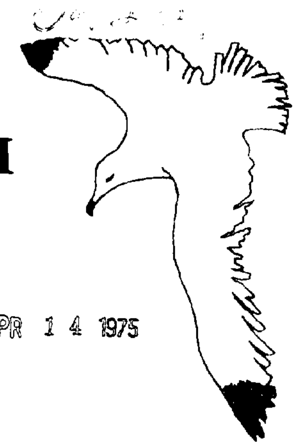
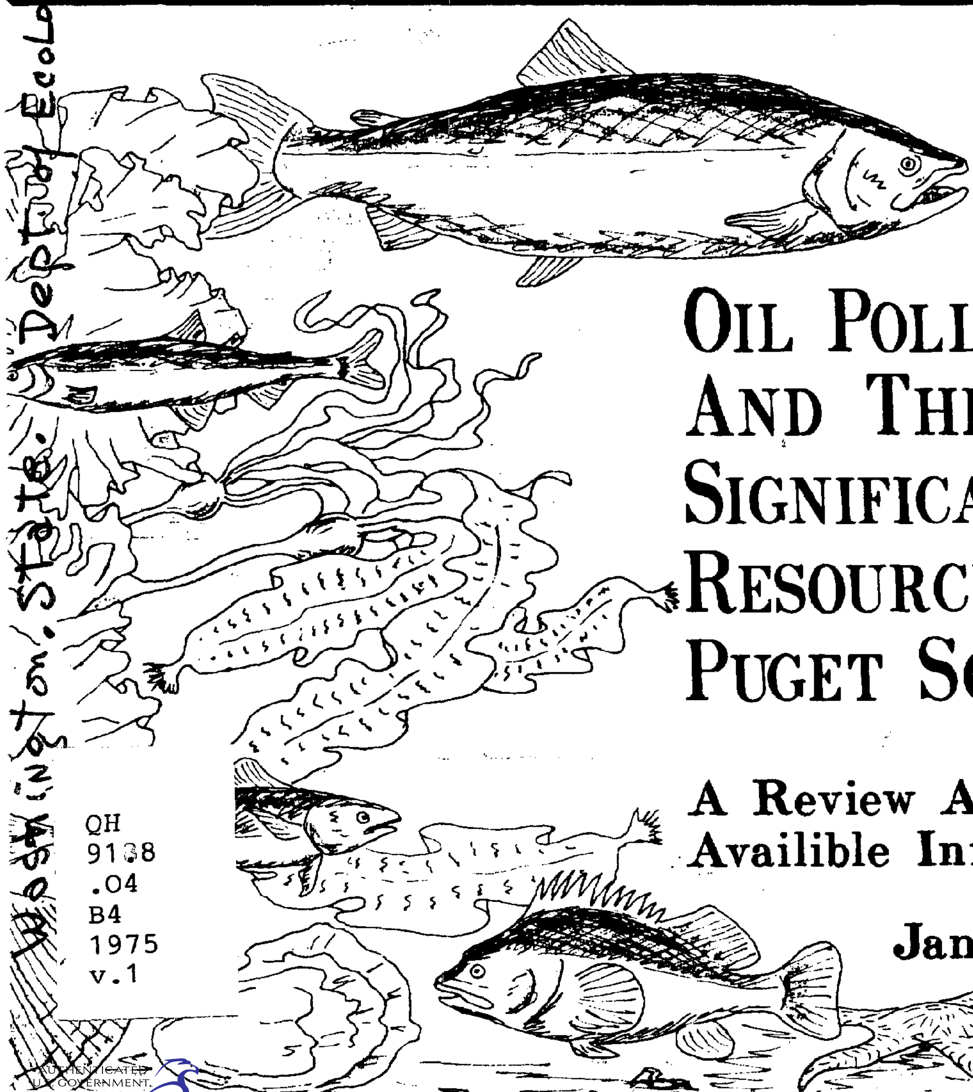
State of Washington
Department of Ecology

