the Solar Energy Research Institute (SERI). The appparatus was erected at the Natural Energy Laboratory of Hawaii and became operational in the summer of 1987. It is used by both ANL and SERI to conduct open-cycle OTEC experiments. After initial debugging, it produced 350 gallons per hour of potable water having a salinity of 86 ppm, one-fifth that of local tap water available at the test site.

BACKGROUND

Ocean thermal energy conversion (OTEC) is a process for converting solar energy collected in ocean water into electricity by utilizing the temperature difference between the warm upper layer of tropical oceans and the cold ocean depths. Three forms of OTEC have been studied by the U.S. Department of Energy (DOE): closed cycle, open cycle, and hybrid cycle. Of these, the latter two (open cycle and hybrid cycle) are capable of producing fresh water as a by-product.

In 1881, the French scientist J.A. d'Arsonval proposed the idea of tapping the thermal energy of the oceans. In 1926, the French engineer Georges Claude, well-known for his invention of the neon light and his pioneering work in cryogenics, began devoting his efforts to making OTEC a reality. In 1930, he succeeded in producing 22 kW of electricity in an open-cycle plant built on the Cuban coast. Because of the technological limitations of the day, his equipment consumed more power than it produced, and the project was abandoned.

Interest in OTEC revived in the early 1970s as renewable sources of energy were more closely examined as a possible means for offsetting future energy shortages or increasing cost of energy from fossil and nuclear fuels. The technical feasibility of the OTEC principle was demonstrated in 1979 by a consortium that included the State of Hawaii, Lockheed, and others.(1)** The experiment, installed in a converted navy barge anchored two miles off the west (Kona) coast of the island of Hawaii, produced 53 kW gross and 15-18 kW net with a closed-cycle system using ammonia as the working fluid.

OTEC CYCLE OPTIONS

Closed-cycle OTEC plants operate according to the same principle as conventional nuclear or fossil-fueled power plants. Tropical ocean water is used to evaporate a working fluid such as ammonia,*** just as nuclear fuel or coal is used to produce steam in a conventional steam boiler. The vaporized ammonia drives a turbine-generator to produce electrical power as shown in Fig. 1. The low-pressure ammonia discharged from the turbine is condensed in a surface condenser using cold water drawn from a depth of 600-1000 meters below the surface. The condensed ammonia is then pumped back to the evaporator to begin the cycle again. This continued cycle of boiling and condensing a contained working fluid to produce power is commonly called a Rankine cycle. This cycle cannot directly produce fresh water.

The open cycle is the one that Claude tried in Cuba and is shown schematically in Fig. 2. In open-cycle OTEC, warm seawater is flash-evaporated into low-density steam in a vacuum chamber. The steam passes through a large-diameter, low-pressure turbine to produce electrical power. To

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**Numbers in parentheses refer to references cited at the end of the paper.

***The temperature range for OTEC is comparable to that for many refrigeration systems. Thus, refrigerants such as ammonia and the Freons are used with closed-cycle OTEC because their physical properties are suited to thermodynamic cycles operating at these temperatures.

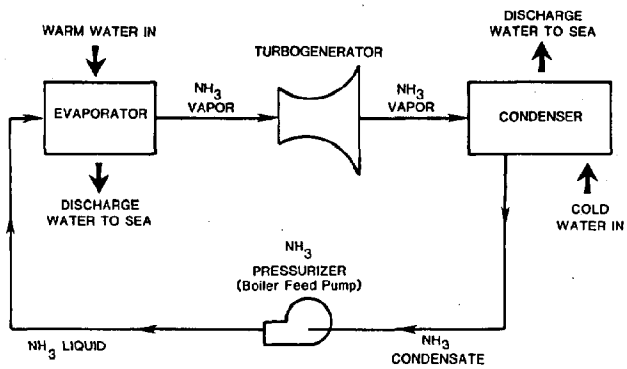

Fig. 1 Schematic for Closed-Cycle OTEC

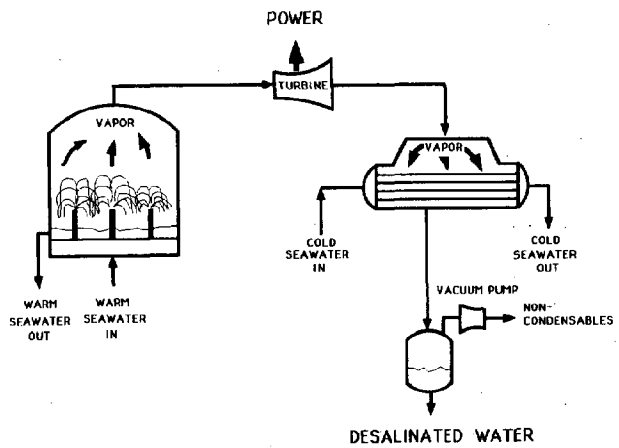

Fig. 2 Schematic for Open-Cycle OTEC

complete the cycle, cold seawater condenses the steam either through direct mixing (the method used by Claude), or by condensation of the steam on a heat-exchanger surface (as indicated in Fig. 2). The surface-condenser option can have the added benefit of producing fresh water as a by-product of electrical power generation, as the condensed working fluid is essentially distilled seawater. This fresh-water option may be especially attractive in the small island markets where OTEC may first be commercialized. The major emphasis of the Department of Energy's OTEC program is currently on the open-cycle system, which has yet to be proven in principle by a successful generation of net electrical power.

A third concept, which is now in the design-study phase, is called the hybrid cycle (2) and combines desirable features of both closed-cycle and open-cycle OTEC. It produces fresh water as in the open cycle and power as in the closed cycle. It is shown schematically in Fig. 3. The hybrid cycle has several important advantages over the pure open cycle:

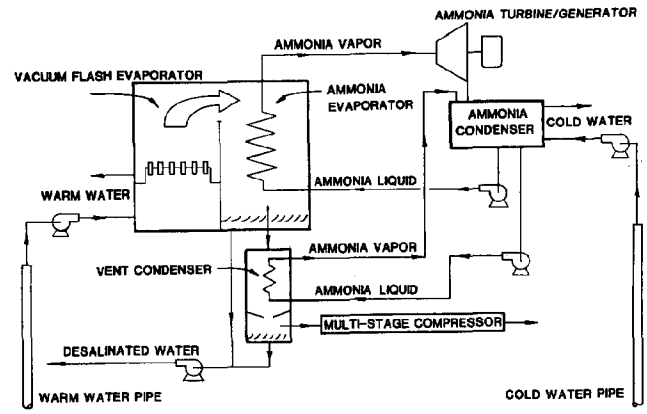

Fig. 3 Schematic for Hybrid-Cycle OTEC

- o A commercially available ammonia turbine can be used to produce electrical power. The open cycle requires a large-diameter low-pressure turbine, which has yet to be developed and remains a major unknown.
- o Condensation takes place at a higher pressure, increasing the fraction of thermal energy that can be recovered and also reducing the parasitic-power requirements for removing noncondensable gases.
- o The power/water ratio can be adjusted to meet local requirements.

The hybrid cycle has an advantage over the closed cycle in that it is capable of producing fresh water.

SITE REQUIREMENTS

Although earlier U.S. studies were based on large (250-400 MW) plants located on floating platforms that might be miles out to sea, recent design studies (3) have concentrated on smaller (10 MW) shore-based plants suitable for small, island markets. There are some very specific requirements for a shore-based OTEC plant, some of which are listed below.

- o A source of warm, nonpolluted surface seawater relatively close to shore. The mean annual water temperature should be at least 25°C. This temperature is typical of tropical locations.
- o A steep offshore slope that reaches depths of 600-1000 meters within a few kilometers of shore. Since water temperatures at these depths are the same worldwide (about 5°C), the temperature difference will be about 20°C, the minimum considered necessary for OTEC.

- An onshore site close to the water that is suitable for major construction activities, including excavation. It is also necessary that the elevation of an OTEC plant be as close to sea level as possible to minimize pumping-power requirements.

- An offshore topography that is suitable for deploying the cold-water pipe. The current thinking envisions a buoyant plastic pipe anchored off the bottom by weights. (In contrast, Claude had to use corrugated-steel pipe sections, flanged and bolted together.)

An unpublished 1982 study commissioned by Argonne National Laboratory identified ten island markets where OTEC is technically feasible and where other conditions appear favorable. The islands identified by this study were:

- Hawaii
- Puerto Rico
- Guam
- Jamaica
- U.S. Virgin Islands
- Phillipines
- Fiji
- American Samoa
- Barbados
- Dominician Republic

Other studies (4,5) have considered the water option and assessed the technical and economic viability of OTEC at many sites world-wide. These studies have concluded that there is a large potential market for the simultaneous production of water and power in those locations where both are in short supply. On many tropical islands, fresh water has a high market value -- $1.21 to $11.36 per 1000 gallons in one of the referenced studies. The price for OTEC electrical power becomes competitive with fossil-produced power when water is also produced and sold at these prices. Even when electrical power is not desired, open-cycle (or hybrid-cycle) OTEC appears attractive for the production of water alone. It has been estimated (4) that the cost of fresh water produced by OTEC is about one-third the cost of fresh water produced by the standard multi-stage, flash-evaporation process using fossil energy as a heat source.

CURRENT RESEARCH

Large-scale experimental research on OTEC materials and fouling issues has, since 1981, been carried out at the Natural Energy Laboratory of Hawaii, located near Kailua-Kona on the island of Hawaii (the Big Island).(6) The open-cycle experiment that produced fresh water at the rate of 350 gallons per hour was built there in 1987 and is called the Heat and Mass Transfer Scoping Test Apparatus (HMTSTA). The purpose of the experiment is to collect data on the performance of evaporators and condensers operating under open-cycle OTEC conditions. This information is needed for the design of a planned systems experiment -- one that will produce 165 kW gross electrical power and establish the technical feasibility of the open-cycle process to produce more electrical power than it consumes. The project is under the direction of the Solar Energy Research Institute (SERI) of Golden, Colorado. The HMTSTA itself was designed, built, assembled, and first operated by Argonne National Laboratory on the basis of criteria furnished by SERI. Although fresh water has long been produced from seawater by the application of an external energy source, this was the first time the energy source has come from the seawater itself. Although an external source of electrical power is used to run the pumps in this experiment, an actual OTEC plant would produce more than enough power with its own turbogenerator.

The figures provide more details on the HMTSTA. Figure 4 is a pictoral drawing showing the major components of the apparatus, and Figs. 5 and 6 are photographs taken during construction. The three heat exchangers (evaporator, main condenser, and vent condenser) were originally tested at Argonne for the closed-cycle OTEC program and modified for this experiment.

As now assembled, the HMTSTA incorporates a surface condenser. This is necessary when it is desired to produce fresh water as a by-product. If electrical power only is desired, it may be more economical to use a direct-contact condenser, which mixes the distilled water vapor directly with cold seawater, the process used by Claude. Argonne has built and is now installing in Hawaii a direct-contact condenser using equipment transferred from another DOE program. After completion of the experimental program with the currently installed surface condenser, the direct-contact condenser will be tested.

Although the reworked surface condenser now installed in the HMTSTA is adequate for testing open-cycle evaporators and for gathering data needed for the design of open-cycle surface condensers, it is not optimized for this purpose. Argonne is now designing a surface-condenser system specifically for open-cycle conditions. A test unit is budgeted for construction in FY 1989.

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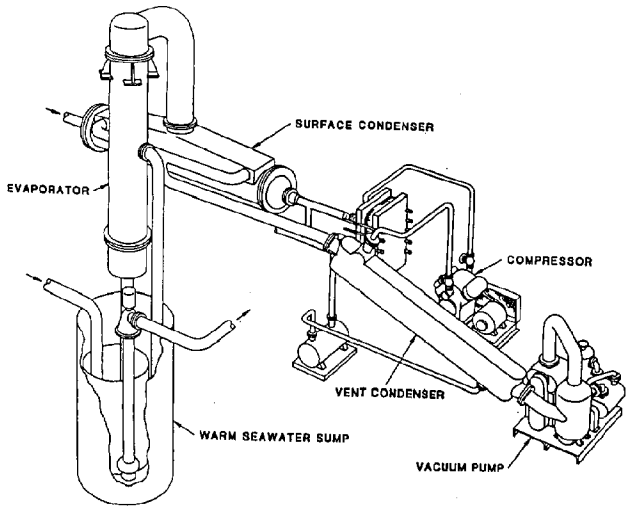
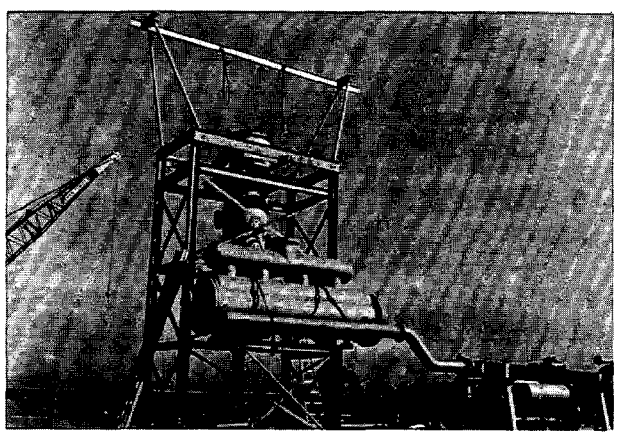


Fig. 4 HMTSTA Pictoral Drawing



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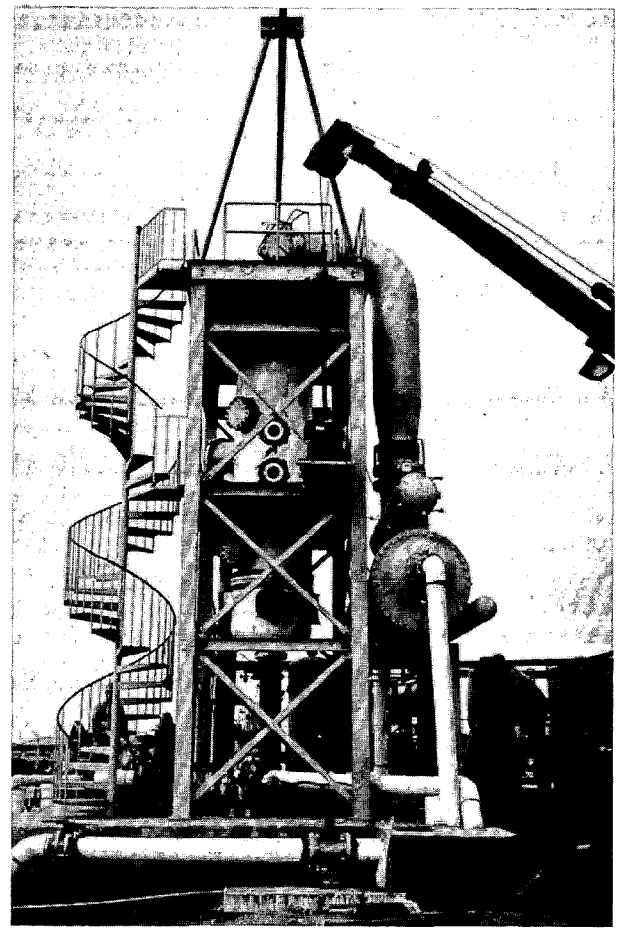

Fig. 6 HMTSTA Elevation Showing Tower

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DELBUOY: WAVE-POWERED SEAWATER DESALINATION SYSTEM

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ABSTRACT

An ocean wave energy system designed to desalinate seawater, rather than produce electricity, has been under development since 1976. The device, referred to as DELBUOY, utilizes no motors or electronics and makes extensive use of engineering polymers for constructing major system components. The research and development of the system, initially performed at the University of Delaware and more recently by ISTI Delaware, Inc., has encompassed wave tank testing, mathematical modelling, materials testing, component engineering, and extensive sea trials of full-scale prototypes. This paper describes the system's design and operating principles, the results from both the modelling and sea trials, the economics of direct wave-powered desalination, and plans for commercialization of the DELBUOY system.

NOMENCLATURE

- a - buoy radius
- ℓ - system capture width
- k - wave number
- P - pump damping force
- S - buoyant spring constant for buoy
- η - average wave amplitude

INTRODUCTION

A new and innovative approach to the problem of providing potable water to islands and arid coastal regions is the DELBUOY wave-powered seawater desalination system [1,2]. The DELBUOY was conceived in 1976 at the University of Delaware where it was under development for nine years. During that time, the system underwent four years of extensive laboratory and computer model testing and initial sea trial (supported by NOAA through the National Sea Grant College Program). This was followed by five years of research and development based on feedback from seven full-scale prototype tests conducted at the Dept. of Marine Sciences, University of Puerto Rico (sponsored by USAID). The first fully operational system, producing a steady supply of fresh water, was deployed in 1982. Since 1985, when the patent rights to the technology were acquired, ISTI Delaware, Inc. has been working to value engineer the design, generate statistical data for system performance and working lifetimes by means of a series of system sea trials, and set up for commercial production. The first limited production run of the system was completed in early 1988, with negotiations presently underway for the first two commercial installations in the fall of 1988.

OPERATING PRINCIPLE

The system is extremely simple in concept and, being modular in nature, the number of DELBUOY units deployed can be matched to site specific water requirements. A single DELBUOY unit is illustrated in Figure 1, with the preferred six unit array shown in Figure 2. The system comprises a light weight, shallow draft cylindrical buoy driving a submerged, single-acting positive displacement pump tethered to the seafloor. The wave- induced heave and sway motions of the float open the pump for the pressure stroke, with energy stored in the natural rubber return springs used to refill the system. Clean seawater is drawn into the pump through prefilters to remove particulate matter. The flow of pressurized seawater from the pump is rectified using check valves, with pressure surges damped by hydraulic accumulation. The pump output is then passed through the reverse osmosis filter, with approximately 80% of the flow returning to the sea as concentrated brine and the remaining 20% of freshwater being pumped to shore through a low pressure plastic pipeline. The large ratio of buoy to pump piston area enables the system to amplify the wave-induced dynamic pressure up to the 5500 kPa (800 psi) pressure required for the reverse osmosis desalination process.

As with most point absorber wave energy systems, the DELBUOY is omni-directional in

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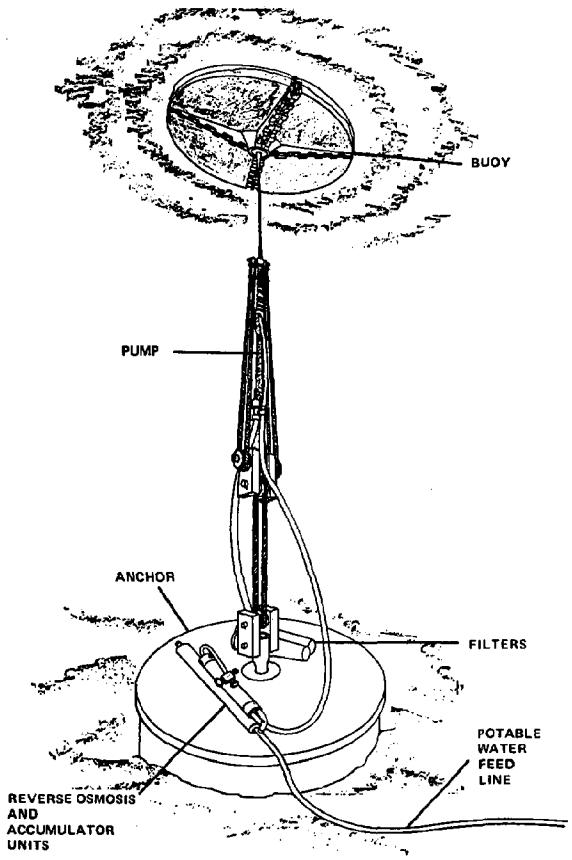

Patent Nos. 4,512,886; 4,421,461; 4,326,840; 4,221,550.
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Figure 1. Schematic diagram of the DELBUOY system.

its response to incident waves. It differs from the majority of point absorbers described to date in the literature in its use of non-linear damping for the power take-off and its broad band, non-resonant response. Although attractive in principle, the practical limitations of operating a resonant point absorber system at sea are substantial. For this and other reasons the DELBUOY was designed to be non-resonant. As a result the system can operate efficiently over a wide range of wave conditions. Intended primarily for use in the Trade Wind zones the system has been designed to operate efficiently in waves of 0.6-1.5 meters and 3-8 seconds.