BASELINE STUDY PROGRAM
NORTH PUGET SOUND





OIL POLLUTION AND THE SIGNIFICANT BIOLOGICAL RESOURCES OF PUGET SOUND

A Review And Analysis Of Availible Information

January 1975

OIL POLLUTION AND THE SIGNIFICANT BIOLOGICAL RESOURCES OF PUGET SOUND:

A REVIEW AND ANALYSIS OF AVAILABLE INFORMATION

PREPARED FOR

STATE OF WASHINGTON DEPARTMENT OF ECOLOGY

PREPARED BY

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BEAK

FOREWARD

This report has been written for a mixed audience, including scientists, legislators, planners and interested laypeople. At times the text will seem oversimplified to some, and unfortunately, overtechnical to others. We have especially tried to avoid being overtechnical. BEAK sincerely hopes that we have made this report as valuable as possible to the greatest number of potential users.

We wish to acknowledge the work and dedication of all those who contributed to the information base from which this report was derived.

Beak Consultants Incorporated recognizes that errors may occur in the computer output accompanying this text due to the large volume of information incorporated into this study, and makes no guarantee regarding the accuracy or completeness of specific pieces of information.

Project Manager

James W. Buell, Ph.D.

Project Approval

Victor W. Kaczynski, Ph.D.
Vice President
BEAK CONSULTANTS INCORPORATED

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I. INTRODUCTION

Beak Consultants Incorporated was retained by the Washington State Department of Ecology to conduct a review and analysis of the available literature on the ecology of the "Significant Biological Resources" of Puget Sound, and on possible effects of spilled oils and petrochemical products on these biota. As part of the study, fact sheets incorporating information on distribution, aspects of habitat, ecology and life history, and susceptibility to oil and petrochemical pollution were prepared for each resource species. In addition, an annotated bibliography and a written report outlining potential effects of oil pollution were supplied. In order to provide a useful finished product incorporating a large volume of material, BEAK independently devised a general computerized information sorting and retrieval system. This system, as it was used for this project, has produced composite species fact sheets and an annotated bibliography which fulfill Objective 6, Task A of Washington State's Marine Analysis Program. Objective 7, Task A and part of Objective 7, Task B have been fulfilled by computerized composite oil impact fact sheets. The remainder of Objective 7, Task B has been fulfilled by the text section of this report. Magnetic tapes including all raw information have also been provided. The organization of biological information in BEAK's part of the Marine Analysis Program has followed guidelines established by the Washington Department of Ecology. The species and habitats to be considered were also defined by the Department.

Traditional literature searches, including computerized programs, have attempted to manage information by incorporating abstracted written materials, developing annotated bibliographies, and preparing key word indices. These services are essentially the same as cross-referenced card index systems, but allow for the management of more information and faster searches of stored sources. The search for material is shortened considerably, but the user must eventually return to the original source for specific information.