Two other design features distinguish the DELBUOY system from most other wave energy conversion systems. The first is the placement of the "expensive" components such as the pump, valves and filters well below the air-sea interface. This reduces the amount of system capital at risk in the high energy surface wave field. This risk is further reduced by the inclusion of a sacrificial connecting linkage between the float and pump. In the event of an extreme storm, a shear pin in the buoy terminations will part before the wave forces approach the operating limits of the system. This sacrifices the buoy and allows the "expensive" components to remain in safety on the seafloor.

REVERSE OSMOSIS

Reverse osmosis (hereafter, RO) may be regarded as a filtering process carried out at the molecular level, in which pure water is forced through the pores of a specially engineered membrane which will not allow the passage of ions such as sodium or chloride. The process is more energy efficient than the more familiar desalination techniques of distillation which require a tremendous amount of energy to initiate the phase change from water to vapor.

RO differs from conventional filtration in that it is not a mechanical screening of particulate matter from the process stream. In addition, not all of the feed-water passes through the membrane. A fraction of the water is recovered as fresh (5-50% depending on the particular system and feed-water), with the remainder passing out of the membrane pressure vessel as a concentrated brine. As a result, the unit is continually flushed and if operated properly can be run continuously for several years without cleaning (manufacturer warranties of up to 3 years are available). The particle content of the seawater entering the system is an important factor influencing performance.

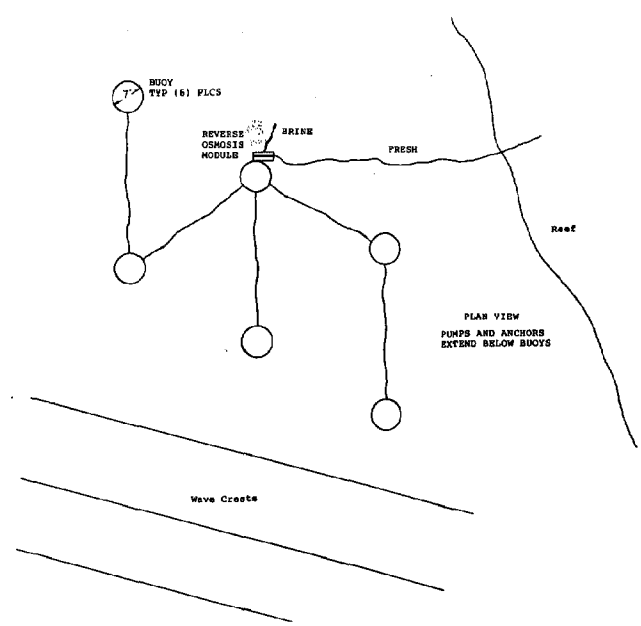

Figure 2. Plan view of the preferred deployment configuration of DELBUOY systems.

Since the membrane bundle forms a relatively fine mesh mechanical filter which can be clogged quickly by colloidal particles prefiltration is an essential component of every system.

Seawater RO has recently become cost-effective, thanks to substantial progress in membrane research [3,4]. As a result, the conventional (electric and diesel powered) RO industry has expanded rapidly over the last decade. Approximately 2,000 major RO installations are currently in operation worldwide, with a combined capacity of 560 million gallons per day (gpd) [5]. Since large area RO membranes can now be conveniently packaged in small cylindrical pressure vessels the process is modular, with systems ranging in size from 10^6 to $>10^6$ gpd. The essential system elements are a prefilter, a high pressure pump capable of producing seawater at 5500 kPa (800 psi), and the membrane package.

PHYSICAL AND NUMERICAL MODELLING

In parallel with the engineering of the DELBUOY prototypes, laboratory and mathematical models were developed to investigate the system's performance characteristics and efficiency over a range of operating conditions [6,7]. Due to the nonlinearities associated with the one-way damping force exerted by the single acting pump, linear theory cannot be used to describe the system. As a result, the majority of the work described in the literature for point absorber systems was not applicable.

A series of tests were performed on 1/10 scale models in wave tanks at both the University of Delaware and the U.S. Naval Academy. To ensure inclusion of all the system's nonlinear damping terms, detail scale models were fabricated complete with hydraulic cylinder, valves, hoses, and return springs. Although the physical models were tested with heave only and with both heave and sway, the mathematical model treated only the system's dominant mode of energy extraction, heave. System response curves for both monochromatic and random wave conditions were developed. In conjunction with the physical models, a time-domain computer simulation of the DELBUOY was developed. Once validated by hindcasting the physical model data, the mathematical model was used to predict system performance at full-scale.

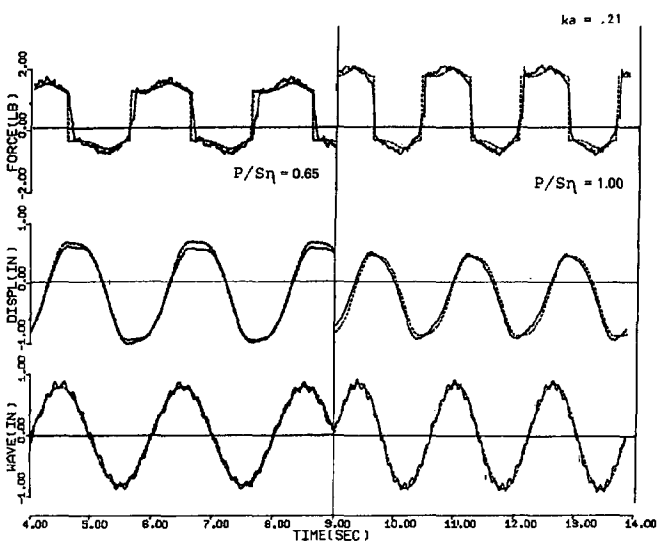

Figure 3. Time series records from wave-tank (——) and mathematical (---→) models showing incident waves, buoy displacements, and pump damping forces.

A portion of the results have been plotted in Figures 3 and 4. In Figure 3, time series are presented for both models at two levels of relative damping under monochromatic wave conditions. The mathematical model's accuracy in simulating the system's nonlinearities is evident. Figure 4 shows a comparison of the model results under two types of random wave spectra. As can be seen from the data, except for the highest level of relative damping the computer simulation was able to hindcast the results from the wave tank tests to within a few percent.

To assure accurate predictions of system efficiency at full-scale the friction and viscous loss terms in the model were adjusted to represent the proportionately smaller values seen in the prototypes. Model predictions for the DELBUOY's capture width (the ratio of the effective length of wave crest from which energy is extracted by the system divided by the buoy diameter) as a function of the relative damping (the pump force divided by the average wave force exerted on the buoy) has been plotted in Figure 5 for two types of wave spectra. As can be seen in the figure the system has a relatively broad band response, enabling the DELBUOY to operate efficiently over a wide range of wave conditions.

SYSTEM ENGINEERING

Although simple in concept, the execution of the design required a substantial amount of engineering. The goal was to design a low cost system able to operate with only annual maintenance for a period of five years. Due to the complex nature of friction, wear, and fatigue an empirical approach seemed preferable. A combination of laboratory experimentation under simulated operating conditions and component testing during prototype system sea trials was used. Over the course of the project a large body of information was generated on the tribology of water

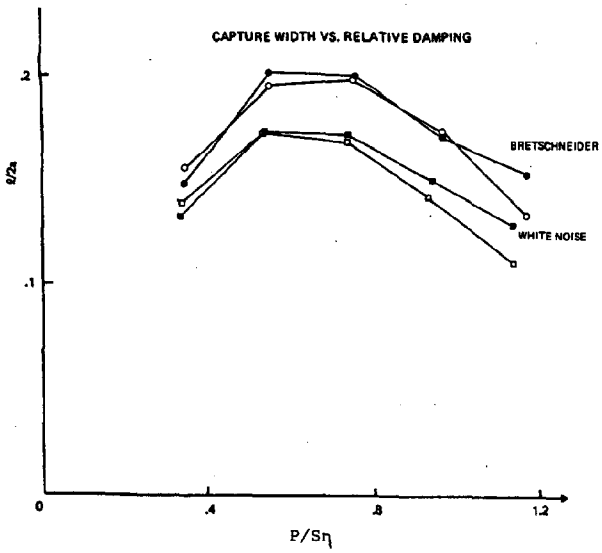

Figure 4. System capture width data from the wave-tank (solid symbols) and mathematical (open symbols) models in two types of wave spectra.

lubricated seals and bearings as well as the fatigue resistance of both polymeric and metallic materials in seawater.

Whenever possible commercially available components were used in the DELBUOY system. Unfortunately, many were found to be either too expensive or unable to withstand the fatigue and corrosive effects of long term operation at sea. As a result, the following components had to be designed specifically for the DELBUOY system:

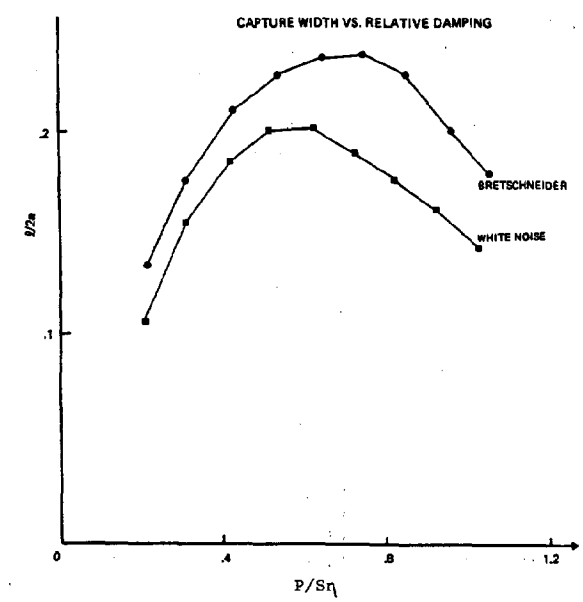

Figure 5. Mathematical model prediction of the capture width for a full-scale DELBUOY under two types of wave spectra.

- -Hydraulic cylinder
- -Large capacity (10 liter) accumulator
- -Check valves
- -Pipeline (system to shore)
- -Buoy
- -Sacrificial linkage assembly
- -Sand filled dead-weight anchor
- -Cable, pump, buoy, anchor, and return spring terminations

The hydraulic cylinder which pumps the seawater through the RO membrane proved to

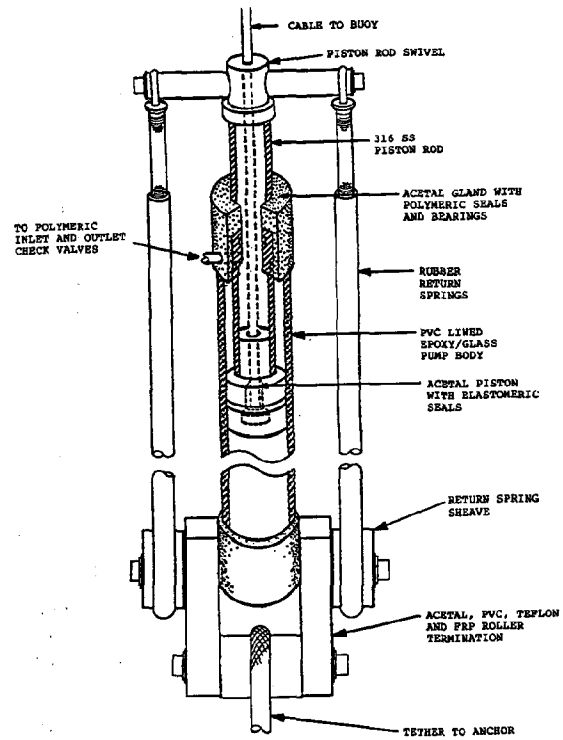

Figure 6. Schematic of the DELBUOY high pressure seawater pump.

be the most difficult component to engineer. For the sake of brevity it will be the only component described in detail (see Figure 6). The initial pump specifications were a long stroke (>2 m) to accommodate storm waves and tides, small piston area (13 cm^2) to amplify the wave induced pressures on the float to the 5500 kPa required for the RO process, and to operate for a period of one year (equivalent to 8 million cycles) without maintenance. The design process progressed slowly in an iterative fashion over a period of six years.

To evaluate the wear rates and frictional characteristics of the seawater lubricated pump seals and bearings, pin-on-disk tests were performed on a wide range of polymeric and metallic materials [8]. To generate data representative of an actual operating

pump, a seawater lubricated pin-on-disk test apparatus was developed for the test sequence. To date the system has logged over 5000 hrs. Of the numerous materials tested, the combinations of Torlon® (polyamide-imide) bearings and carboxylated nitrile seals running against 316 stainless steel (316 SS) and polyurethane seals on PVC where found to be the most satisfactory. Both were found to operate for hundreds of hours at the loads and speeds encountered in the DELBUOY pump with very low friction (<.05) and rates of wear (<.5 mm/year).

Several designs for the pump body were evaluated; including plastic coated/clad steel and aluminum, rigid PVC, and lined fiberglass/epoxy composites (FRP). Of these, the FRP was found to have the best combination strength-to-weight, rigidity, ease of fabrication, and corrosion resistance. The high strength and modulus of the glass fibers enabled the FRP to withstand the hoop-stress from the internal pressure, as well as the axial and buckling loads from the pumping and refill strokes. The plastic liner was installed to reduce the friction and wear rates of the piston seals. Although the two types tested, PVC and neat epoxy resin, were found to give comparable results the PVC proved to be easier to fabricate.

The operating conditions for the piston rod and pump body are comparable, however the smaller diameter of the rod required that the material of construction have a very high flexural modulus. With the exception of the more exotic composites, FRP was not sufficiently stiff to carry the buckling loads exerted by the return springs during the refill stroke. As a result, only metal and coated metal rods were considered. Several types of piston rods were tested; including steel and aluminum with either epoxy or PVC coatings, copper-nickel, and 316 SS. Of these, the 316 SS proved to be the lightest and least expensive.

For the piston head, gland and pump fittings, acetal was found to afford a better combination of cost, ease of fabrication, dimensional stability, and fatigue resistance than alternatives such as PVC, 316 SS, and FRP. Terminating the piston rod and pump to the float and anchor, respectively, proved to be more difficult than anticipated. After a series of sea trials, the most reliable technique was found to be to pass the cable completely through the piston rod to the back side of the piston head. This approach served to keep the entire rod assembly in compression and lessened the stress concentration and crack propagation experienced by tensile members. To eliminate twisting and kinking of the cable, a combination of torque-balanced cable and a swivel incorporated into the acetal piston rod cap were designed into the system. For the lower termination, a clevis roller was designed using PVC, acetal, teflon, FRP, and copper-nickel.

A similar design approach was employed to develop the other system components. In general, the use of polymeric materials for sealing, bearing and structural components has proven very successful. For the few metallic components used in the system, plastic jacketing and minimizing crevices in the design has eliminated corrosion problems.

SYSTEM PERFORMANCE

To confirm laboratory results and evaluate the performance of system components under actual operating conditions, a series of full-scale prototypes were tested. Over the past eight years nine prototypes have undergone sea trials off the southwest Puerto Rico. These trials have permitted the accumulation of several years of operating and wear data on the individual components which together form the present system. From this data set accurate predictions of both maintenance requirements and component lifetimes have been made.

The most recent trials of the first production design show that for the majority of the components the goal of maintenance-free operation for a period of one year has been achieved. Data allow us to predict with confidence a system working lifetime of the order of five years. Fresh water production figures collected during the last two trials indicate that the preferred six pump system will produce in excess of 1500 gpd in the design wave field. In addition, the system capture widths observed at sea have ranged from 0.1 to 0.2; this corresponds well with values predicted by the mathematical model.

ECONOMIC ANALYSIS

The amount of energy required to desalt a unit volume of seawater using the reverse osmotic process depends on the type of membrane used, the system size, and the amount of energy which is allowed to go to waste in the high pressure brine returned to the sea. For systems in the 2000 to 20000 gallon per day (gpd) range using spiral wound type RO membranes, the requirement is approximately 40 kwh/1000 gallons [9]. The energy is "free" in the DELBUOY system since all the power requirements are supplied by the wave driven pump. Therefore, 1000 gallons of fresh water from DELBUOY will always cost less than the same volume supplied by a conventional system by an amount equal to

at least 40 x (local power cost in kwh) given that other costs are comparable.

In Figure 7 a comparison has been made between water costs for the DELBUOY and conventional RO systems for a range of power costs representative of Caribbean Island communities and system sizes. As can be seen in the figure, DELBUOY is cost effective for small installations (< 8000 gpd) when the power costs exceed $.15(U.S.)/kwh. For larger systems the break even point is at $.20/kwh. In locations where conventional RO systems are driven by diesel the power costs will be 25% higher, making the DELBUOY system more economically attractive. Having purposely designed the DELBUOY to produce fresh water rather than electricity leads to major advantages in both transmission and storage, as well as the higher market value of an end use product (water) over an intermediary such as electricity. Other advantages of the DELBUOY system are its modular design and relatively small size. The number of units deployed can be adjusted to specific site requirements. Because the individual units are only 2.1 m in diameter, the fabrication and deployment costs are low, with no special techniques required. It should be noted that these advantages have enabled us to test nine full-scale prototypes at sea during the last eight years. Most other wave energy devices require large economies of scale to be cost effective. As a result, only a few groups such as the Norwegians [10] have constructed and tested full-scale systems. As a consequence most groups have yet to encounter the real-world limitations imposed on their technologies.

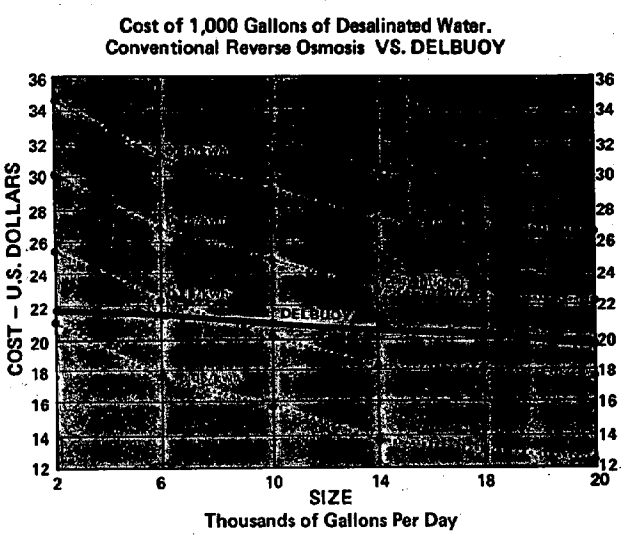

Figure 7. A cost comparison between DELBUOY and conventional electric reverse osmosis systems; conservative data for shipping, installation, and maintenance costs for Caribbean sites have been used.

The market potential for the DELBUOY is clear. Although the global need for potable water has become somewhat of a journalistic cliche, the world-wide shortage is well documented [11]. Based on conservative estimates, the market potential for desalinated drinking water exceeds 4.8 billion gpd. In the Caribbean alone, where 50% of the 32.4 million residents do not have a dependable supply of water [12], this equates to a potential market of >$ 2 billion per year.

CONCLUSIONS

Wave powered desalination can be achieved by means of a relatively simple buoy/pump/anchor system coupled to a standard reverse osmosis filter. By engineering the system from appropriate materials and component designs, the device is capable of operating with only annual maintenance for a period of up to five years. As a result, the device is now economically viable for use in areas such as the Caribbean.

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A WAVE ENERGY ENGINE AND PROPOSALS FOR ITS DEVELOPMENT AND USAGE

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ABSTRACT

The Engine is introduced and the scale model test briefly reviewed. Then, a proposal for building a prototype for test and evaluation is presented. Finally, a proposal, including an economic analysis thereof, is offered for a small power station in a remote coastal location.

INTRODUCTION

Present and future societies' survival, world economic cycles, nations' economies, third world development and world health are explicably linked to the supply of energy. As we use up our non-renewable sources of energy at ever increasing rates, the need for development of renewable sources becomes increasingly urgent. Now is the time and it is this society's task to find renewable sources of energy for use 50 years, 500 years, and 1,000 years from now.

Ocean wave energy is one renewable source of energy. Though generally dispersed, it exists in abundance, proximate to populations and/or applications where its capture costs are competitive with non-renewable sources at today's prices. This is an unfair comparison, of course, because the prices for oil, coal, gas, etc. include neither the costs for replacing them nor those for undoing the damage to the environment.

Like so many others, I find the sea both fascinating and inspiring. When given to thought of the waves' energy, I have often conceived ideas for the capture thereof and I usually pursued each to realization of conceptual or technical flaws. From its conception, I have known that the Engine that I shall introduce herein would work, and scale model tests along with other work to date bear this out. I am convinced that the Engine is significant, that it merits further tests and development, and that after such, could be economically competitive for providing power to those island nations, other nations, and remote marine facilities where wave energy abounds and fuel costs are high.

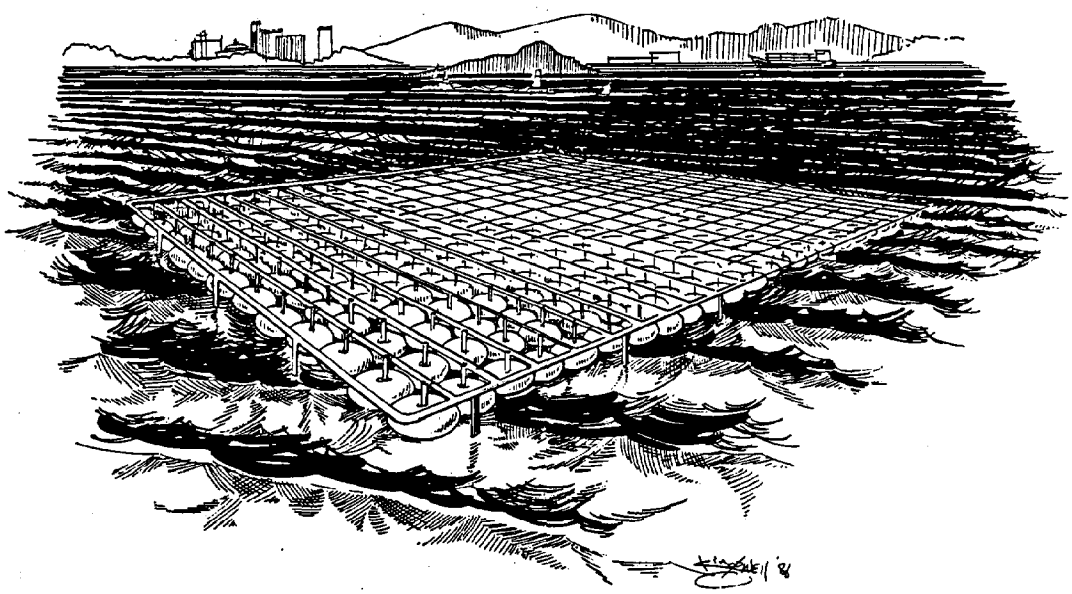


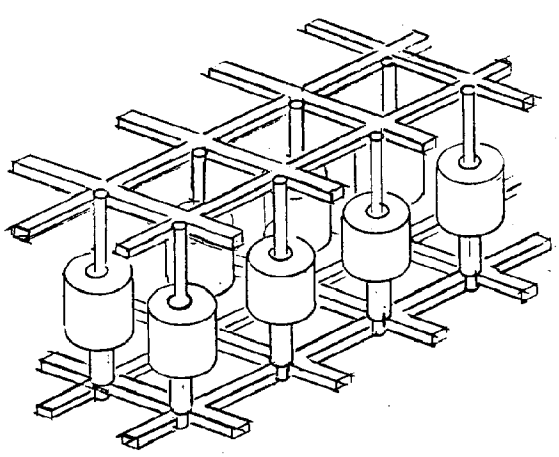
FIG 1

CH2585-8/88/0000-1055 $1 ©1988 IEEE

THE ENGINE

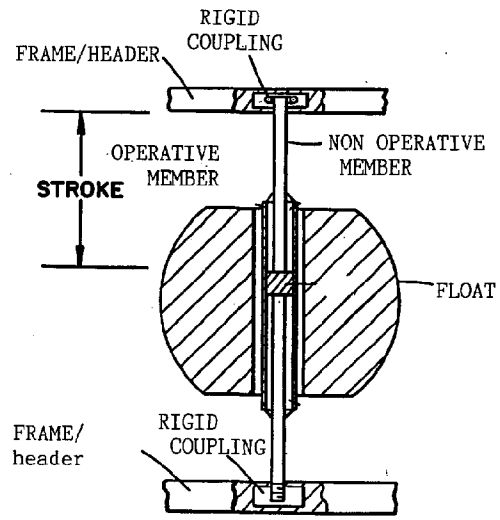
The need for a reference against which wave motion can do work occurs to anyone considering capturing ocean wave energy. An ideal reference would be unaffected by tides, wave direction and wave height. In the absence of such we usually seek to control the variables through siting and by optimization of design and construction. My Engine provides its own reference, can accept and extract wave energy from all directions, and is effective through a large range of wave heights and lengths.

The Engine floats. An array of flotation devices are each connected to an associated energy converter and these in turn are each connected to a common frame (see figures 1, 2, & 3). Wave action within the field of the array subjects individual floats to successively rising and falling water surface levels as referenced to the draft of the Engine. Thus, the buoyancy forces of approximately one-half the floats support the Engine. The Engine's draft is a function of the average wave height within the array. Likewise, the plane of the Engine, as defined by the frame, is a function of this average wave height and with a large array would be nearly parallel to the sea's level surface. The floats are attached to the operating member of their associated energy converter and transfer the forces of buoyancy thereto. The non-operative member of each energy converter is affixed to the common frame. The energy converters could be: pumps pumping air, water or other fluids for driving an electric generator; pumps supplying seawater to an RO Cell-based desalination system; or they could be of yet other forms for producing electricity more directly, reducing gases, etc. When operating close to shore the Engine doubles as a breakwater.



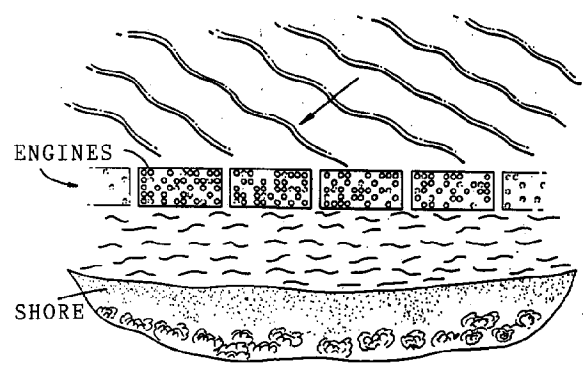
FRAME/CONVERTER SCHEME

FIG 2



FLOAT/ENERGY CONVERTER

FIG 3



SERIES OF UNITS AS A BREAKWATER

FIG 4

Almost any wave motion of whatever form within the area of the array causes motion of the floats and thus capture of wave energy. The Engine's operation is not affected by tides and a given Engine could be effective through a large range of wave heights and lengths. It can be constructed to accept and extract energy from waves from all directions. Other than as is required for mooring, its operation is not dependent on the shore or seabed, so it can operate in the open ocean.

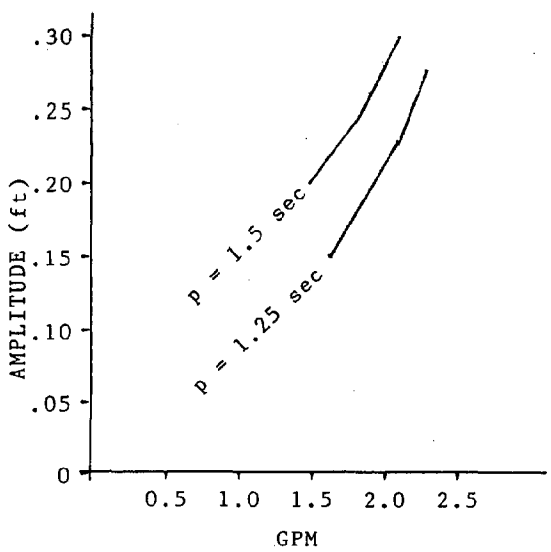
When the Engine is constructed as in figures 1, 2 & 3, individual float/energy converter units can be removed and replaced during operation and as required.

SCALE MODEL TEST

The scale model was meant as an approximation of a section of a full scale model to 1/8 scale. The overall dimensions are 72 inches long by 48 inches wide by 16 inches high. The frame of 3/4 inch copper tube also served as the suction and discharge headers. For energy converters, I used twelve 3/4 inch, double acting, double rod end cylinders valved as pumps. The fluid pumped was fresh water. The ellipsoidal floats are of closed cell foam having R = 4.5 inches and r = 1.5 inches. They were bored to receive and bonded to the cylinder walls.

Testing was at U.C. Berkeley's Naval Architecture Towing Basin. The prime objective was to establish functionality of the concept and of the scale model. The model was not instrumented to any extent. Pressure measurement was by test gauge and its control was by manual throttle valve. Flow measurement was by collection and using a stop watch.

We made a total of nineteen runs. The first seven were for the purpose of setup, i.e., rough trimming, coordination of test personnel's duties, and acquainting myself with the basin's operation. For runs No. 8 through 18, we observed and took measurements of the model's operation while experiencing waves having amplitudes from .15 feet to .30 feet with periods ranging from .8 second to 1.765 seconds. For these waves and with the pressure "controlled" at 1.5 psig, the range of outputs was 1.5 gpm to 2.3 gpm. The output's curves for 1.25 and 1.5 second period waves are shown below.



Herewith is a brief evaluation of the test results:

Output: As one would expect, output was directly proportional to wave amplitude and inversely so to period.

Stroke: At 2 gpm we were seeing some 20 inches of stroke and a model, which I shall introduce shortly, would predict as much as 21.6 inches of stroke. Therefore, stroke was 92% of expected.

Pressure: I attributed the low pressures to several factors. We needed some additional 25-30 pounds of ballast. The model needed to be longer. Better pressure control was needed. The valves, their reaction time, and the relative sizes of the cylinders, lines, etc. were factors. Also, the coupling between the valves and the cylinders was less than desirable. For run No. 19, we moved the model to a location nearer the wave generating apparatus and deliberately produced a choppy surface. Although no measurements were taken, the output was obviously higher than with the other runs. Here, of course, the effect of the model's length was less.

Now, for the mathematical model alluded to earlier.

Ideal output/converter = stroke x force/period
where: stroke = wave hgt - reset.

For the model:

Ideal Output = 1.35 in x 4.0 lb/1 sec
@ conv. = 5.4 in-lb/sec

x 16 conv. = 86.4 in-lb/sec
= 9.7 watts

(Measured output was 1.3 watts or 13% of ideal. Output pressure would ideally have been 11.25 psig.)

Extending this model to a full scale Engine with floats having 600 lbs net displacement each, on 1 meter centers and in a sea having waves 2 meters high with a 6 second period:

Ideal output = 60 in x 600 lb/6 sec
(per conv.) = 6000 in-lb/sec
= 680 watts

Such an Engine in these seas would remove 180 kw/km in the first row. An Engine ten rows deep with each succeeding row removing 80% would remove 3,035 kw/km.

PROPOSAL FOR A PROTOTYPE

There are, as I see it, two plausible ways of proceeding with the Engine's development. One is to do extensive scale model testing. The other is to design and build a full scale prototype. Both would involve developing and testing full scale float and energy converter components at dockside.

I am much a proponent of the prototype development. The concept works and I think that the efficiency problems could be solved by drawing on technology, mathematics and even invention. The questions of component and material suitability may not lend themselves well to

solution with scale model testing. Further, there is a question regarding the transferability of information and technology from scale model testing to a full scale unit operating at sea. Finally, beyond the question of return, I believe that funding sources would be more impressed by an at-sea demonstration with obvious output.

My proposed prototype would consist of a sectionable frame and energy converters. Fluid power output (without conversion to electrical) would be measured at this phase.

The frame is to be constructed in six connectible sections. Each section is to be 24 ft by 12 ft by 4 ft, to be constructed of 3 in by 3 in tubular steel serving doubly as suction and discharge headers and provide connections for eighteen energy converters on 4 ft centers.

There are to be seventy-two operative energy converters of test-proven design and thirty-two dummy converters for maintaining trim and for flexibility of configuration.

ESTIMATE OF COST:

I. Engineering & Development		
Salary & Expenses	$78,000	
Machine Shop	5,000	
Dockside Testing	5,000	
		$ 88,000
II. Fabrication & Assembly		
Frame	$75,000	
Energy Converters:		
72 @ $500	36,000	
32 @ $150	4,800	
		115,800
III. Sea Test		
Tugs:		
2 @ $700/hr x 48	33,000	
Dynamometer	5,000	
Video Recorder	2,000	
		40,600
Total:		$244,600

PROPOSAL FOR 1 MW POWER STATION WITH AN ECONOMIC ANALYSIS

The Engine would be 340 m x 20 m with 1,700 operative energy converters and be situated in an area with waves from 1 to 3 m high nine months of the year.

The size and configuration of an actual Engine would, of course, be factors of site choice and of the information gathered from prototype operation.

The format used for the economic analysis is based on an accounting method developed by the Federal Energy Regulatory Commission for comparing the costs of alternate energy sources with those of existing utilities.[1] I have rearranged it to what I believe to be a more easily understood form.

The final figures used for comparison, i.e., Capacity Cost, Fuel Cost and Energy Cost, come out the same.

The calculations are based upon energy converter float units of this description:

Distance between centers	=	2.00 m
Float diameter	=	1.80 m
Float height	=	.66 m
Cylinder length	=	2.30 m
Rod length	=	4.60 m
Net displacement	=	3,300 lbs
Operative member weight	=	260 lbs
Total converter weight	=	500 lbs

Regarding the average wave height and period and their effect on the "Plant Factor" used in the analysis, I want to specify site conditions as follows:

Waves/period	Days/year
3-5 m/6.6-8 sec	91
2-3 m/6-6.6 sec	91
1-2m/ 4-6 sec	91
<1 m/ <4 sec	92

The energy output profile of a column 10 rows deep for these waves listed using the model, output = stroke x force/period, would look like this:

First Quarter = [(90 in x 3300 lbs)/7.3 sec]/4m²

= 10,171 in-lbs/sec/m²

= 1.149 KW/m

Column Output/m = 10* x 1.149 KW/m

= 11.49 KW/m

Second Qtr = [(78 in x 3300 lbs)/6.3 sec]/4m²

= 1.154 KW/m

Column Output/m = 6.5* x 1.154 KW/m

= 7.50 KW/m

Third Quarter = [(40 in x 3300 lbs)/5.0 sec]/4m²

= .746 KW/m

Column Output/m = 3.35* x .746 KW/m

= 2.5 KW/m

Fourth Qtr = 0

* Energy absorbed per row varies with wave height.

[1] Economics of Wave Energy Conversions, Utilization of Ocean Waves--Wave to Energy Conversion, McCormick & Kim, Ed., ASCE, 1987.

Average output/col/m =

$$\frac{\text{1st Qtr + 2nd Qtr + 3rd Qtr + 4th Qtr}}{4}$$

$$= \frac{11.49 + 7.5 + 7.46 + 0}{4}$$

= 6.61 KW/col/m

with allowance for 10% failure =
.90 x 6.61 KW/col/m
= 5.949 KW/col/m

Number of columns for 1 MW = $\frac{1 \times 10^3 \text{ KW/MW}}{5.949 \text{ KW/col}}$

= 168.1

= 170

Therefore: Length = 340 m
Width = 20 m

Capacity Costs = Fixed Charges + Operating Costs

Fixed Charges = Investment x Capital Costs/Exp

Investment:

Frame	$2,400,000
Energy Converters:	
1700 @ $600	1,020,000
Turbine & Generator	500,000
Mooring	480,000
Cable	120,000
Cable Laying	100,000
	$4,620,000

Capital Costs/Expenses:

Cost of Money	10.50%
Depreciation	1.00
Insurance	.50
Taxes	2.50
	14.50%

Fixed Charges: $4,620,000 x .145 = $669,900

Operating Costs = Operation & Maintenance + Administration

Operation & Maintenance Costs:

Energy Converters:	
1700 @ $150	$255,000
Frame	120,000
Cable	12,000
Mooring	24,000
	$411,000

Administration
& General Expenses: $411,000 x .35 = $143,850

Operating Costs:

Oper & Main Costs	$411,000
Admin & Genl Exp	143,850
	$544,850

Capacity Costs:

Fixed Charges	$ 669,900
Operaring Costs	544,850
	$1,214,750

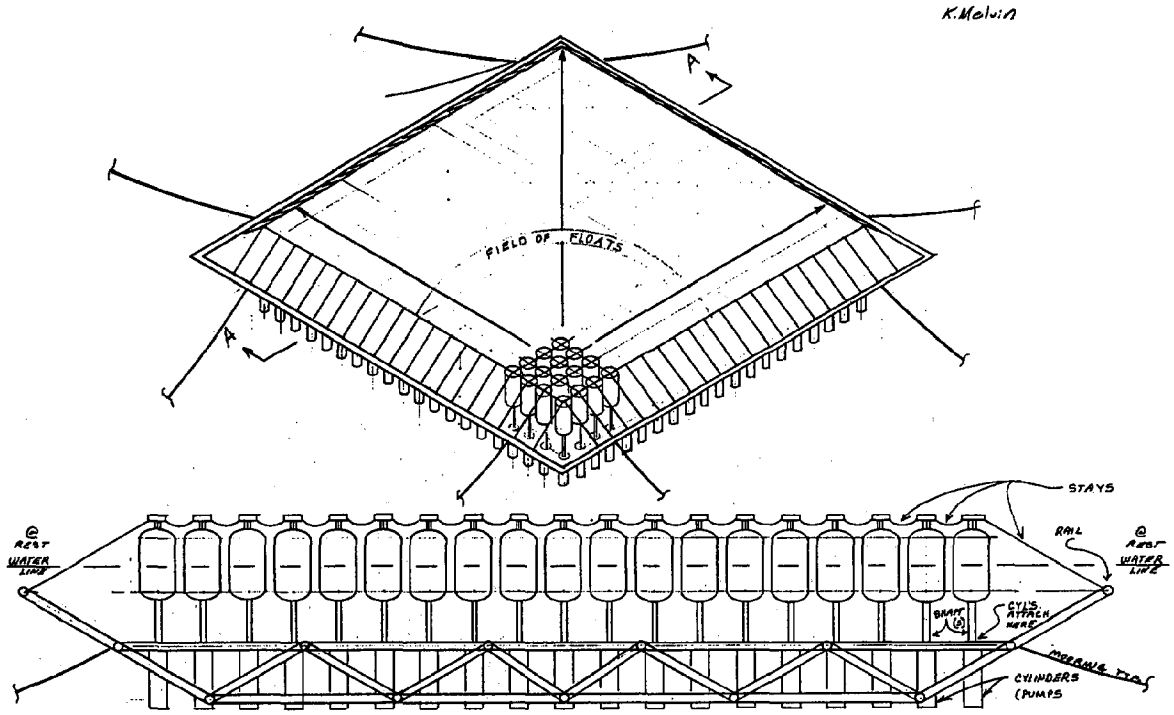
Capacity Costs/KW: $1,215

Capacity Costs/KW net: $1,215

Fuel Costs: $000

Energy Costs: $\frac{\$1,215/\text{KW}}{8760 \text{ hr/yr}}$ = 139 mills/KWh

Lo the might sea! Or, survivability of the Engine in storms. There are sites where storms are so furious, construction cost might prohibit consideration. Having said that, construction cost would and should be evaluated when seas don't approach such majestic levels of ferocity. I know of some things which could improve survivability under these extreme conditions. When a unit spans one or more wavelengths the mooring forces are reduced. The upwards shock, in the main, is absorbed in the energy converters (pumps), and the frame in aggregate can flex. The unit operates at overall neutral buoyancy, so ballast and trim tanks could be used to produce total or partial submersion during violent storms. Winching down of smaller units merits evaluation. Such approaches should be compared to "Hell for Stout" construction. The unit has a low profile (navigational marking is requisite) and its wind loading factor would be less than that of a comparable sized loaded barge.