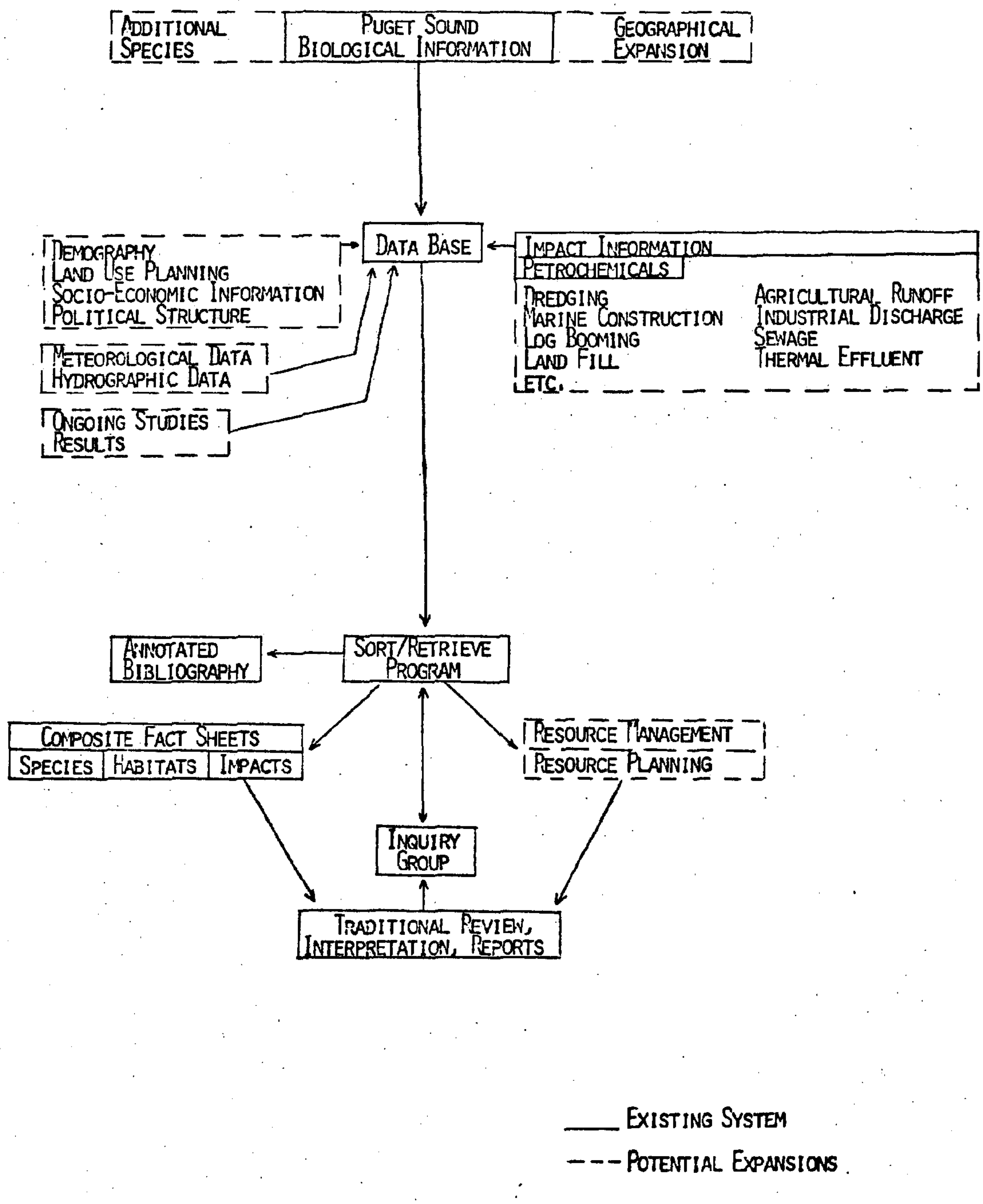
BEAK's system of computerizing data on a more detailed level was utilized here because of the unique goals of the project. Information was gathered by qualified biologists reading within their fields. Data-type information from written materials was abstracted and stored in an integrated retrievable database. The data were organized to maximize the retrieval of information in such categories as organism group, species, area of distribution, life stage, habitat, petrochemical type, and impact. The computer output from the system consists of an annotated bibliography and fact sheets which display information on distribution, habitat, and oil impact for each species in composite format. In addition to composited information, each fact sheet includes information for each species on life history, economic value, predators, prey, and comments on the article made by the reviewer. The methods section will describe methodologies employed by the computerized system in more detail.

For probable oil pollution impact assessment, a total of nine general habitat types, encompasing over 150 combinations of habitat characteristics, have been considered in this study. The 250 species designated for the literature search have been assigned to thirteen broad organism groupings. By identifying these habitat types and gathering data for input on species groups, the number of organism-habitat combinations was reduced to a manageable size and it became possible to estimate impacts for each of these combinations.

A block diagram of BEAK's system as it exists (and as it can be expanded) is presented in Figure 1. All inputs have involved: (1) the reading and abstracting of articles, (2) coding and keypunching of selected materials, (3) several editorial steps, and (4) storage of the information. Information in the output will be useful to planners and legislators concerned with projected petrochemical pollution in the Puget Sound area. Further, the output will be useful to scientists interested in examing background data on the biota of Puget Sound and, of course, the impacts of oils upon them.

If BEAK's system is expanded (as indicated in Figure 1), its application to local and regional planning, siting studies, the projection of natural resource management needs, and the assessment of actual and potential impacts of a wide variety of human activities should be apparent.

FIGURE 1


ADDITIONAL SPECIES
PUGET SOUND BIOLOGICAL INFORMATION
GEOGRAPHICAL EXPANSION
DATA BASE
DEMOGRAPHY
LAND USE PLANNING
SOCIO-ECONOMIC INFORMATION
POLITICAL STRUCTURE
METEOROLOGICAL DATA
HYDROGRAPHIC DATA
ONGOING STUDIES RESULTS
IMPACT INFORMATION
PETROCHEMICALS
DREDGING
MARINE CONSTRUCTION
LOG BOOMING
LAND FILL
ETC.
AGRICULTURAL RUNOFF
INDUSTRIAL DISCHARGE
SEWAGE
THERMAL EFFLUENT
ANNOTATED BIBLIOGRAPHY
SORT/RETRIEVE PROGRAM
COMPOSITE FACT SHEETS
SPECIES
HABITATS
IMPACTS
RESOURCE MANAGEMENT
RESOURCE PLANNING
INQUIRY GROUP
TRADITIONAL REVIEW, INTERPRETATION, REPORTS
EXISTING SYSTEM
POTENTIAL EXPANSIONS

II. METHODS

The methods used by BEAK to accomplish the purposes of this project have been briefly mentioned in the Introduction. Essentially these involved the use of a computerized sorting and retrieval system to rearrange information from the available literature into comprehensive fact sheets on distribution and habitat associations. To facilitate the review of all material entered into the system and to allow a reader to locate the original data source, an annotated bibliography, listed alphabetically by author, was also compiled by computer. The textual portion of this report serves interpretive and predictive functions.

In order to build the data-base from which composite fact sheets were derived, information was extracted from the literature and entered onto species and oil impact information sheets. The data were subsequently keypunched from these sheets directly into the data-base. The species information sheets contained the following categories for data entry:

- Species
  - Life Stage
    - Area
      - Location
        - Month
          - Habitat
            - Physical-Chemical
              - Abundance

- Predators
- Food
- Life History
- Value
- Comments

In addition to these categories, oil impact information sheets contained the following categories:

- Petrochemical Studied
  - Impact Parameter
    - Impact Criterion
      - Dose
        - Result

Nine major habitat types (described below) were accessed by species, life stage, area, and time of occurrence. The habitat composite sheets are organized as follows:

Habitat Type
Vertical Zonation
Species Jan. Feb. Mar.
Life Stage
Area * (star indicates occurrence)

Each piece of information occurring on these fact sheets is accompanied by its reference number and the value rating that had been assigned to it.

Approximately 250 species of plants and animals were considered in this study (See Appendix B). For most of these species, the system recognizes five life stages (Tables 1 and 2), covering development from eggs or gametes to reproducing adults. "Area" refers to one of the following areas:

Open Coast	Hood Canal
Strait of Juan De Fuca	Southern Puget Sound
San Juan Archipelago	Straits of Georgia
North Puget Sound	Discovery Passage
Whidbey Basin	Greater Puget Sound
Admiralty Inlet	General (specified)
Puget Sound Basin	

"Location" is defined as closely as possible within the "Area," using latitude and longitude whenever appropriate. When available, the month during which the study was conducted is indicated. The habitat is specified as closely as possible. Definitions of terms used in habitat description are given in Table 3. The habitat designations which appear on the composite species fact sheets combine appropriate description words for each of five groups of habitat characteristics (Table 4). For example, "Demersal-benthic/Subtidal-photosynthetic/Inorganic/Mixed/Very coarse" might appear. By combining descriptors in this way, over 150 combinations of habitat characteristics can be applied to actual habitats observed in the field.