ENGINE AS ORIGINALLY CONCEIVED

FIG 5

WAVE FOCUSING BY A SUBMERGED PLATE

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ABSTRACT

Some fundamental research results are presented for the wave focusing phenomenon by a submerged plate placed horizontally in a natural sea environment. Two types of horizontal plates, which are termed as a convex and a crescent ones in the present paper, are investigated both theoretically and experimentally. A Green Function Method using the Doublet Distribution is first explained based on the assumption of a thinness of the plates in order to interpret the wave pattern around the plates. Next, a simple, shape design method that can attain maximun efficiency in focusing waves is proposed based on the simple wave-ray theory. A shape of plate determined by the present design method (a crescent type of plate) is investigated experimentally on whether it indeed has a predicted capability of wave concentration or not. Succeedingly, how the change of incident wave angle influences the wave concentration phenomenon is briefly discussed.

INTRODUCTION

About 74% of the Japanese coastline faces the open sea or has bays opening out to it. The utilization of those coastlines is restricted due to high waves, drifting sand and the strong diffusion phenomenon, all of which cause coastal erosion.

The utilization of these areas serves to greatly improve our marine productivity and technologies to control the high waves, to use its energy efficiently, and to construct inexpensive, safe marine control structures are required.

Japan Marine Science and Technology Center(JAMSTEC) is engaged in the R&D of wave control technology by installing underwater structures through which wave energy can be concentrated and absorbed to economically create wide, calm ocean areas.

JAMSTEC is also engaged in the R&D of construction technology for marine control structures using electric current generated from this wave power and the resulting electrodeposit [1] .

A horizontally submerged thin plate is conceived as a new type of structure for controlling the natural wave field. The plate is assumed to be located at a certain depth from sea surface in deep water. Its shape is defined similarity to the cross section of an optical focusing lens(Fig.1).

This paper concerns with hydraulic model experiments on wave focusing phenomenon by the submerged thin plate. The comparison between experment and theoretical calculation is shown.

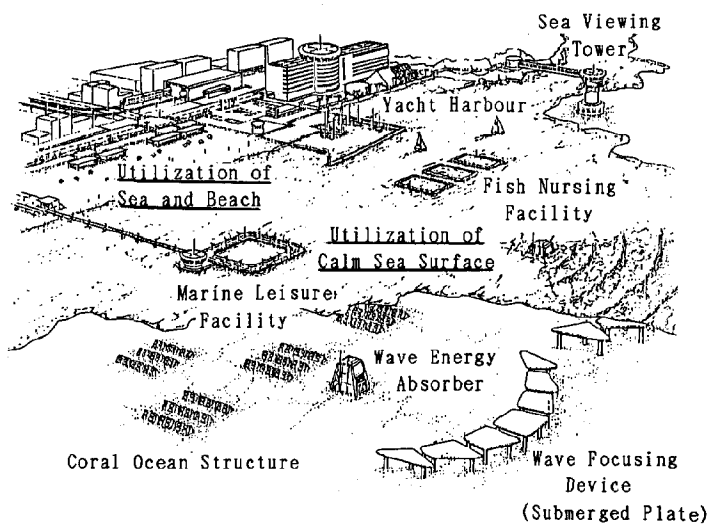

Fig.1. Conceptual drawing of marine control

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ANALYSIS

Prior to explaining the design procedure on the shape of plate, a general analysis method is herein introduced to clarify the wave focusing phenomenon. By assuming that the thickness of plate is infinitely thin, the Doublet Distribution Method [2] is introduced.

A set of governing equations can be written for the present problem defined in Fig. 2 [3]

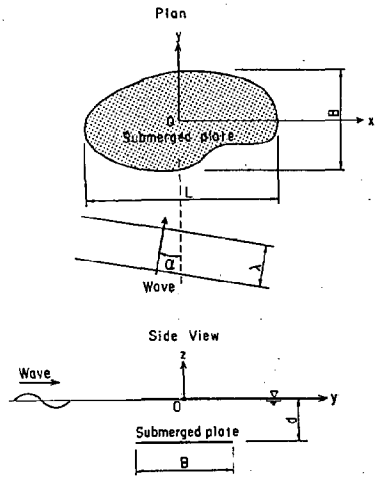

Fig. 2. Theoretical Model and Coordinate system

$$\nabla^2\phi_d=0 \qquad (\text{in } \Omega) \qquad (1)$$

$$\partial\phi_d/\partial z-K\phi_d=0 \qquad (\text{on } \Gamma_t) \qquad (2)$$

$$\partial\phi_d/\partial z\to 0 \qquad (\text{as } z\to-\infty) \qquad (3)$$

$$\sqrt{R}(\partial\phi_d/\partial R+iK\phi_d)\to 0 \qquad (\text{as } R\to\infty) \qquad (4)$$

$$\partial\phi_d/\partial z=-\partial\phi_w/\partial z \qquad (\text{on } \Gamma_s) \qquad (5)$$

$$(R=\sqrt{x^2+y^2})$$

where all notations appeared in the equations (1) to (5) are defined as follows.

ϕ_d = diffracted wave potential
k = wave number
$R = \sqrt{x^2 + y^2}$
i = imaginary unit
ϕ_w = incident wave potential
Ω = fluid domain
Γ_t = sea surface
Γ_s = surface of a submerged plate

The unknown diffracted wave potential is assumed to be expressed as the following integral form.

$$\phi_d(P)=\iint_S \delta(Q)G(P;Q)dS_Q \qquad (6)$$

where

δ (P) = unknown strength of doublet
G(P, Q) = Green function (doublet)
dS_Q = surface element of the plate

By substituting the expression (6) into one of the boundary conditions (5), a following integral equation can be obtained.

$$\iint_S \delta(Q)\left(-\frac{\partial}{\partial z}G(P;Q)\right)dS_Q=-\frac{\partial}{\partial z}\phi_w(P)$$

The Green function which appears in eq. (6) must satisfy the remaining relations from (1) to (4) and thus can be written by

$$\begin{aligned} G(x,y,z;x',y',z') &= -\frac{z-z'}{4\pi r^3}-\frac{K}{2\pi r_1}+\frac{z+z'}{4\pi r_1^3} \\ &+\frac{1}{4}K^2e^{K(z+z')}\Big\{H_0(KR)+Y_0(KR) \\ &+\int_0^{K|z+z'|}\frac{e^v}{\sqrt{v^2+(KR)^2}}dv\Big\} \\ &+i\frac{1}{2}K^2e^{K(z+z')}J_0(KR) \end{aligned} \qquad (8)$$

where

(x, y, z) = coordinate of P point (outside of the plate)
(x', y', z') = coordinate of Q point (on the plate)

R = distance between points P and Q

$$R=\sqrt{(x-x')^2+(y-y')^2}$$
$$r=\sqrt{(x-x')^2+(y-y')^2+(z-z')^2}$$
$$r_1=\sqrt{(x-x')^2+(y-y')^2+(z+z')^2}$$

In addition, the functions J_0, Y_0 and H_0 in eq. (8) are the Bessel Functions of its first and second kinds and the Sturve Function, respectively. In order to solve the integral equation (7) for the unknown strength δ (Q), a conventional collocation method, i.e., division of model plane into many small segments and evaluation of the unknown source strength at the centroid of the segment, is employed. Note that in the evalucation of the Green function and its first derivative, when P = Q, a usual singularity problem occurs so that a special measure has to be taken to avoid the singularity problem. See ref. [4] for the detailed discussion. In any event, since the unknown strength of the doublet can be determind by solving the simultaneous equations resulting from eq. (7) after descretization, the diffracted wave potential can be recovered from the descretized form to eq. (6). It is now all obvious that all the necessary physical quantities like wave height distribution and/or pressure distribution can be obtained by using suitable expressions for them that are related to the total potential of the wave, i.e., $\phi=\phi_d+\phi_w$.

Note that all the numerical results obtained from the afore-mentioned procedure have been on the following assumptions:

(a) wave amplitudes are small
(b) water depth is infinite and
(c) plate thickness can be disregarded.

The validity of all these assumption should be acertained

through comparing the numerical results with the actual phenomenon. This would be done in later section.

A DESIGN PROCEDURE

In this section, a design procedure for the shape of plate to concentrate waves will be discussed. Of course, a trial and error design method to determine a final and near optimal shape of plate would be possible by using rigorous analysis method such as described in the previous section. However, such trial-and-error method is generally quite inconvenient, so that a simple method is herein proposed based on the wave refraction theory (wave-ray theory) [5] .

According to the theory, the wave rays are deflected twice, i.e. at the front and rear edges of plate. When the wave ray is deflected at the rear edge, it is observed that there arises some refracted waves at the edge and disturbs the wave field behind. Therefore, a plate design problem is herein simplified as follows.

(a) The rear edge of plate is assumed circular. This assumption has been considered not to cause the unnecessary refracted waves at the edge. In other words, a wave once deflected at the front edge is allowed to pass the rear edge without any alteration on wave direction.

(b) Based on the assumption in (a), determine the shape of the front edge so as to focus the wave energy at a remote and predetermined focal point once all of the incident wave conditions are givin (see Fig. 3).

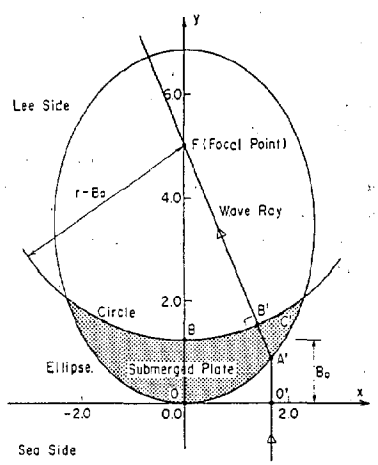

Fig. 3. Shape determination by the wave refraction theory

First of all, let us assume the rear edge curve as follows.

$$x^2 + (y-r)^2 = (r-B_0)^2 \qquad (9)$$

This expression is an analytical form for a circle with its center (o, r) and its radius $r-B_0$ with respect to the coordinate system shown in Fig. 3. In eq. (9), the notations r and B_0 are the distances from the coordinate origin to the focal point and the width of plate along y coordinate respectively.

Now, in order to determine the front curve of the plate, let us consider the required time for a representative wave ray to reach the focal point. Select two representative wave rays passing the points O', A', B', and F in Fig. 3. and O, B, F in the same figure. Both wave rays must have the same interval of time to reach the focal point at the same time. This condition can be written by the following expression.

$$\frac{\overline{O'A'}}{c_0}+\frac{\overline{A'B'}}{c}+\frac{\overline{B'F}}{c_0}=\frac{B_0}{c}+\frac{r-B_0}{c_0}=\text{Const.} \qquad (10)$$

where C_0 and C are respectively wave velocities in water and on the plate. By substituting the relation $B'F = r - B_0$ into eq. (12), it can be simplified to

$$\frac{\overline{O'A'}}{c_0}+\frac{\overline{A'F}}{c}=\frac{r}{c}=\text{Const.} \qquad (11)$$

This condition must hold for an arbitrary point A to be a general point on the front curve of plate. The equation (11) gives the following general solution.

$$\frac{x^2}{\{r\sqrt{(c_0-c)/(c_0+c)}\}^2}+\frac{\{y-rc_0/(c_0+c)\}^2}{\{rc_0/(c_0+c)\}^2}=1 \qquad (12)$$

Note that the final expression (12) represents the elliptical curve with its one of the centroid at the specified focal point (0, r). It is now theoretically concluded that in order to concentrate wave rays at a focal point, the front and rear edge shapes of plate must be elliptical and circular respectively. The obtained shape is quite similar to the one of crescent moon so that it is called as a crescent plate in the present investigation. As shown in this section, a simple and analytic design formula has been obtained for the shape of submerged plate. However, note that the derivation is primarily based on the assumption that the influence of the diffracted waves can be neglected in concentrating wave rays. This of course should be verified through performing laboratory tests.

EXPERIMENTS AND NUMERICAL ANALYSIS

In order to confirm the afore-mentioned analysis and design procedure, some hydraulic tests were performed in a large wave tank (length 60m, width 20m and depth 1.5m) in Kajima Institute of Construction Technology. Two types of representative plates were selected as test models. One is a convex type and the other is a crescent type (see Figs. 4 and 5).

In Figs. 4 and 5, the mesh layouts for the present numerical collocation method are dipicted together with the model dimension. The design conditions for the crescent plate is summerized in Table 1 and the coordinate systems to interpret the experimental results are shown in Fig. 6.

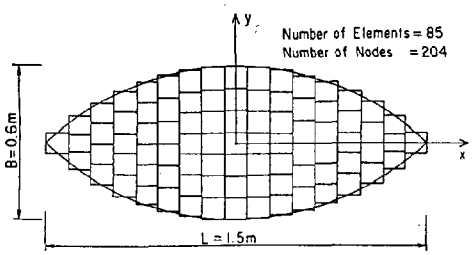

Fig. 4. Dimension and mesh layout for the submerged convex-shaped plate

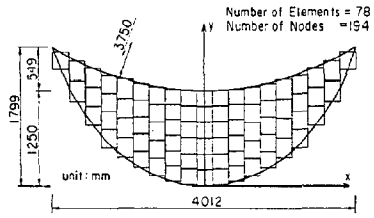

Fig. 5. Dimension and mesh layout for the crescent-shaped plate

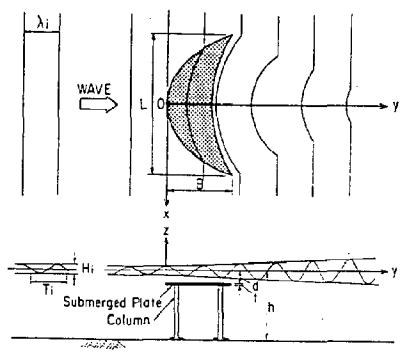

Fig. 6. Coordinate system and notation

Table 1 Design conditions for the crescent shaped submerged plate

Wave period	Ti (sec)	1.2
Wave length	λi (m)	2.23
Submerged water depth	d (m)	0.2
Water depth	h (m)	1.0
Width of Submerged plate	Bo (m)	1.25
Focal length	r (m)	5.0

All experments were performed by changing a submerged depth of plate and the conditions are summerized in Table 2.

Table 2 Experimental and computational conditions

Case	Submerged water depth d (m)	Wave period Ti (sec)	Wave height Hi (m)	Incident angle λ (degree)	B/λi
1	0.2	1.0	5.0	0	0.801
2	0.2	1.2	5.0	0	0.561
3	0.2	1.4	5.0	0	0.421
4	0.2	1.2	3.0	0	0.561
5	0.2	1.2	7.0	0	0.561
6	0.2	1.2	5.0	180	0.561
7	0.2	1.2	5.0	10	0.561
8	0.2	1.2	5.0	20	0.561
9	0.15	1.2	5.0	0	0.561

Since all experimental results can not be presented in the present paper, only a few representative cases will be shown.

The photo 1 demonstrates a typical wave focusing phenomenon when a convex-shaped plate is considered. Waves come from the upper part of the picture and concentrate on the middle of plate, breaking near the rear edge of plate. On the other hand, the photo 2 shows the wave focusing phenomenon by the crescent-shaped plate.

photo 1 Photograph demonstrating wave breaking phenomena
(a submerged convex-shaped plate)

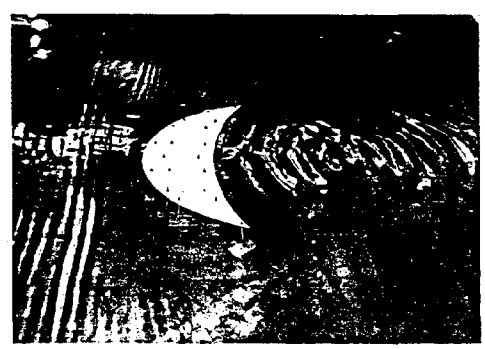

photo 2 Photograghs demonstrating wave focusing phenomenon
(a submerged crescent-shaped plate)

In this case, a clear focal point can be identified as the original design procedure has been intended. Wave height distributions were measured for both shaped and were compared with the corresponding theoretical values predicted by the Doublet source method explained in the previous section. Fig.7 is for the convex shape case and Fig.8 for the crescent plate case. In both cases, qualitatively speaking, the present analysis method can predict pretty well the wave height distribution on and around the plate, regardless of the extremely simplified assumptions involved in the present numerical procedure. In the crescent plate case (Fig.8), note that the incident wave height is amplified about 2.8 times at a specified focal zone. In any event, it would be quite obvious that the proposed simple design procedure for the submarged plate, is reasonable in a sense that it can really concentrate waves.

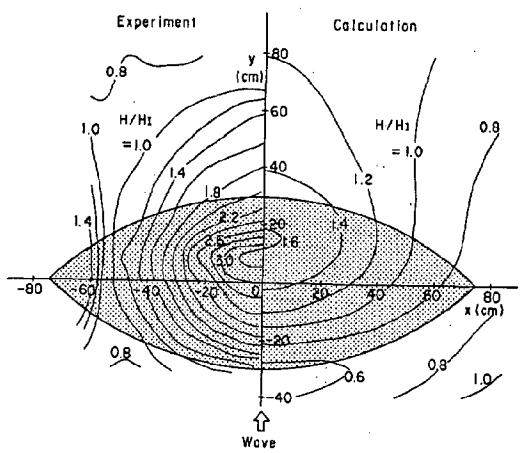

Fig.7. Wave height distribution around a submerged convex-shaped plate (T = 1.2sec, d = 0.1m)

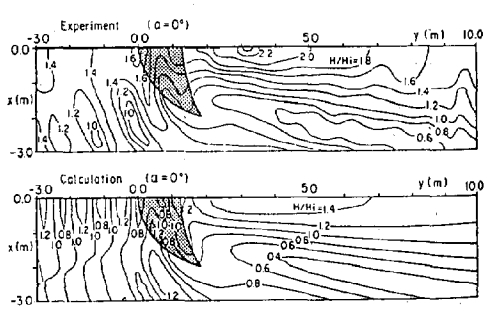

Fig.8. Wave height distribution around a submerged crescent-shaped plate (T = 1.2sec, d = 0.2m, α = 0.0°)

In Fig.9, the case in which the incident wave direction has an angle of attack 20° is shown together with the corresponding theoretical prediction. This case was investigated on whether the capabillity of wave focusing still exists or not when wave direction is varied. In this case too, a distinctive focal zone can still be identified, although its position is somewhat displaced from the center line of the plate (compara the results in Fig.8).

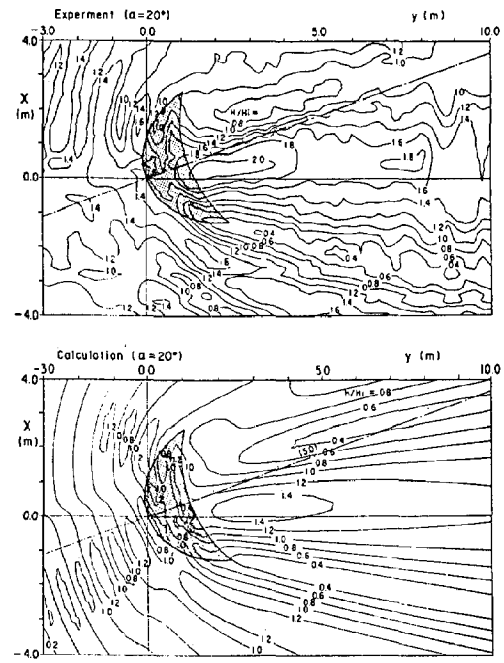

Fig.9. Wave height distribution around a submerged crescent-shaped plate for various incident wave angle (T = 1.2sec, α = 20.0°)

A detailed design procedure for the crescent submerged plate is now under investigation, too. A design example is shown in Fig.10 It consists of six indipendent precast concrete plate members and is supported with many piles. The construction method is also studied now, and we are hoping to actually construct it at some coastal place in Japan to further verify its function in site.

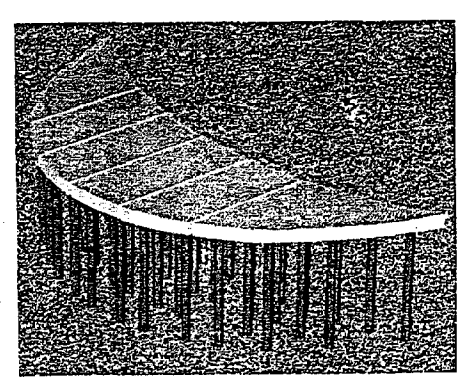

Fig.10. A design example for the submerged plate

CONCLUSION

In the present investigation, a namerical and a design procedures have been proposed to understand the wave focusing phenomenon and to determine an appropriate shape of plate suitable for wave concentration. Both procedures have been verified through performing some hydraulic experiments with large scales. As the result, the following conclusions were obtained.

(1) The two proposed shapes of submerged plate are proved to have a capability of controlling waves. Particularly they possess a capability of wave concentration.

(2) A convex-shape plate can concentrate waves on the rear edge of plate. However, it is found that this type of plate always accompanies the wave breaking phenomenon.

(3) A crescent-shape plate designed by the proposed procedure can concentrate waves at the specified focal point without any wave breaking. The incident wave height is increased 2.8 times at a focal point, when all design conditions are satisfied.

(4) The present numerical procedure to analyze the wave focusing phenomenon can pretty well predict the wave height distribution around the plate. However, when the incident wave period becomes large, there arises some wave non-linearity such as wave breaking. If this happenes, the numerical procedure can give only a poor prediction.

Our research efforts still continue to (a) measuring wave pressure distribution on the plate and (b) developing some efficient energy absorption devisce placed at the focal zone to extract wave energy with maximum efficiency.

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The Backward Bent Duct Buoy - an Improved Floating Type Wave Power Device

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Abstract

For the past 20 years,or so, the wave power electric generator has been used in the navigation tail-tube buoy; however,application of the generator to the other buoy shapes was restricted because of difficulty in fitting an air chamber in the buoy.
The Backward Bent Duct Buoy (BBDB) configuration solved this problem. Furthermore,the design has significantly increased the wave power conversion efficiency over the tail-tube buoy.
The BBDB is applicable to navigation aids (including light buoys,lightships), telemetering buoys, military warning buoys, and other utility buoys. It can also be used as offshore station-keeping buoys,with or without moorings. By up-scaling the BBDB, floating wave power gene -rators are created that can supply power to both island and coastal communities. The energy costs of such systems is estimated to be about 38 yen/KWh for islands in the subtropic zone and about 15 yen/KWh in high wave power zone such as the coastal waters of the United Kingdom, Ireland and western Australa.

1. Introduction.

A small wave power generator for navigation aids was developed as a result of a study undert -aken between 1964 and 1965. In fact, 700 of these wave energy generators have been used in Japan, while 500 have been sold to the other countries including 20 in the United States.
Experiences with these turbines have given conf -dence for both a long life of the wave power generators and a possible up-scaling of air turbine for other application.
"KAIMEI" was constructed in 1976 by the Japan Marine Science Technology Center (JAMSTEC), and its test was conducted as an international project by International Energy Agency (IEA).
The KAIMEI is a ship-shaped " attenuator" (a system aligned to the wave direction.)
For ship-type attenuator, matching of ship length and wave length is required.
The hull of KAIMEI is 80 m in length,12 m in breadth and 5.5 m in height (dry) and displaces approximatly 820 Long tons. There are 13 air chambers and 4 buoyancy rooms on the hull, the chambers having a total water -plane area of 50 m^2. Four different kinds of air turbine were tested on KAIMEI.These were impulse turbines supplied by Japan and the UK, the McCormick counter-rotating turbine supplied by the United States and Wells turbine supplied by Japan.
The KAIMEI was tested in the sea of Japan near Yura. Yura is located on the coast on the northern part of the sea of Japan. The sea is quite calm in the summer, but strong west or northwest winds are present in the winter.
The system was moored in 40 m of water.
The moorings consisted of 4 chains at the bow and 1 slack chain at the stern. This mooring configuration allowed KAIMEI to adjust to changes in wave and wind directions. In addition, a soft power cable line was connected to land through underwater cable.

The KAIMEI project extended approximatly ten years from the time of construction to the end of the sea test. The hull was found to be in excellent condition after the ten year study. Thinning of the hull plating was small except for some pinhole corrosion. The moorings and power cable to shore all remained intact. The turbines and generators experienced only minor problems. From these facts, it was concluded that a floating-type wave power device is feasible, but conversion efficiency from wave to air output of KAIMEI was not good.
Hence, a new wave power device is now proposed as a floating type wave power power system.

2. The Backward Bent Duct Buoy (BBDB).

(a) Background of BBDB.

For a small air turbine system, such as a navigat -ional buoy, the shape of the float is limited by the center pipe as illustrated in Fig 1.
The center pipe buoy has good stability in waves, as any spar-type buoy does, but it does not have good stability in high currents.
The other buoy shapes, such as catamarans and disks,are not compatible with air turbine generator since there is no room for air chamber in buoys with these shapes.

The Backward Bent Duct Buoy (BBDB), sketched in Fig 2, is an air chamber bent backward from the wave direction.

Frontward facing ducts were first studied with no plans to test a backward facing duct. Since there is no vertical center-pipe the duct can be deployed

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in waters of any depth greater than the draft of the host buoy. In addition, the duct opening does not face any currents since the buoy " keeps course" because of its design. This means that, comparatively speaking, the BBDB has a low-drag design. The application of all types of air turbine turbines to BBDB is possible. The result of BBDB tests in a water tank are now presented.

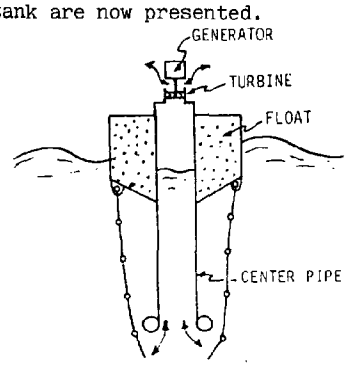

Fig 1 Center pipe wave power buoy.

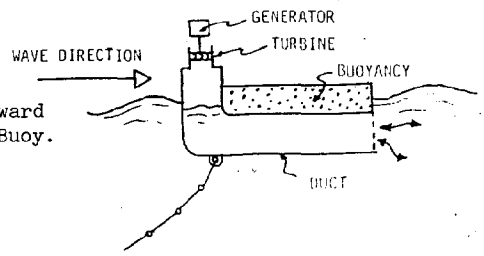

Fig 2 Backward Bent Duct Buoy.

(b) Water Tank Tests.

Wave tank tests of BBDB were conducted in Japan and Ireland. We shall discuss the Japanese study only. In Fig 3, a photograph of three models is presented.

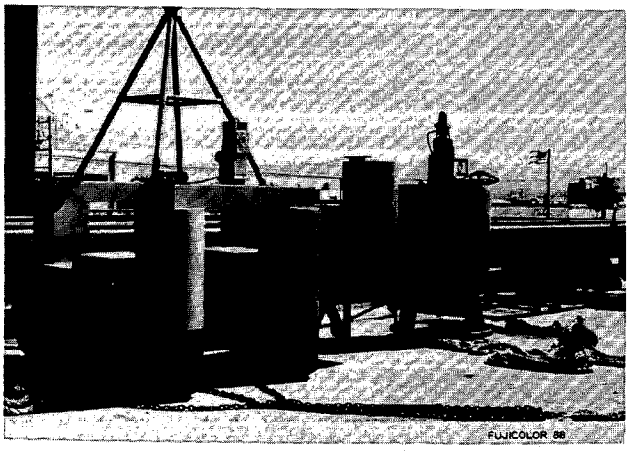

Fig 3 Water tank models of three kinds.

Refering to Figure 3, the buoy on the left ia a twin-hull BBDB which is 2412 mm in length and 1990 mm in width. The middle buoy is a single-hull BBDB which is 2422 mm and 600 mm in width, and the buoy on the right is a short tail-tube buoy with under water plate.

These models were tested in a water tank of the Japan Ship Research Institute. We will discuss the test result of the twin -hull BBDB in this report.

In the pipe-type model, we tested both a single-hull and twin-hull . Naturaly, there are differences in the performances of BBDB and front facing duct due to orientation.

When the opening of the horizontal duct is facing backward, maximum air pressure ratios of about 0.5 (for box-type) and 0.6 (for pipe -type) are obtained. The nozzle throttle ratio for these tests was 1/100. The pressure ratio for front facing duct was only 0.25 maximum. The pressure ratio KAIMEI was only in the range of 0.1 to 0.3, and the air pressure ratio range for center-pipe navigational buoy was about 0.3. BBDB can be expected to have much greater output than the center-pipe buoy or KAIMEI.

The result in Fig 4 shows conversion efficiency from wave power to air output.
The wave power is power in pipe's width (1.2 m in this case).

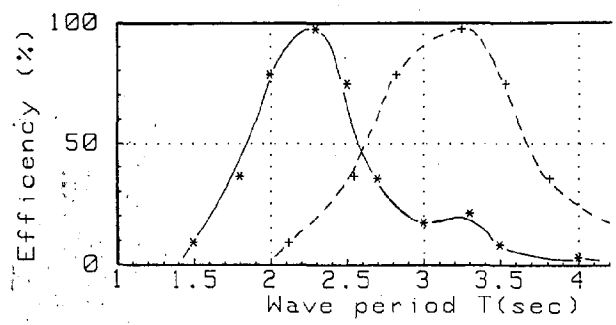

Fig 4 Conversion efficiency of the twin-hull BBDB model in the water tank test.

The solid line in Fig4 shows is for 2.4 m long twin -hull BBDB, and the peak efficiency is about 100 % at 2.3 seconds.

Furthermore, it can be used in short period waves of from 1.5 seconds - 3.5 seconds, but it cannot be used in waves of high periods. Hence, it is necessary to scale up in order to use the BBDB in higher period waves.
The dotted line in Fig 4 shows results of up-scaling by a factor of 2 (4.8 m in length and 4 m in width which is showen in Fig9).

In addition, the water tank test indicated a smaller drag force against current and wave.
If the BBDB is adopted for wave power conversion, we can expect not only a good conversion efficiency but also a significantly smaller mooring force.

3. The Sea Test.

We used two buoys for the first at-sea test :
The first model was a single hull BBDB with an out-rigger and with no underwater weight.

The second model was a twin hull BBDB of 2412 mm length,1990 mm width, and the distance between the two horizontal pipe ducts was 900 mm.
Both buoys were moored in 20 m of water by 3 small anchors for each. The deployment was on 20 April 1987.
Two days after, both BBDB were overturned by high waves(Max-6.5 m) due to a shortage of stability.
The reason for overturning was that the center of gravity of the buoy was higher than the center of floatation. Additional stability of buoys was then supplied by outriggers for the single hull and by increasing the width of two-floats for the twin-hulls.
After both buoys were recovered, they were reconstructed to change stability by adding weight to the lower position of the buoy in order to make the center of gravity below the center of floatation.
Sea test started again on 21 May 1987 and continued until 17 September 1987. During these 4 months of sea tests, the two BBDB systems opearated as navigational light buoys for a stationary net of the salmon fishery. The twin-hull BBDB of 2.4 m length is showen on site in Fig.5.

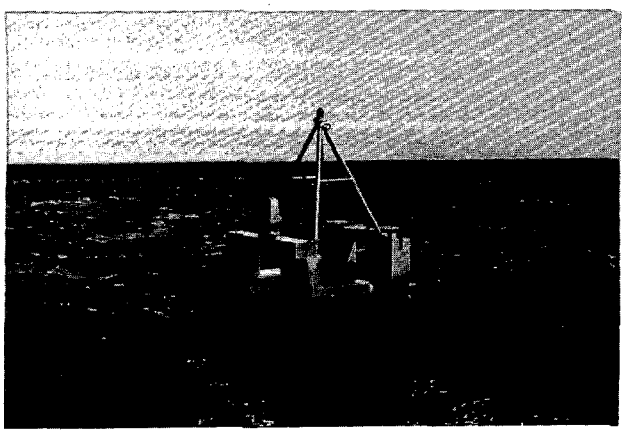

Fig.5. Twin-hull BBDB is opearating on sea.

At the beginning of September, a typhoon passed the test site and a maximum wave height of 9 m was recorded. There were no problems due to these high waves, and , the system endured high current (3 Knot max),However. One problem was encountered during test, wave period of the test site.
Since the test site, Yura, is located in an open sea area, wave period was longer than the expected wave period. In Yura test, wave properties were measured using an Ultrasonic type wave probe by another organization. The electric output of the BBDB was measured by an electric amp-meter on the buoy and was checked in intervals of several days. For one example, a typical small wave of 0.6 m height and 4.5 second period caused the twin hull BBDB to produce 2.5 amp-hours per day and 1.3 Watt.

High electric output of BBDB in short wave periods (2-3 seconds) was obtained during the first tests.

These tests,however, did not give us confidence for continued high output of the BBDB; therefore, a second sea test on an island sea was planned.
The test site selected is near Tahara-chou of Mikawa-Bay, located on the Pacific side of Japan and near Nagoya, sketched in Fig.6.

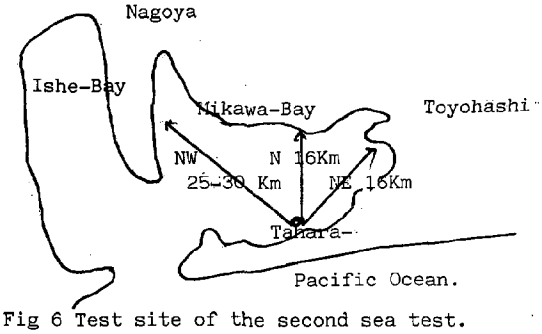

Fig 6 Test site of the second sea test.

The fetch for this test site is about 25 Km to the northwest and about 16 Km to the north and northeast.
The resulting wave period was expected to be from 2.3 second to 3 seconds, a range most suitable for a BBDB of 2.4 m in length. Two buoy types were tested: The first buoy is a twin-hull BBDB which is showen in Fig.5. The second buoy is a short-length center -pipe buoy with an under water plate. Both buoys for heaving control were moored on 10 March 1988, and tests started on 12 March 1988. 4 months of data were obtained.

During this sea test, we found that we missunderstood the reason for the small electric output. That is, it was not due to the mis-matching of wave period, but was due to the miss-selection of air turbine.
In the 4 months test, period of the first sea test and for half of a month of the second sea test, a Savonius turbine generator was on the twin -hull BBDB Buoy. Since the Savonius turbine is one of the simplest non-valve turbine which rotates in the same direction by alternative air flow, it was adopted for our BBDB test.
Unfortunatly, the capacity of the turbine was poor, so it was replaced by a mono-valve impulse turbine for the last half-month of the second sea test.
The electric output increased by about a factor of 3 by this replacement, and reached our expected level. The second sea test finished at begining of July,1988. We now discuss one example of test data.

4. Measured Values.

The electric output was measured by an amp-hour meter on the buoy. It recorded 20.4 amp-hours for about 2 days. There was no wave meter during the second test, so we got wind data from the meteorogical observatory near the test site. The wave data was calculated from wind data from a local meteorological observatory by the Darbyshire method. Table 1 contains the significant wave height $H_{1/3}$. Significant wave period, $T_{1/3}$, and wave power per meter (Watt/m) determined by the wind speed.

Table 1. Estimation of wave by wind speed on the test site.

Wind speed	Fetch 16 Km		
	$H_{1/3}$	$T_{1/3}$	Wave power
5 m/s	0.115 m	2.25s	15.7 W/m
6 m/s	0.17	2.47	35.6
8 m/s	0.301	2.85	129.1
10 m/s	0.471	3.18	354
Wind speed	**Fetch 30 Km**		
	$H_{1/3}$	$T_{1/3}$	Wave power
5 m/s	0.17 m	3.26 s	47.1 W/m
6 m/s	0.245	3.57	107
8 m/s	0.436	4.12	391
10 m/s	0.681	4.62	1066

Since wind waves are random, we must assume a power spectrum. If the wave heights and wave length follow a Rayleigh distribution, then the wave power distribution is showen in Fig.7.

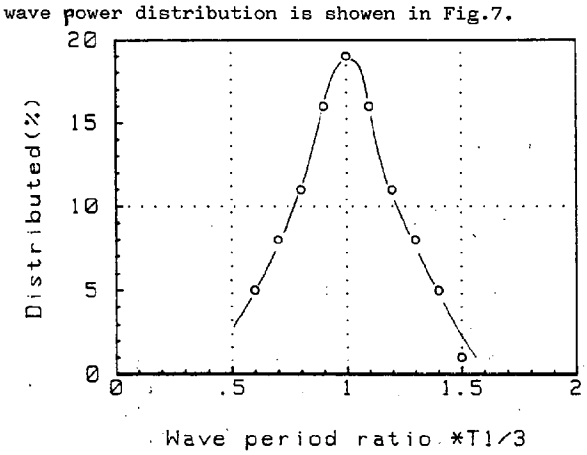

Fig.7.Assumption of wave power percent by wave period ratio (in each 0.1 x $T_{1/3}$)

The air output from the 2.4 m BBDB is presented in Table 2 for 16 Km fetch and a wind speed of 6m/s.

Table 2. One example of calculation in Fetch 16 Km and 6 m/s of wind.

x $T_{1/3}$	T	Power %	Conversion efficiency	converted percent
1.5	3.7sec	1%	0.05	0 %
1.4	3.43	5	0.1	0.5 %
1.3	3.19	8	0.2	1.6
1.2	2.94	11	0.2	2.2
1.1	2.7	16	0.34	5.4
1.0	2.45	19	0.8	15.2
0.9	2.2	16	0.95	15.2
0.8	1.96	11	0.75	8.3
0.7	1.71	8	0.3	2.4
0.6	1.47	5	0.08	0.4
			Total converted percent	51.2%

The wave power per meter is 35.6 Watts/m.

The buoy which is 1.2 m and the conversion efficiency from wave to air is 0.512 as calculated in table 2. The conversion efficiency from air to electric power is assumed to be 0.24 (turbine 0.6, electric generator 0.4) and the generated power is 5.2 Watts.

Repeating the same calculation using fetch and wind speed, we obtain an electric power showen in Fig.8 for 2.4 m BBDB.

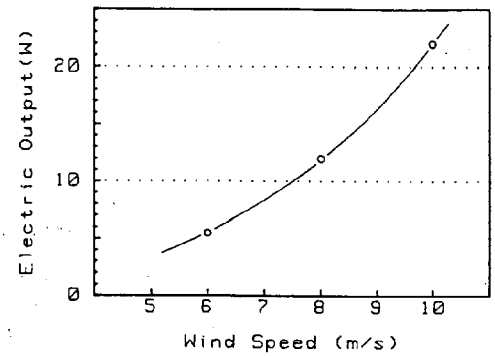

Fig.8. Electric output by wind speed of 2.4 m twin-hull BBDB on Mikawa-Bay.

Using this output curve and wind speed data during each hour, the converted electric output was calculated to be 220 Watt-hours (18.4 amp-hours,12V) for about 2 days. The measured output was 20.4 amp-hours which is 10 % higher than the calculated output. Therefore, we conclude that the output of BBDB can be calculated by this method.

Throughout these sea tests, we gained confidence to the high-power output of BBDB when a proper electric generator is coupled with a turbine. In addition, we changed our opinion about the effect of fetch. The BBDB was found to opearate in seas of any fetch, and in random waves.

5. Various uses of BBDB.

(a) Navigation aids.

Buoys used for navigation aids require power outputs from 5 watts to 40 watts. A wave power range of 50-100 watts is required for 5-10 watts demand. We are testing a twin-hull BBDB of 2.4 m length for this application.

This 2.4 m size is suitable for inland seas only. We recomend up-scaling by a factor of 2 (5m length) for navigational use on large inland seas and partly open ocean areas. A diagram of the BBDB is showen in Fig 9.