Physical-chemical data include such parameters as temperature, salinity, light, dissolved oxygen, turbidity, etc. Abundance data assume a wide variety of forms depending upon the information source. Predators and food organisms are indicated to the narrowest taxon. Life history information is entered in

Table 1
LIFE STAGES OF ANIMALS — DEVELOPMENTAL STAGES

ORGANISMS	I EGGS	II LARVAE	III JUVENILES	IV ADULTS	V REPRODUCING ADULTS
Mammals			Juvenile	Adult	Rep. Adult
Birds	Egg	Nestling	Fledgling	Adult	Rep. Adult
Fish	Egg	Fry	Juvenile	Adult	Rep. Adult
Echinoderms					
Holothurians (sea cucumber)	Egg	Dipleurula Auricularia	Doliolaria Pentactula	Adult	Rep. Adult
Asteroids (starfish)	Egg	Bipinnaria	Brachiolaria	Adult	Rep. Adult
Echinoids (urchins)	Egg	Blastula Gastrula	Echinopluteus	Adult	Rep. Adult
Arthropods					
Copepods	Egg	Nauplius	Copepodid	Adult	Rep. Adult*
Balanus (barnacle)	Egg	Nauplius	Cypris	Adult	Rep. Adult
Isopods (beach isopods)	Egg			Adult	Rep. Adult*
Amphipods (sand flea)	Egg			Adult	Rep. Adult*
Euphausiids	Egg	Nauplius Calyptopsis Furcilia (Zoea)	Cyrtopia	Adult	Rep. Adult
Pandalids (shrimp)	Egg	Zoea	Mastigopus (Mysis)	Adult	Rep. Adult*
Anomurans (king crab)	Egg	Zoea	Glaucothoe	Adult	Rep. Adult*
Brachyura (crab)	Egg	Zoea	Megalops	Adult	Rep. Adult*
Mollusks					
Polyplacophorans (chitons)	Egg	Trochophore	Juvenile	Adult	Rep. Adult
Gastropods (snails)	Egg	Veliger	Spat	Adult	Rep. Adult
Pelecypods (bivalves)	Egg	Larva	Juvenile	Adult	Rep. Adult
Cephalopods (squid, octopus)	Egg	Larva	Juvenile	Adult	Rep. Adult
Annelids					
Nereids (segmented worms)	Egg	Trochophore	Nectochaetal larvae	Adult (atoke)	Rep. Adult (epitoke)

* Broods eggs

Table 2

LIFE STAGES OF PLANTS (PUGET SOUND OIL BASELINE STUDY)

SPECIES	I GAMETES	II ZYGOTE	III SPOROPHYTE (A)	IV SPORES (A)	V SPOROPHYTE (B)	VI SPORES (B)	VII GAMETOPHYTE
RHODOPHYTA (Red Algae)							
Gigartina: papillata	spermatia carpogonia	procarp (zygote)	carposporophyte (haploid? diploid?)	carpospores (haploid?)	Petrocelis stage? (no observed tetrasporophyte		gametophyte Plants dioecious some monoecious
exasperata	spermatia carpogonia	procarp (zygote)	carposphorophyte (diploid)	carpospores (diploid)	tetrasporophyte (diploid)	tetraspores (haploid) tetrasporangia from veg. cells of cortex	gametophyte plants dioecious
Iridaea: cordata	spermatia carpogonia	procarp (zygote)	carposporophyte (diploid)	carpospores (diploid)	tetrasporophyte (diploid)	tetraspores (haploid) tetrasporangia from accessory branches of medullary filaments	gametophyte dioecious
Porphyra: torta miniata perforata nereocystis abbottae	spermatia carpogonia	carpospores (diploid)			sporophyte conchocelis stage (diploid)	conchospore (meiospore)	gametophyte (haploid) monoecious
san juanensis			monosporophyte (haploid?)	monospores (haploid?)			
PHAEOPHYTA (Brown Algae)							
Nereocystis: leutkeana kelp	eggs sperm	zygote (attached to gametophyte)			sporophyte (diploid) annual	meiospores (uniloc sporangia) haploid	gametophyte male and female
Macrocystis: pyrifera	eggs sperm	zygote (attached to gametophyte)			sporophyte (diploid) perennial	meiospores (uniloc sporangia or sporophylls) haploid	gametophyte male and female

Table 2 (cont.)