This buoy is constructed of 6 mm steel plate, and the total weight is about 8 tons which is nearly the same as that of an ordinary tail-tube buoy based on the wave period distribution in Tokyo Bay. the total conversion efficiency from wave power to air output is to be 38.3%, and the average wave power intensity in Tokyo Bay is 0.231 KW/m. The average electric power calculated is 41 watts .

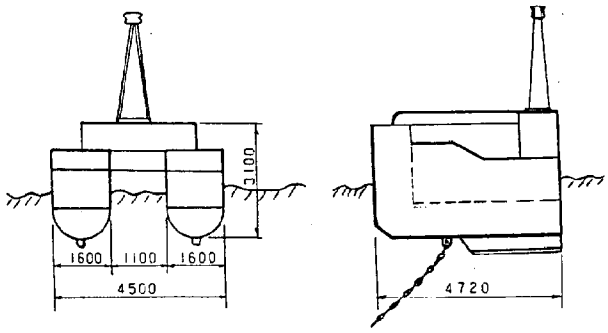

Fig 9. 5 m twin-hull BBDB.

This value is four-times higher that of the common tail-tube navigation buoy with a wave power device.

In open ocean coastal areas, the total conversion efficiency drcreases due to longer wave periods (8.06% from 38%) , but the wave power intensity itself increases to 1.846 KW/m. The average electric output, therefore, is estimated as follows , 71 watts.

The electric output calculated (by the same method as for 2.4 m BBDB) for an ordinary Japanese L-1 navigational tail-tube buoy is showen in Fig.10 with that of a 5 m BBDB. The weight and volume of both buoys are almost the same, and the 5 m BBDB has a 6-times higher electrical output than the ordinary L-1 navigational buoy. In addition ,the drag force will be smaller in high currents and high waves. We conclude, then, that the BBDB will improve the electrical capability of navigational aids by using a factor of 6.

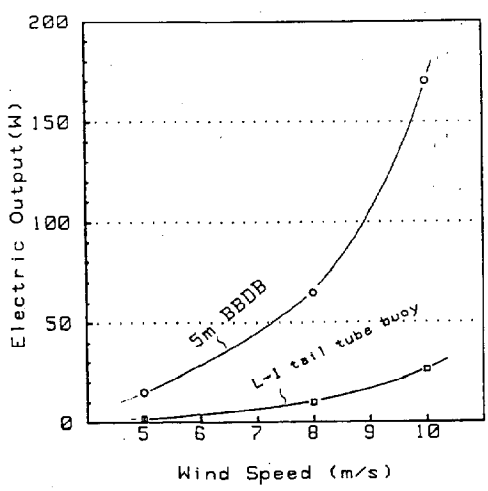

Fig 10 Calculated electrical power for 5 m BBDB and L-1 tail-tube buoy against wind speed in Tahara sea area (inland sea).

(b) Open sea buoy for telemetering, underwater warning,fish gathering and station keeping.

Many kinds of buoys for weather telemetering have been developed. These include discus buoy and ship-shape buoys which are the main buoy shapes. The typical electric power demand for such buoys is 2 KW and is supplied by motors or batteries. Hence, wave power is most attractive for this application. If up-scaling the single hull BBDB is by a factor of 10, the buoy has dimensions of 24 m length,6 m width and 7 m draft.

As showen in Fig 11, 24 m BBDB has a peak conversion efficiency at 7 seconds, and has good efficiency for waves in open sea having periods of from 5 seconds to 11 seconds. Therefore, the total conversion efficiency in open sea waves is expected to be about 40%, and efficiency of the turbine and generator can be expected to be approximatly 12 KW in the Sea of Japan.

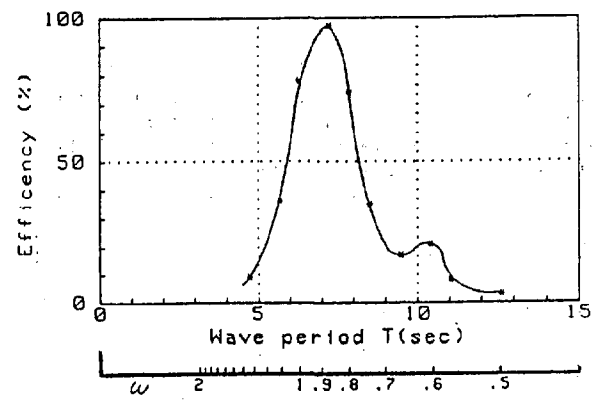

Fig 11. Conversion efficiency of L-24 BBDB.

For a 5-times up-scaled single-hull BBDB, the buoy has dimensions of 12 m length,3 m width and 3.5 m draft. The peak period of energy conversion shifts to 5 seconds, and the total conversion efficiency in open ocean waves is decreased to 19%.

The resulting average electric output is estimated to be 2.6 KW. This output should be adequate for each demand on the buoy.Open sea buoys of 12 m to 24 m length will be usefull for telemetering weather and oceanographic information. The self-power from waves and low drag against current and towing make the BBDB most desireable for this application.

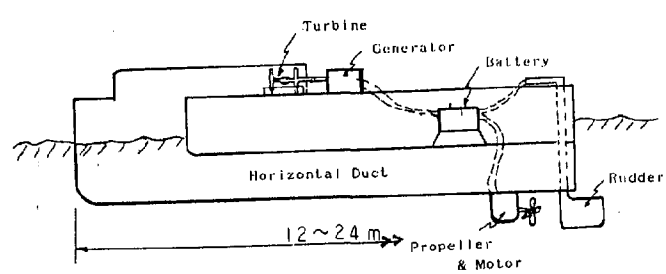

Fig 12. Wave power propelling.

Another application of an open sea BBDB buoy is in underwater warning against submarines,i.e., for defense purpose. In this application, the buoy is either moored, free drifting or station-keeping.

Fig 12 shows one example of a station-keeping BBDB buoy which is from 12 to 24 m in length and 3 to 6 m in width.

The generated power is stored in the battery and is used to propel the buoy while keeping position on the ocean with an energized rudder. If the drag coefficient is 0.2 for the cross -sectional area of the hull, the average speed of 1.5 knot may be possible by wave power generation.

A technical feature of this system will be a capability of propelling itself into the waves. When these military uses of the BBDB are adopted, the best turbine to use is McCormick turbine, because of the lower self-noise than that of other turbine.

Still another open sea use is that of fish gathering buoy. It is knowen that fish gather around buoys, so the BBDB may be usefull for increasing the fish population when it is controlled properly.

(c) Large BBDB for Island or Coastal Power Supply.

The last target of this study is a large BBDB for island or coastal power supply.

One possible design for this purpose is the box shape, sketched in Fig 13.

The floating system is 24 m in length, 36 m in width and 13 m in overall height. The displacement is about 830 tons for 36 m length buoy, both having a steel plate thickness of 12 mm.

The buoyancy is about 2000 tons, which is more than enough reserved buoyancy.

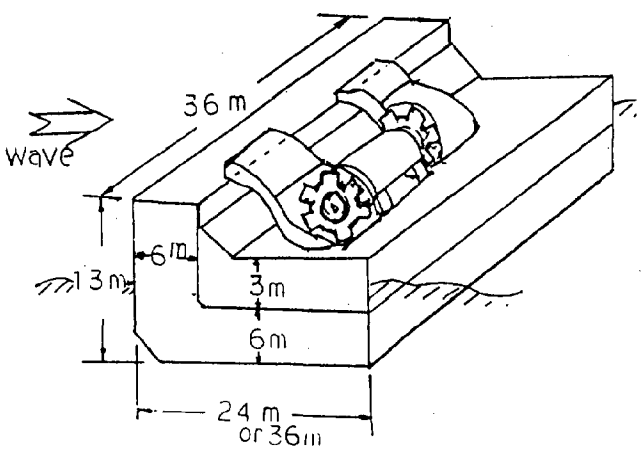

Fig.13. A large BBDB for island or coastal power supply.

Wave data in Hawaii and U.K.(two candidate islands) have been studied, and average wave power intensity is 21.6 KW/m for Hawaii and 50.8 KW/m for UK.

The total energy conversion efficiency for these intensities was calculated based on the box -type tank data using wave power distribution data. The results are as follows.

24 m in length---28.11% for the Hawaiian wave condition.

36 m in length---43.4% for the Hawaiian area, and 37.6% for UK area.

Conversion efficiency from the air output to electrical output is 60%.

Using these factors, the electrical output (averaged through the year) is estimated as follows.

24 m long buoy---131 KW in the Hawaiian area.

36 m long buoy---- 202 KW in the Hawaiian area and 687 KW for the UK.

Construction costs were estimated by IHI and other menbers of the KAIMEI study group. These construction costs are estimated as follows.

Ship hull:
24 m long type--295,000,000 yen
36 m long type---383,500,000 yen
Turbine---------- 80,000,000 yen.
Electric Generator with control
1000KW----------100,000,000 Yen
3000KW----------300,000,000 Yen
Miscellaneous----------20,000,000 Yen
Mooring----------20,000,000 Yen
Cable ----------20,000,000 Yen
Transportation from factory to Site.
-------40,000,000 Yen

Total construction costs
(1) 24 m long buoy---575,000,000 Yen
(2) 36 m long buoy
For Hawaii----683,500,000 Yen
For the U.K.--883,500,000 Yen

The expenses per year are estimated at 10% of these costs. The generated output per year are
(1) 24 m long buoy---1,147,560 KWh in Hawaii
(2) 36 m long buoy---1,769,520 KWh in Hawaii and 6,018,120 KWh in the U.K.

The energy cost are estimated to be
(1) For Hawaii---18 Yen/KWh
(2) For the U.K.---15 Yen/KWh

These costs for the 36-meter buoy are much lower than the KAIMEI (350 Yen/KWh); however, more efforts are needed to decrease the energy costs. We beleive that significant cost reduction is possible.

MODERN ESKIMO WHALING IN THE ALASKAN ARCTIC

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ABSTRACT

Since the 1960's, subsistence whaling in the Alaskan Arctic has experienced a resurgence due to improved health conditions, population growth, "cultural revitalization," and a growth in the local economy. This resurgence has been accompanied by some material changes in subsistence whaling. Recently, there has been growing cooperation between the Inupiaq (Eskimo) whalers and the oil industry that has created further changes in the whale harvest. Some of the current features of whaling practices, whaling technology, organization, and distribution are described; and the cultural importance of whaling to the Inupiaq is discussed. It is apparent that, while today's subsistence whale hunting has changed over the last 100 years, whaling has remained a deeply rooted cultural event.

1. INTRODUCTION

Native people in Alaska participate in subsistence hunting and fishing activities which are central to their livelihood and their culture. Among the Inupiaq and Yupik of Arctic Alaska, there is no subsistence activity which is more important than the harvest of the bowhead whale (Balaena mysticetus).[1] Pursuit of this animal has long been a focal point of their culture. Whaling has provided a major food source, a means of achieving status and prestige, and has created bonds and kinship ties within and between villages. The bowhead has been a source of resources (oil, baleen, and whale bone), a central element of ceremonial activities, and the center of many religious beliefs (1).

This paper briefly discusses the history of bowhead whaling and some of the current features of whaling practices, technology, and organization. Subsistence whaling still plays an extremely important role in the society and culture of the Inupiaq and Yupik people. Though superficially altered by the influence of outsiders, Inupiaq and Yupik subsistence whaling has retained its cultural significance. The recent cooperative program between Inupiaq whalers in the Beaufort Sea and the oil industry is described in this paper as an example of the blend of technological adaptation and subsistence whaling.

2. HISTORY OF BOWHEAD WHALING IN THE ALASKAN ARCTIC

Archaeological evidence indicates that northwestern Alaskan Eskimos have been hunting bowhead whales since approximately 500 AD (2). There is evidence that whaling probably developed about 1,000 years earlier on St. Lawrence Island (3) and around 1700 BC. at Cape Krusenstern on the Chukchi Sea (4). Bowhead whaling was not feasible until village populations were large enough to sustain a sufficient number of whaling crews necessary to participate in a cooperative bowhead hunt (5). A cooperative social system developed in whaling villages in these areas through the extension of kinship, hunting partnerships, adoption, and the karigi, or men's associations, and created a means of distributing such large quantities of food and raw materials (6). Forty to fifty tons of food and raw materials were shared when the bowhead was caught.

A limited whaling culture developed during the early Thule tradition at the present-day whaling village sites on St. Lawrence Island, and at Wales, Point Hope, and Barrow. Wales, Point Hope and Point Barrow did not practice whaling extensively until climatic changes in the 16th century brought an expansion of polar ice which had retreated about four hundred years earlier. These changes created more favorable conditions for whaling through the spring and fall (7). By the

[1]The bowhead whale harvest continues today in nine whaling villages. Gambell and Savoonga are located on St. Lawrence Island; Wales is on the Seward Peninsula on the Bering Strait; Kivalina, Point Hope, and Wainwright lie on the Chukchi Sea coast; and Barrow, Nuiqsut, and Kaktovik are on the Beaufort Sea coast. All of the whaling villages are Inupiaq with the exception of Gambell and Savoonga which are Yupik. The expression "Eskimo" is often used as a generic term for the Native people of the Arctic. In order to be more specific, Inupiaq (pl. Inupiat) and Yupik are used in the text of this paper where appropriate.

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18th century the culture of these villages had a strong whaling tradition which was extremely well adapted to Arctic conditions.

The historical period of the whaling villages begins with the written accounts of European explorers. In the more southerly regions, this contact began as early as 1728 when Vitus Bering visited St. Lawrence Island (8); in the northern regions, contact was as late as the early to mid-19th century (9). In all of the villages, contact with Europeans was only sporadic until the mid-19th century--generally considered the beginning of the "historical" period. Until this time, the Inupiaq and Yupik people co-existed with the bowhead in a presumably stable ecosystem (10).

In 1848, Captain Thomas Roys discovered the bowhead whaling grounds of the Bering Sea. The whales were oil rich, slow moving, and laden with baleen. A moderate-sized adult bowhead could provide up to 100 barrels of oil (one barrel equals 31.5 U.S. gallons) and 1,500 pounds of baleen. Roys' discovery led to an oil rush in the Bering Strait region; by 1852, more than 200 ships had entered the Western Arctic in search of bowhead oil (11).

The bowhead whaling industry thrived until 1880 when the price of whale oil collapsed in the face of competition with the new, up-and-coming petroleum industry. This was the period of the famed Yankee whalers and communities like New Bedford, Nantucket, and Mystic were among the richest towns in the United States. The cost of Arctic whaling was extremely high, shipwrecks were common and, together with the near depletion of the bowhead population, Arctic whaling might have ended. However, the demand for baleen or "whalebone" used for buggy whips, corsets stays, and skirt hoops drove up the price of baleen. The skyrocketing price of baleen and the decrease in the number of bowhead whales ultimately were the factors which brought the Inupiaq and Yupik of northwestern Alaska into constant contact with the white whalers (12).

White whalers observed that Inupiaq and Yupik shore-based whaling technology was perfectly suited to hunting the bowhead. As the whales moved north towards their summer feeding grounds, the Inupiaq and Yupik hunted them from the leads in the ice with their skin-covered boats or umiaqs and used seal-skin floats attached to a harpoon line to retard the movement of the whale. In order to inprove the efficiency of their own operations in the face of depleted stocks of bowhead whales, the white whalers began to operate year-round whaling stations along the northwest Alaska coast (13).

In 1885, the first coastal whaling station was established at Point Barrow. Within the next 12 years, thirteen whaling stations were established between Point Barrow and Cape Seppings. The stations were maintained by a skeleton staff of whites; the boat crews were made up of Inupiaq. At times, there were as many as 60 boat crews with around eight Inupiaq on each crew (14). It is conceivable that every adult male Inupiaq in these communities was very involved in the commercial whale harvest either directly as a crew member or indirectly by providing food and furs for the whalers.

The whaling station owners assumed their roles alongside the Inupiaq whaling captains. The whaling station owners retained the baleen and the Inupiat kept the maktak (whale blubber) and meat for their own use (15). Payment to the Inupiat for whaling was usually in the form of rifles, cartridges, and other manufactured goods. Shore-based whaling introduced Western goods to the Inupiat and created a demand for firearms, flour, and other merchandise. Inupiat from other areas were drawn primarily to Point Hope (an Inupiaq village) and Point Barrow by the promise of trade goods and whale meat. They came from as far as Cape Prince of Wales and the upper Noatak River. Most Inupiat came months before the whaling season and whaling soon became a standard part of their seasonal activity, especially with the decline in the caribou population in the late 19th century. The influx of these Inupiat from other areas more than tripled the number of Inupiaq whaling crews in Point Hope (16).

By the early 1900's the price of baleen had risen to more than $5.00 per pound, making an adult bowhead worth more than $10,000 (nominal dollars). The extraordinary profits from one large bowhead could nearly pay for the entire expense of sending a ship to the Arctic to pick up the baleen. By 1908, however, the whaling industry had collapsed after the invention of the steel spring replaced baleen (17). The heyday of Arctic commercial whaling came to an end and the whaling stations closed.

According to Bockstoce (18) and Marquette and Bockstoce (19), the number of whaling crews fell back to the aboriginal level after commercial whaling ended. The decrease of Inupiaq whaling was related to the collapse in the commercial whaling industry as well as to the concomitant decline in the Inupiaq population due to contact with white diseases. The entire population of the Alaskan Arctic (from Kotzebue Sound north to Demarcation Point) fell from an estimated 10,000 in 1850, to 3,000 in 1900 (20). In 1900 there was a measles and pneumonia epidemic that was followed in 1918 by the worldwide influenza epidemic (21). The population continued to decline until the 1920's.

The Inupiaq had never stopped whaling as a subsistence activity throughout the commercial period. The meat and maktak were shared ceremonially with villagers as was done in precontact times. The only differences in shore-based commercial whaling from subsistence whaling were the use of firearms, payment for baleen, and payment for serving on the crew. Meat distribution and the whale ceremonies continued in the same fashion (22). After the collapse of commercial whaling, the Inupiaq returned to a strictly subsistence harvest of the bowhead, although they had adopted the best whaling technologies of the

commercial whalers combined with their own traditional techniques. Darting guns and bomb-lance shoulder guns had been introduced to the Inupiaq and were a part of their equipment by the early 1900's (23). The darting gun has a small, smooth bore attached to the end of the harpoon shaft. The instant the hunter harpoons the whale, the bore discharges a small bomb into the whale. The bomb explodes a few seconds later, not always killing the whale, but the flight is greatly restricted. The shoulder gun, usually made of brass, weighs about 35 pounds and fires a similar bomb through the air. The shoulder gun is accurate up to approximately 20 yards and enables the hunter to shoot the whale from a distance (24). Although there have been a few improvements along the way, Inupiaq and Yupik whalers still use such equipment.

In 1931 an international ban on commercial hunting of bowhead whales was instituted by the Convention for the Regulation of Whaling. However, no limit was placed on the Alaskan subsistence harvest. Subsequent conventions reaffirmed the ban on commercial whaling but did not limit aboriginal subsistence harvests of the bowhead whale. Subsistence whaling continued unfettered throughout the 40's and 50's at more or less stable levels and saw a resurgence in the 60's. Stimulated by improved economic conditions (the result of the infusion of Federal transfer payments and employment), a general revitalization and interest in their culture, and improved health conditions and population growth, Inupiaq and Yupik people fielded more and more whaling crews. State and local government expenditures fueled a dramatic expansion of the whaling village economies through the late 70's, which, in turn, contributed to even more crews.

As worldwide sightings of the bowhead became increasingly rare, an increased awareness in the welfare of this species grew. Beginning in 1972, the International Whaling Commission (IWC) requested that the United States provide data regarding Alaskan whaling and the Bering Sea bowhead stock. Moreover, increases in the number of bowhead whales landed; killed but lost; and struck but lost by Inupiaq and Yupik during the mid-1970's, led to a growing concern about the adverse impact of unregulated hunting on the endangered bowhead population. This concern led to a decision by the IWC in June 1977 to ban the taking of bowhead whales for subsistence by all member nations' people including Alaska Inupiaq and Yupik (25).