SPECIES	I GAMETES	II ZYGOTE	III SPOROPHYTE(A)	IV SPORES(A)	V SPOROPHYTE(B)	VI SPORES(B)	VII GAMETOPHYTE
SPERMATOPHYTA							
Zostera: marina Eelgrass	differentiated gametophytes with sperm and egg nucleus (monoecious)	dehisced reproductive turion with seeds maturing and finally shed			sporophyte (submersed perennials with annual leaves)	free microspores (pollen) attached macrospores	female gametophyte attached to sporophyte; male unattached
Phyllospadix scouleri Surfgrass	differentiated gametophytes with sperm and egg nucleus (dioecious	seed			sporophyte (submersed perennials with annual leaves)	free microspores (pollen); attached macrospores	female gametophytes attached (female) to sporophyte; male unattached

TABLE 3

Habitat Definitions

Major habitat zones:

Demersal-benthic
- Uppermost horizon (extreme high water to mean high water)
- High intertidal (mean high water to mean sea level)
- Middle intertidal (mean sea level to mean lower low water)
- Low intertidal (mean lower low water to extreme low water)
- Subtidal - photosynthetic (extreme low water to lower limit of photo zone)
- Subtidal - nonphotosynthetic (lower limit of photo zone to bottom)

Pelagic
- Surface (to 1 meter depth)
- Midwater - photosynthetic (1 to 20 meter depth)
- Midwater - nonphotosynthetic (20 meter depth to 1 meter from bottom)
- Bottom (within 1 meter of bottom)

Laboratory

Major substrate types and textures:

Inorganic
- Solid rock (continuous strata)
- Boulder (>256 mm diameter)
- Cobble (64 - 256 mm)
- Pebble-gravel (4 - 64 mm)
- Sand
  - Very coarse (1 - 4 mm)
  - Coarse (0.5 - 1.0 mm)
  - Medium (0.25 - 0.5 mm)
  - Fine (0.12 - 0.25 mm)
  - Very fine (0.06 - 0.12 mm)
- Silt (0.004 - 0.06 mm)
- Clay (<0.004 mm - smooth and slick)
- Mixed
  - Very coarse (solid rock, boulder, cobble)
  - Coarse (boulders, cobble, gravel)
  - Medium (small cobbles, gravel, sand)
  - Fine (gravel, sand, coarse mud)
  - Very fine (sand, mud, clay)

Organic
- Shell fragments - $CaCO_3$
- Detritous (accumulated wood, sticks and undecayed coarse materials)
- Fibrous peat (partially decomposed plant remains)
- Pulpy peat (finelly divided plant remains)
- Muck (black, finely divided organic matter)
- Eelgrass
- Kelp
- Periphyton

TABLE 4

Habitat Descriptor Groups

I	II	III	IV	V
Demersal-benthic	Uppermost horizon	Inorganic	Solid rock	Very coarse
Pelagic	High intertidal	Organic	Boulder	Coarse
Laboratory	Middle intertidal		Cobble	Medium
	Low intertidal		Pebble-gravel	Fine
	Subtidal-photosynthetic		Sand	Very fine
	Subtidal-nonphotosynthetic		Silt	
	Surface		Clay	
	Midwater-photosynthetic		Mixed	
	Midwater-nonphotosynthetic		Shell fragments	
	Bottom		Detritous	
			Fibrous peat	
			Pulpy peat	
			Muck	
			Eelgrass	
			Kelp	
			Periphyton	

paragraph form and includes such information as migration and spawning habitats, fecundity, growth patterns, etc. "Value" is a qualitative category and reflects the commercial, recreational, predator, competitor or prey status of the organism.