The IWC moratorium on Alaska Inupiaq and Yupik hunting of bowhead whales focused national and international attention on the issue. Many organizations spoke out in favor of allowing a compromise and a limited subsistence bowhead hunt to continue. As a result, at a special meeting in December 1977, the IWC modified the total ban in recognition of the subsistence and cultural dependence of Alaska Inupiaq and Yupik on bowheads, and established a limited quota for Alaskan subsistence hunting of the bowhead whale. The quota in 1977 was set at 14 landed and 20 struck. Better information collected in recent years on the size of the bowhead population indicates an increasing stock. This, together with studies documenting the cultural necessity of bowhead whaling, has led to a gradually increased quota of 42 landed and 45 struck for 1989.

As a result of the actions of the IWC to limit Inupiaq and Yupik subsistence whaling in 1977, the Alaskan whalers organized to argue their case in the international political arena. They formed a political organization, the Alaska Eskimo Whaling Commission (AEWC), to negotiate the quota. Through a cooperative agreement with the Federal government, the AEWC is responsible for the management of the subsistence bowhead harvest. The AEWC is composed of one whaling captain from each whaling village.

3. WHALING PRACTICES

Modern whaling has retained some of the characteristics of the old shore-based commercial whaling of the 19th century, but exemplifies the adaptability of Inupiaq and Yupik whalers to new techniques. Today's technology for the whale hunt is based on the technology used during the shore-based commercial whaling period at the turn of the century. The shoulder gun, darting gun, and harpoon, as mentioned earlier, continue to be used. In the 1980's, research was done to improve the efficiency of the hunt through a perfection of the "bomb" used. Otherwise, this technology has remained virtually the same for almost a century. The Inupiaq and Yupik whalers have adopted new technologies such as CB radios to notify other whalers when a whale has been struck or sighted, plastic floats are used instead of seal-skin floats, and they use snow machines to haul umiaqs and gear onto the ice and to haul whale meat and maktak to shore. Tents and other camping equipment, "modern" clothing, etc. have replaced some of the more traditional types of gear, however, white parka shells, mukluks (skin and fur boots), and caribou furs (instead of blankets or sleeping bags) are still found.

Today's spring whaling occurs in all of the whaling villages except Nuiqsut and Kaktovik during April, May, and sometimes early June. The spring whale hunt occurs primarily in the ice leads with camps located along the ice in anticipation of the northward whale migration. Spring whaling from the ice is done in umiaqs, wooden boats covered with bearded seal skin. Skin boats are more advantageous in the spring because the leads are narrow, the boats are quieter (noise frightens the whales and sends them under the ice out of reach of the whalers), easier to patch if punctured, easier to move from the ice to the water, highly shock resistant, and easier to paddle or sail than an aluminum skiff. Umiaq boats covered with plywood can also be found in the village of Kivalina. Aluminum skiffs are sometimes used later in the whaling season after the ice opens. In Nuiqsut and Kaktovik in the Beaufort Sea, the ice leads are too distant in the spring to allow for a bowhead hunt, however, in

the fall the whale migration occurs closer to the shore. Nuiqsut and Kaktovik whaling occurs in the fall in open water from powered aluminum boats, which provide the greater speed and range needed to hunt bowheads in open water. There is also a limited fall harvest in Barrow if their quota has not been reached.

4. CULTURAL IMPORTANCE OF BOWHEAD WHALING

One aspect of subsistence whaling that has not changed is its importance to the Inupiaq and Yupik people. The Inupiaq and Yupik traditionally had a close relationship to the supernatural with specific beliefs in animal souls and beings who controlled the movements of animals. Bowhead whaling today remains at the center of Inupiaq and Yupik spiritual and emotional life; it embodies the values of sharing, association, leadership, kinship, Arctic survival, and hunting prowess. The whale hunt ties together these values with feasting, and food preferences, and symbolized cultural integrity (26).

An important activity connected to bowhead whaling is the ritual sharing of meat and maktak throughout the year. Unlike other species, there are special celebrations or ceremonies connected to bowhead whaling, as well as other feasts throughout the year where bowhead whale meat and maktak are shared. Traditionally there were a number of feasts and ceremonies which centered around the whale hunt (27). At the beginning of the whaling season the captain shared the remainder of the whale meat from the previous season (if there was any left) with his crew and/or relatives. Special feasts were held on the ice when the whale was caught and later when the whale was butchered. The most important ceremonial feast was at the end of the whale season when whaling villages held Nalukataq or Blanket Toss (in all villages except for Gambell and Savoonga where a whale carnival was held), a celebration to show gratitude and respect to the whale which had given itself to the people. The whale meat and maktak were distributed, prayers of thanks were offered, and dances were performed. These feasts and ceremonies continue today with the addition of whale meat and maktak sharing at Thanksgiving, Christmas and other special occasions. Sharing of all subsistence foods continues to link family members and friends in the villages as well as serving as a link between villages. With whom one cooperates and shares is a major component of the definition of significant kin ties (28). Maktak and whale meat are shared primarily between villages close to the whaling villages, but also with family and friends in Fairbanks, Anchorage, and Seattle (29). The structured sharing of the whale helps determine social relationships within and between communities (30).

The ramifications of the whale hunt are more than emotional and spiritual. The organization of the crews does much to delineate important social and kin ties within villages and to define community-leadership patterns as well. Whaling crews tend to be composed of relatives. Participating on a whaling crew strengthens these ties between kin. Whaling captains are also respected men in the villages, often leaders in formal political organizations, or respected elders in the village.

5. OIL/WHALERS WORKING GROUP

Inupiaq and Yupik whalers have seized opportunities to adapt to new whaling technologies. Historically, this adaptation is characteristic of many hunting and gathering cultures. Relying on food supplies which are subject to the vagaries of the environment, migration, and weather, the hunters pursue strategies which are opportunistic and flexible. The Yankee whalers adopted Inupiaq shore-based whaling techniques and the use of quiet and lightweight whale boats to expand their harvest; the Inupiaq and Yupik whalers, in their turn, readily made use of Yankee shoulder guns and darting guns.

Modern-day technological adaptation, however, is constrained to an extent by tradition, but also, most visibly, by the self-regulation of the AEWC and the village whaling captain associations. In part, the whalers are acceding to the influence of the IWC and the Federal government, but they also are seeking to maintain the essentially communal organization of the harvest. Ironically, it is the oil industry exploiting new resources which has introduced another opportunity for technological improvement to whaling.

In the last 20 years, the petroleum industry has explored the Beaufort Sea for new oil prospects. Even under the regime of depressed international oil prices, the industry remains keenly interested in this area. Producible leases in the Beaufort Sea OCS have been discovered, and development of these tracts may begin in the next decade. The potential for conflict between oil exploration and whaling has long been recognized and concerns about it have led to increasing tensions between the parties involved. To their credit, however, the Beaufort Sea whalers and the oil industry have successfully implemented a program which serves to mitigate some of these conflicts. Though wrapped in the legal and corporate mantle of Western culture, it represents another example of the kind of adaptation to changing conditions which characterizes traditional Inupiaq whaling.

In 1986 a formal agreement was entered into by several oil industry operators, the AEWC, and the village whaling captains' associations from Nuiqsut and Kaktovik. The purpose of this agreement was to allow oil and gas exploration activities to proceed without restricting or interfering with Inupiaq whaling. Improved communications was the key to achieve this goal. A system of radios was installed and Inupiaq radio operators were hired to work on oil industry vessels. Throughout the operating season, all participants were to call the base station in Prudhoe Bay and report their plans and positions. In this way vessel traffic could be modified to avoid interference with whalers. The oil industry operators also agreed to provide additional

assistance to the whalers subject to certain restrictions. Specifically, the oil and gas companies agreed to obtain the equipment for a VHF communication system to permit each of the operators of industry vessels to talk to each of the whalers. Industry built a radio tower on the coast near Deadhorse and equipped a base station there. A "slave" radio tower also was built at Kaktovik village and donated to the North Slope Borough with the provision that industry had the right to use it in perpetuity for its own communications requirements. Each of the 16 whaling captains (10 from Kaktovik and 6 from Nuiqsut) was given a radio for use from mid-August until the completion of whale hunting. At the season's end, the equipment was returned to the operators to be repaired so that it might be used again the following year.

The Deadhorse Communications System Coordination Center was staffed by Inupiaq operators 24 hours a day under the supervision of Alaska Telecom Inc. These operators were required to record the twice-daily reports from their Inupiaq counterparts aboard industry vessels and the reported positions from the whaling captains (required every 6 hours after launching). The radio operators then were instructed to plot the locations and areas of probable industry operations and make the determination whether or not a conflict might arise. The agreement placed the responsibility of avoiding conflict on industry: "...all industry vessels and aircraft will use all reasonable efforts to avoid interfering with or restricting subsistence whaling" (31). Such efforts might include ceasing seismic operations, changing course or speed, or cancelling operations until a bad-weather day when whaling could not occur.

As per the agreement, the Inupiaq whalers had at their disposal a communication system which was a marked improvement over the CB radios they had used before. Instructions were given not to use the system to "scout" for bowhead whales or otherwise report the location of whales to the subsistence hunters. Another advantage the Inupiaq saw in the communication system was in their requirement that the radio tower in Kaktovik have a red light on it--not only for planes, but for their own guidance when they came back from hunting trips in poor weather.

The 1986 Oil/Whalers Cooperative Program was a significant step to mitigate the potential conflict between offshore oil and gas operations and subsistence whaling.[2] But where it demonstrated the "adaptability" of Inupiaq subsistence whalers best was in its subsidiary component, i.e., industry agreed to provide "certain kinds of assistance" to the whalers. This included towing caught whales, transporting whale meat and maktak to avoid spoilage, and caching emergency supplies (food, fuel, etc.) for use through the duration of the hunt.

The Nuiqsut and Kaktovik whalers are at a decided disadvantage when compared to their counterparts on the Chukchi Sea coast and in the Bering Strait. Without the corralling influence of ice leads, the bowhead migrates westward across the Beaufort Sea restricted only by the vagaries of its food sources and its preference for certain water depths. The whalers of the fall hunt are forced to set out in their powered aluminum skiffs over considerable distances. Every attempt is made to harvest the whale close to the flensing site so that it may be butchered before is spoils. Despite the cold water, the whale is so large that the meat can spoil very quickly in the thoroughly insulated carcass. With specific approval from the National Oceanic and Atmospheric Administration, that restricts when and how the industry may help and requires special reporting and notification, the oil and gas industry has provided invaluable help to the whalers (32). Nuiqsut whaling captains have been the beneficiaries of this agreement on two occasions. In 1986 an industry work boat towed a harpooned whale to Cross Island and subsequently transported the meat and maktak to Nuiqsut (via Hercules air transport). In 1987 a work boat servicing geophysical operations towed a whale caught by a Nuiqsut whaler to West Dock at Prudhoe Bay.

6. CONCLUSION

Alaskan Inupiaq and Yupik whalers continue to hunt the bowhead whale just as their ancestors did for centuries before them. As with all cultural traditions, changes have occurred as the whalers have adapted to different conditions, particularly in the realm of technology. Yet some of the technology created hundreds (and even thousands) of years ago is perfectly suited to the bowhead whale hunt and remains in use today: the use of the toggle harpoon (adapted to the darting gun), floats (now made of plastic), and skin boats. More recently, new adaptations are occurring as the whalers join with the oil industry in attempts to reduce interference with whaling. Industry has supplied better communications technology and offered assistance in hauling whales. Just as the Inupiaq in the Chukchi Sea worked with the Yankee whalers during the turn of the century and new technology was acquired, the Inupiaq in the Beaufort Sea are acquiring new technology from the oil industry. Yet, the cultural importance of bowhead whaling--ceremonies, feasts, sharing, strenghtening of kinship ties, status for whaling captains, religious beliefs, etc.--has not changed, despite the technological changes. Bowhead whaling continues to be the most important event in the lives of the Inupiaq and Yupik whalers in Alaska in the 1980's. Whaling continues to be their way of life.

[2]That the Cooperative Program was renegotiated in 1987, and expected to be renegotiated in 1988, suggests that this arrangement has been successful.

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OBSERVATIONS ON THE 1987 SUBSISTENCE HARVEST OF NORTHERN FUR SEALS ON ST. PAUL ISLAND, PRIBILOF ISLANDS, ALASKA

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ABSTRACT

This paper provides background about the subsistence harvest of northern fur seals and describes some aspects of the 1987 fur seal subsistence harvest on St. Paul Island. The northern fur seal is important to the subsistence of Pribilof Islands Aleut residents because the species reappears annually for breeding purposes and has been used for local subsistence since Aleuts were brought to the islands by Russian fur merchants more than 200 years ago. Residents of St. Paul Island have carried out a subsistence harvest of northern fur seals since 1985, brought about by the termination of commercial sealing and the federal withdrawal of financial support for sealing operations on the island. The need to carry out the subsistence harvest with "experienced sealers using the traditional harvesting methods" has created contradictions that are yet unresolved and are compounded by the need to create a new means of livelihood on the island to replace commercial sealing.

1. INTRODUCTION

St. Paul Island is located in the southern Bering Sea, one of two inhabited islands of volcanic origin that make up the Pribilof Islands. Comprising 44 square miles, St. Paul Island is approximately 770 miles from Anchorage and 320 miles from Cold Bay, the nearest major airport. The community of St. Paul has a population of approximately 470, the vast majority of whom are Alaskan Natives of Aleut descent.

The northern fur seal, Callorhinus ursinus, has been an integral part of Pribilof Aleut life for more than 200 years--since the time Russian fur merchants transported Aleutian Islands Aleuts there to carry out a commercial harvest for fur seal pelts in 1867. Today, approximately 75 percent of an estimated 2 million northern fur seals breed on St. Paul and St. George Islands in the Pribilof Islands group. Although a commercial pelt harvest is no longer carried out, a subsistence meat harvest now takes place annually on the islands during the months of July and August.

This paper provides background about the subsistence harvest of northern fur seals and describes some aspects of the 1987 fur seal subsistence harvest on St. Paul Island. The author personally observed the 1987 subsistence harvest in order to acquire first-hand sensitivity to associated issues and to better carry out environmental assessments for OCS lease sales in the Bering Sea. Because the Pribilof Islands are located strategically in the Bering Sea to service offshore OCS operations, potential effects from future exploration, production and transportation operations are assessed in environmental impact statements; and subsistence is one of the major issues addressed in such documents in Alaska.

2. SETTING

The northern fur seal derives its name from its geography of habitat and the luxurious fur that maintains its body temperature. The fur has over 300,000 hairs per square inch and is so impermeable to water that the skin remains dry even when the seal rubs or scratches itself in the water (1). Geographically, the northern fur seal ranges widely within the North Pacific Ocean, migrating as far south as the California Channel Islands and the Sea of Japan and as far north as the Pribilof Islands to breed. Unless sick or injured, these mammals rarely touch land from the time they leave their rookery (breeding area) islands in the fall until they return the following year. Most fur seals of breeding age return to the rookery of their birth; the sequence of return is governed largely by age.

Large breeding males, the so-called "beachmasters," are the first to return in order to establish and defend territories within a given rookery. There are 7 fur seal rookeries on St. Paul Island, which generally are gently-sloping, boulder-strewn areas adjacent to the sea. Females returning to their rookery are intercepted by beachmasters as they attempt to pass their respective territories. The number of females persuaded to remain in a male's territory may vary from 1 to 100, with the average being around 60 (2). With the birth of males and females being approximately equal, this reproduction arrangement results in a considerable surplus of nonbreeding, subadult male fur seals.

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In contemporary times, commercial sealing to acquire fur seal pelts has been largely restricted to nonbreeding, subadult "bachelor" males. This was not always the case, however, with harvest excesses at sea (pelagic sealing) causing the United States, Great Britain, Japan, and Russia to conclude a Convention in 1911 for the protection of the fur seals of the North Pacific. Commercial sealing was only to be carried out on land, thus reducing the excessive losses incurred through pelagic sealing, with 30 percent of the pelts from the Pribilof Islands seal harvest allocated between Canada and Japan.

During the 30 years that the Convention of 1911 remained in force, the U.S. Government--through the National Marine Fisheries Service (NMFS) and its predecessor organizations--managed the annual commercial harvest and financially maintained the Pribilof Aleuts on their islands (3). A similar interim Convention that was instituted in 1957 among Canada, Japan, the Union of Soviet Socialist Republics, and the United States remained in force through 1984, when it expired in the absence of U.S. Senate ratification of the Protocol needed to extend the Convention (4). Consequently, a commercial harvest for fur seal pelts could not be carried out in 1985, resulting in the need to draft emergency regulations to carry out a subsistence harvest to meet the dietary needs of Pribilof Aleuts.

3. SUBSISTENCE

The term "subsistence" is used here in a dietary sense, which falls far short of its social and cultural meaning among St. Paul Aleuts (5). Even in a dietary sense, however, St. Paul residents use a variety of seasonally-available renewable resources for subsistence purposes in addition to the fur seal, including sea lions, other seals, halibut and cod, shellfish, birds and bird eggs, reindeer, and terrestrial plants and berries. Although but one of many resources, the fur seal is the backbone of Pribilof Islands subsistence because of its availability and regularity of return to the islands.

The last subsistence harvest of northern fur seals was carried out on St. Paul Island in 1916 (6), much beyond the recollection of most inhabitants. People's dietary needs had heretofore been met as a byproduct of the commercial pelt harvest, since far more fur seals (25,000 or so in recent times and a high point of 102,255 seals in 1961)(7) were killed than could possibly be used for human consumption. St. Paul residents obtained fur seal parts (flippers, shoulders, hearts and livers, ribs, etc.) directly from the commercial killing grounds. Most of the remaining carcasses and byproducts from the pelt harvest were processed and sold by the Government for a variety of purposes, including fishing bait, dog food (8), fertilizer, and mink food.

4. EMERGENCY SUBSISTENCE REGULATIONS

The subsistence harvests of northern fur seals that began in 1985 were authorized by emergency rules promulgated by NMFS under the Marine Mammal Protection Act and the Fur Seal Act. The harvests are authorized to be carried out by Pribilof Islands Natives and required to be monitored and reported on by NMFS personnel, with the provision that Pribilof Aleuts also cooperate with federal fur seal research (which relies on tissue samples from the harvest). Among other things, the rules specify the timing, locations, and manner in which the harvest is to be carried out and place restrictions on the uses of harvest byproducts. The emergency final rules (9) specify the subsistence harvest period to extend from June 30 to August 8 of each year and authorize an extension of the harvest period if subsistence needs have not been met but specify limits for female seals taken as a means of terminating the annual harvest. The rules further list the rookeries on St. Paul Island to be used in the harvest and contain provisions for maximum subadult seal size (124.5 centimeters) and the prohibition of taking adult fur seals, pups, or subadult female fur seals. The cutoff date of August 8 is used because female seals begin to mingle with subadult bachelor males beyond this date, and it is virtually impossible to differentiate the sex of these seals by simple observation. The manner of carrying out the harvest is specified as follows:

> "No fur seal may be taken except by experienced sealers using the traditional harvesting methods, including stunning followed immediately by exsanguination. The harvest method shall include organized drives of subadult males to killing fields unless it is determined by the NMFS representatives, in consultation with the Pribilovians conducting the harvest, that alternative methods will not result in increased disturbance to the rookery or the increased accidental take of female seals." (10)

The regulations for the disposition of fur seal pelts and carcasses basically specify use only for noncommercial purposes, unless transformed into handicraft articles. In the past, however, the commercial orientation of the harvest allowed little opportunity for an extensive fur seal-oriented crafts tradition to become established. Requests to use fur seal meat in the island restaurant (which caters primarily to tourists), for fishing bait, or as dog food (for sale elsewhere, since the landing of dogs on the Pribilofs is prohibited by Federal regulation in order to prevent molestation of fur seals) were denied (11). A request by St. Paul's Tanadgusix (Alaska Native Claims Settlement Act village) Corporation for permission to sell pelts and other harvest byproducts from the first 6,000 seals taken on St. Paul as a means of funding "traditional harvest methods" also was denied (12).

5. THE 1987 HARVEST

The 1987 subsistence harvest of northern fur seals on St. Paul Island was organized and carried out jointly by the Tanadgusix Corporation (TDX) and the village IRA (Indian Reorganization Act) traditional Council. The harvest took place over 4 weeks, Monday through Friday, plus one additional day in September. Using a system developed the previous year, IRA Council personnel solicited and received orders for the number of seals wanted that day from families prior to each daily kill, whereas TDX personnel were responsible for preparing the seals for butchering and disposing of the remains of the harvest. Family members were responsible to be present where the sealing took place in order to butcher the number of seals ordered. Much of what went on prior to and after the harvest was communicated over CB radio frequencies, so everyone in the community had a chance to participate.

Each morning at around 8 a.m., a procession of trucks, pickups, and cars moved out from the TDX staging area in town toward the rookery chosen for that day's harvest. When the NMFS person in charge was informed by CB radio where the harvest would take place and for how many seals, several Government vehicles joined in at the tail of the procession. Generally among the contingent, in addition to the NMFS observer, were researchers from the National Oceanic and Atmospheric Administration (NOAA) Marine Mammal Laboratory, other visiting scientists, a veterinarian, and a scientist observer of the Japanese Government.

The "traditional harvest methods" used by St. Paul residents in 1987 employed a total of about 20 people and were extremely efficient because of the division of labor utilized. However, the harvest may have proceeded at a slower pace than during the commercial harvest era because of the emphasis on butchering and processing meat rather than simply accumulating seal pelts. At the entrance to the rookery, about a half-dozen young men would begin driving the available subadult bachelor male seals--which congregate at the landward edge of the rookery--inland toward the grounds chosen for the killing. This accomplished, the vehicle caravan entered the rookery and the harvest crew prepared for the kill.

The harvest crew at the killing grounds generally consisted of 14 people; about 6 others were employed back in town to wash, scrape, brine, and store the pelts (supposedly in hopes that one day they might be sold). Principal among the crew were 3 stunners, 1 of whom was the crew boss. Others among the crew were 1 chest cutter/sticker (to pierce the chest and bleed the seal), 3 skinners, 3 skin pullers, 1 skin sorter, 1 dump truck operator/seal driver, 1 crew truck operator/seal driver, and 1 other seal driver.

When all was ready, several drivers cut out a pod of 6-8 seals from the larger group and herded them toward the stunners. Using 8- to 10-foot-long bats or clubs--in order to keep a safe distance from the sharp teeth of the seals--the stunners crushed the thin skulls of the selected age-class seals and allowed the others in the now highly excited pod to return to the rookery. Almost immediately after being stunned, the seals were bled and lined up for skinning and butchering. The process of dispatching small pods of seals was repeated until the prescribed number of seals was taken, at which time the larger group of seals was released for return to the rookery.

During 1987, 1,710 fur seals were harvested for subsistence on St. Paul Island. Of this number, some 1,600 seals were taken during the prescribed season. Another 211 seals had been requested to be harvested on September 2, but the harvest was terminated after 110 seals had been taken--this was because the number of female seals taken had reached the maximum permissible number of 5. On the whole, the harvest produced some 38,800 pounds of usable meat, which represented 22.7 pounds of usable meat per seal (based on field reports), or approximately 83 pounds of usable meat per inhabitant of St. Paul.

Compared with the two previous subsistence harvests of northern fur seals, the 1987 effort used more seals than in 1986 (by 411 seals) but far fewer than were taken in 1985. Some 3,384 seals were harvested in 1985, or about twice as many as were taken in 1987. There are a number of reasons for this, including the fact that the harvest on St. Paul Island in 1985 was also to meet the needs of St. George residents. As the first subsistence-only harvest in generations, no systematic way had been developed to link actual family needs with harvest requirements, as was later worked out in 1986 and used again in 1987; families tended to behave as when the commercial harvests were being carried out, taking what they wanted from the product of the killing grounds; and there were problems with transporting and storing large quantities of meat.

6. ASSOCIATED ASPECTS

Although the method by which to connect family household needs with harvest requirements has been achieved through the order placement process, the difficult question of how to pay for the harvest year-after-year in order to carry it out as specified in the emergency final rules is not as easily answered. One could argue that payment should not be expected for a purely subsistence effort when the entire community benefits. On the other hand, however, legitimate costs are incurred during the short harvest season (such as vehicle-operation and material costs, among others). If the season were lengthened to allow for a smaller-scale "family orientation" to the sealing process, then perhaps there would be a greater likelihood of increasing the take of female seals. The "experienced sealers" that are required to be used heretofore have expected to be compensated in some way if drawn away from their normal jobs to carry out the harvest, especially since the abilities to carry out seal-harvest tasks are not evenly distributed within the population of the island. In 1986, this was accomplished by allowing needed

employees of TDX, the IRA Council, and the City of St. Paul time off with pay in order to carry out the harvest. The harvests of 1985 and 1987 were underwritten financially by TDX, perhaps with the expectation of eventually being able to sell the pelts. (An amendment to the Marine Mammal Protection Act to this effect was recently proposed and rejected.) As of this writing, the dilemma has not been resolved for the 1988 subsistence harvest.

Although the subsistence harvest of northern fur seals presents contradictions and dilemmas that may take years to resolve, the context provided by related actions magnifies social and economic stress experienced on St. Paul Island and the resulting interactions over subsistence procedures. U.S. termination of financial support for commercial sealing in 1984 left open the hope that local residents could continue to carry out commercial sealing as an important means of economic livelihood. Yet quickly following withdrawal and the negotiations carried out to substitute other means of economic livelihood, such as commercial fishing, came requests to declare the northern fur seal a depleted species under the provisions of the Marine Mammal Protection Act (13). This designation, if brought about, could terminate that hope with a great deal of finality and put increased social stress on the quest for achieving a meaningful economic livelihood and means of subsistence on St. Paul Island. Although questions over the welfare and human use of fur seals remain to be resolved, one aspect of certainty remains: as long as there are fur seals, they will return to the Pribilof Islands.

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ENDANGERED SPECIES AND MARINE MAMMAL PROTECTION DURING OFFSHORE STRUCTURE REMOVALS IN THE GULF OF MEXICO

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INTRODUCTION

The first oil and gas lease sale on Federal Outer Continental Shelf (OCS) lands in the Gulf of Mexico (GOM) was held in 1954. Since that historic sale, there have been 57 other oil and gas lease sales in the GOM Region. Approximately 25,720 wells have been drilled on these leases through 1987. From 1953 through 1986, approximately 3,890 oil- and gas-related structures have been installed and 455 have been removed on the Federal OCS. The National Research Council (1985) projected that approximately 2,600 of the oil- and gas-related structures in use today will be removed by the year 2000. (See the figure following the text.)

Prior to 1986, explosive contractors had few requirements during structure removals; cost considerations determined explosive methodologies. The most common practice was to buy the cheapest explosive available, prepare a linear or ring-shaped bulk charge, emplace, and detonate the charge. Since delays are very costly in salvage operations, "overcharging" (using more explosives than necessary) was the common practice to ensure successful severing of the structure's pilings and well tubulars (DeMarsh, 1987).

In April 1986, the Regional Director of the MMS Gulf of Mexico OCS Regional Office received a letter from the Director of the National Marine Fisheries Service (NMFS) laboratory in Galveston, Texas, that expressed concern regarding two major stranding events--one in the fall of 1985 and the second in the summer of 1986. Dead marine turtles and other animals were associated with these stranding events along the beaches of the upper Texas and southwestern Louisiana coasts. Coincidentally, a number of structures in State territorial waters had been removed. The NMFS suggested that a correlation may exist between the explosive removal of structures and the stranding of sea turtles and other animals.

The Regional Director of the Gulf of Mexico OCS Regional Office responded to these concerns and sent a letter to all lessees and operators in August 1986 requesting that the office be notified 30 days in advance of any plans to remove structures. Since the Regional Director determined that explosive structure removals may affect threatened and endangered species, he sent a second letter to all lessees and operators requesting additional information to facilitate interagency consultations under Section 7 of the Endangered Species Act, as amended. Each proposed explosive structure removal or group of explosive structure removals then underwent Section 7 consultation procedures.

Since 1986, the MMS has received 180 applications for structure removals (both explosive and nonexplosive methodologies). Eighty-one explosive removals and 47 nonexplosive removal applications have been approved as of July 22, 1988.

REQUIREMENTS FOR REMOVALS

In compliance with the 1958 Continental Shelf Convention, the United States agreed to completely remove any installations (structures/platforms) that are abandoned or disused on the OCS. According to Section 22 of the current oil and gas lease form [MMS-2005 (March 1986)], lessees are required to remove all devices, works, and structures from the lease block within a period of 1 year after termination of the lease. In compliance with 30 CFR 250.112(i), all obstructions must be removed at least 15 feet below the mud line. The lessee must also verify that the site has been cleared of obstructions per one of the procedures listed in 30 CFR 250.114.

ENDANGERED/THREATENED SPECIES AND PROTECTED MARINE MAMMALS IN THE GULF OF MEXICO

Five species of sea turtles inhabit the GOM. Three species--Kemp's ridley (*Lepidochelys kempi*), hawksbill (*Eretmochelys imbricata*), and leatherback (*Dermochelys coriacea*)--are listed as endangered by the U.S. Fish and Wildlife Service. The loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) turtles are listed as threatened species in the GOM. Studies by Fritts et al. (1983) and Fuller and Tappan (1986) as well as stranding data from the Sea Turtle Stranding and Salvage Network (Schroeder, 1988) indicate that sea turtles may occur across the GOM. Raymond (1987) characterized sea turtle populations as low with generally wide distribution throughout the GOM.

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Aerial surveys conducted by Fritts et al. (1983) also examined GOM waters for the occurrence of marine mammals in two large study subunits (each approximately 9,514 square miles in area). Results from these surveys indicate that the bottlenose dolphin (*Tursiops truncatus*) is by far the most likely marine mammal to be encountered. Other dolphins (Risso's spotted, striped, and spinner) were sighted less frequently. Sperm whales (*Physeter catodon*), beaked whales (*Mesoplodon* spp.), pygmy killer whales (*Feresa attenuata*), and short-finned pilot whales (*Globicephala macrorhynchus*) were also occasionally sighted. Other marine mammals may also inhabit the GOM.

METHODS FOR STRUCTURE REMOVALS

Explosives

The most popular and effective method of structure removal has been and continues to be the use of bulk explosives to sever the structure's pilings and well tubulars. However, lease operators and their explosive contractors have modified their methods of operations. The MMS has discouraged the use of low velocity explosives for structure removals. Explosive contractors have responded, and now the three most commonly used explosives are Composition B, Composition 4, and RDX (DeMarsh, 1987). These are all higher velocity explosives with detonation rates greater than 7,600 meters per second. Current information indicates that higher velocity explosives channel more of their energy into a shock wave, which is the primary shearing mechanism for severing a structure's tubulars. Lower velocity explosives may expend as much as 40 percent of their energy upon detonation in the formation of a gas bubble with the remaining 60 percent of the energy forming the shock wave (DeMarsh, 1987). Obviously, a lower quantity of higher velocity explosives can be utilized to accomplish the desired objectives. The MMS is continuing its investigations and evaluations of explosives and their impacts on the environment from structure removals.

Explosive contractors are also developing technologies to "focus" the direction of explosive blasts. Charges with special containment plates above and below the explosives, true-shaped charges, and explosive tapes are examples of this evolving technology. However, there are limitations to the utilization of these explosives. Obstructions in structure tubulars, centralization of the charges to maintain the effective special orientation of the explosives, and multiple casing strings with grout in the annuli (for true-shaped charges) present difficulties in using these technologies.

Mitigation for Explosive Removals

Precautions required by the MMS and NMFS have been very effective in lowering the risk of injury or death to sea turtles and marine mammals from explosive structure removals. Since the imposition of the following mitigative measures, there has been no evidence to indicate that any of the explosive structure removals since the summer of 1987 have injured or killed a sea turtle or marine mammal.

- Qualified observer(s), as approved by NMFS, must be used to monitor the area around the site before, during, and after detonation of the charges. Surface observation must begin 48 hours before removal of the structure. If sea turtles are observed in the vicinity of the structure and are thought to be residents of the site, the waiver is canceled and divers must take surveys before and after the charges are detonated.

- On the day of blasts, a 30-minute aerial survey must be conducted within 1 hour before and 1 hour after the detonation. A qualified observer must be used to check for the presence of turtles and, if possible, to identify species. If weather conditions (fog, excessive winds, etc.) make it impossible to conduct the aerial survey, the blast may be allowed to proceed if approved by the designated NMFS and MMS onsite representative on site.

- If any sea turtles are observed in the vicinity of the structure (within 1,000 yards of the site) before detonating charges, the blast will be delayed until steps are taken to remove them. The survey must be repeated before detonation.

- Detonation of explosives will occur no sooner than 1 hour following sunrise and no later than 1 hour before sunset. However, if it is determined by the NMFS or MMS onsite representative that special circumstances justify a modification of these time restrictions and modification is not likely to adversely impact listed species, the blast may be allowed to proceed.

- During all diving operations (working dives as required in the course of the removal), divers will be instructed to scan the subsurface areas surrounding the structure site for turtles and marine mammals. Any sightings must be reported to the NMFS or MMS onsite representative. Following the blast, divers must report and attempt to recover sighted injured or dead sea turtles or marine mammals.

- Charges must be staggered to minimize the cumulative effects of the blast.

- A preliminary report summarizing the results of the removal and mitigation measures must be submitted to MMS and NMFS within 15 working days of the removal.

Nonexplosives

Since early 1987, various types of nonexplosive techniques have been designed, tested, and utilized to remove structures.

One such technique is the use of mechanical cutters, which involves installing a "bird cage" device on the top of the piling or caisson to be removed, lowering the cutting tool into the tubular to the desired depth, and then rotating the tool with a hydraulic swivel. The cutting tool has stabilizers at each end, which are designed to center the tool in the hole. As the tool rotates, cutting arms with carbide steel tips are hydraulically extended and the cutting procedures begin. Though successful in some applications, difficulties may arise that limit this procedure. During a structure-removal operation with MMS and NMFS observers aboard, a mechanical cutter attempted to cut through a 42- by 1.25-inch piling, 4 inches of cement grouting, and a 48- by 0.5-inch leg. The attempt was unsuccessful for several reasons. The seas were rough throughout the entire operation, and the men had problems installing the equipment and putting the tool into the piling (one man was injured in the attempt). They could not effectively stabilize the tool in the hole (it wobbled badly while rotating, thus preventing an even cut). The angle of the leg and pile (+ 15°) probably prevented stabilization. Finally, the tool's cutting diameter was not wide enough when fully extended to cut through the pile, grout, and leg. The structure was ultimately removed by divers with arc-cutting tools. The removal of large, complex structures will require improvements in mechanical cutter tools.

Rotating abrasive sand cutters have also been used successfully on several occasions in the Gulf. This procedure is similar to the techniques described with mechanical cutters, except abrasive material is pumped down hole with a carrier liquid. A nozzle directs the abrasive stream. As with the other cutters, centralizing the cutter head is essential to the procedure's success. Maintaining appropriate "stand-off" is critical. This procedure has proved to be a success in removing offshore structures.

Another abrasive cutter device proposed to be used in 1988 is a rotating torch-flame cutting tool. Its application is similar to the rotating mechanical cutter but uses a burning gas mixture to sever the structure's tubulars.

A fourth nonexplosive technology involves a cryogenic fracturing technique. The legs/pilings of the structure are evacuated of all materials (mud, water, etc.) to the desired depth; liquid nitrogen is then pumped down to that area in attempt to cryogenically embrittle the steel tubular. Once this is accomplished, a shock is applied to the tubular with the intention of fracturing the embrittled metal. The technique has been tried on three separate occasions. The first attempt involved striking the "frozen" pile from above with a pile driver. It was concluded that the force of the impact was not being effectively transferred to the "frozen" area of the pile. The structure was eventually removed using explosives. For its second attempt, the operator fabricated a piston-driven impact tool, which was designed to strike the inside of the embrittled pile, thereby shattering the metal. However, the tool failed to produce the amount of force at its impact point needed to fracture the metal, and again, explosives had to be used to complete the job. In early February 1988, cryogenic procedures were once again proposed with the detonation of a 5-pound charge down hole after the liquid nitrogen embrittlement. The 5-pound charge proved to be inadequate, but a 10-pound charge for each of the piles cleanly shattered the metal, and the structure was removed. Although this technique utilized explosives, the amounts detonated were very small, thereby reducing the potential impacts on the sea turtles, marine mammals, and fish.

Arc cutting with divers either from inside or outside of a tubular is by far the most time consuming and dangerous of all nonexplosive removal techniques. Concerns for diver safety include an unexpected shift of the tubular as it is severed, sloughing of sediments into a space excavated around the outside of a tubular to facilitate diver operations, and encountering gas while burning through the tubular.

CONCLUSION

In summary, structure removal technology is advancing dramatically. Emphasis has been and will continue to be on lessening potential impacts to sea turtles and marine mammals. Regulatory and economic consideration will continue to play a major role in structure removal decisions. It is to be hoped that, in the near future, economical techniques will be devised that will have no impacts on endangered, threatened, and/or protected species.

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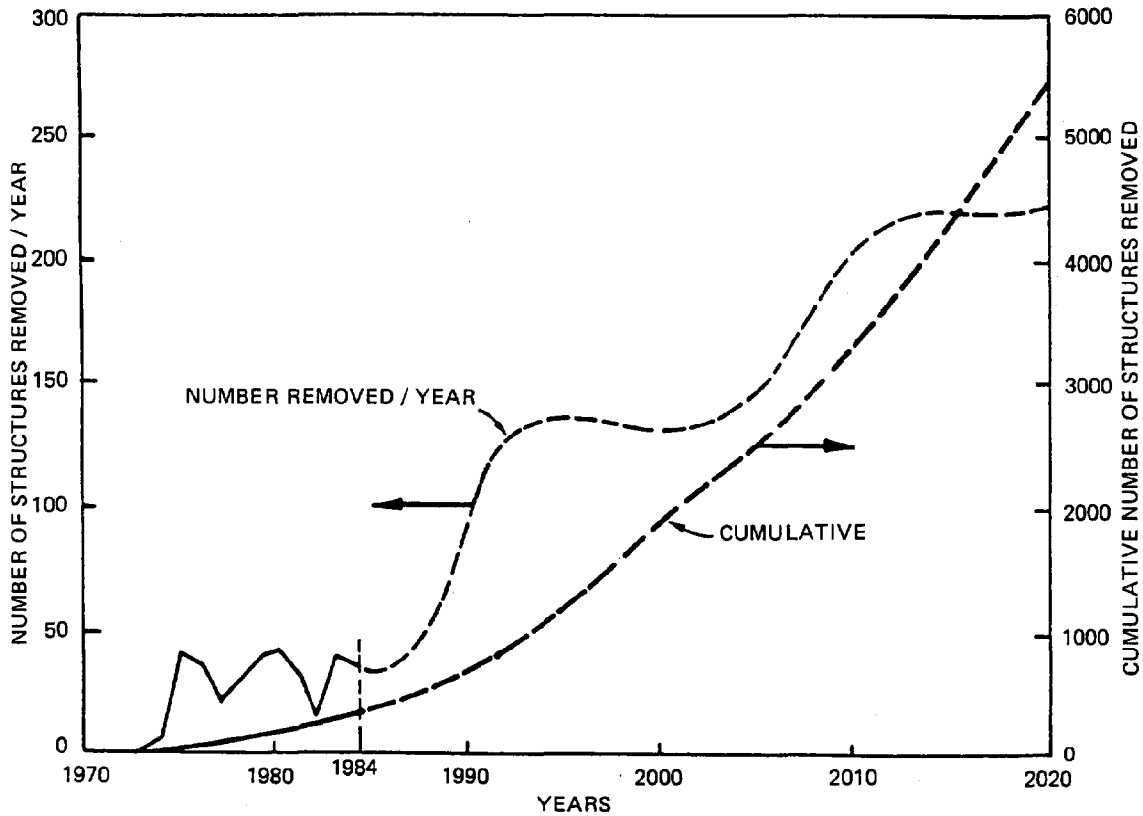

Structures removed and to be removed---Gulf of Mexico.

Source: Historical data from Minerals Management Service and industry sources; forcast developed by committee based on assumptions described in the text.

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