The petrochemical referred to in an oil impact fact sheet can be any one of the 35 crude oils and petrochemical products given in Table 5. Impact parameters have been divided into direct and indirect impacts as follows:

Direct	Indirect
Mortality	Food supply
Reproduction	Predators
Predation	Environment (specified)
Tainting	
Avoidance	
Growth	
Physiology (specified)	
Mobility	
Density (specified)	

The impact "criterion" given on oil impact fact sheets depends on the information source, and may include such entries as LD_{50}, TLM, % mortality, etc. "Dose" refers to oil exposure or treatment. The outcome of a set of experimental or observational conditions is given as the "result."

After designing the data input system described above, the literature search was begun by using commercial search services to provide an idea of the availability of pertinent information and help define the direction in which to proceed. Commercial search services were neither detailed nor comprehensive enough in their coverage to be used alone, however. Large areas of pertinent information were defined, and these were then searched in more detail.

After having been read, articles were rated regarding their usefulness to the project, not merely for their scientific excellence or validity, on a scale of 1 (excellent) to 5 (poor). Information of questionable validity is of

TABLE 5

Petrochemicals

Crude oils	Petrochemical products
Canadian (Alberta)	Gasoline
Mid-East mix	Jet fuel A (Gas type)
Canadian (Cook Inlet)	Jet fuel B (Kerosene type)
Nigerian	JP4
Arabian	JP5
Venezuelan	Aviation fuel
Canadian	Marine fuel
Alaskan	Diesel No. 2 (heating)
Indonesan - Minas, Attaka	Diesel, truck
Bolivian	Fuel oil
50/50 California - San Joaquin, Santa Maria	Kerosene (crystalline)
South America - Oriente	Turbine fuel
San Ardo	LPG (propane)
Sumatra	Asphale
Sweet	Petroleum coke
Four Corner	Residuals (bunker)
Lasalina	Aromatic hydrocarbons
Other (specified)	Aliphatic hydrocarbons
	Other (specified)

questionable usefulness, but information of high veracity may also be of only marginal usefulness, and may therefore receive a low rating. The suitability of the data for inclusion into the system was the major consideration behind the rating.

The storage-retrieval system conceived by BEAK uses Data Management Language (DML), a computer language provided by Computer Sciences Corporation (CSC). The program was run on a Univac 1108 computer in both timesharing and batch modes. The use of a time-sharing system has the advantage that users in several locations can simultaneously access the data-base.

To reduce the amount of computer storage space required, and to facilitate the cross-referencing of the information, codes were created for the major data input components of the program. Habitats were given a five-digit code, each digit representing one of the five classes of habitat descriptors given in Table 4. In this way, habitat zones could be combined with a large variety of substrate types and textures allowing much detailed information to be stored in limited computer space.

Other input data were coded to reflect either general ecological or oil impact information using the first digit of a two-digit code. The second digit represented parameters such as month, life stage, etc.

After the data were abstracted and coded, they were edited and then keypunched for entry into the data-base. The data-base was edited once in its "raw" state and again after the compositing process.

The output contained in the species and oil fact sheets was used as part of the basis for writing the projected impact section of this report.

Using the composited species and oil impact fact sheets, the text was prepared to follow the logical sequence of the program's development. General impacts of oils (crudes, light products, and heavy products) on each of nine generalized habitats is discussed. Under each habitat type, each of thirteen organism groups were discussed relative to their occurrence in that habitat. The nine habitats are given in Table 6. Habitat types referred to in the text are independent of depth, and, with the exception of "open water," primarily represent substrate types. The five "mixed" habitats used in the composite fact sheets have been condensed into two in the text. "Mixed - Coarse" in the text combines "mixed/very coarse" and "mixed/coarse" from the composite sheets. "Mixed - Fine" in the text combines "mixed/medium," "mixed/fine," and "mixed/very fine" from the composite sheets. Other habitat types should be self-explanatory. Under each habitat type, each of thirteen organism groups were discussed relative to their occurrence in that habitat and their susceptibility to oil impacts in those habitats.

Each subsection of the "Expected Impact" portion of the text is followed by an indication of the reliability of the material presented in that subsection. Criteria used for assigning reliabilities are as follows:

****: Very reliable: The information presented is well documented in the literature and is supported by generally accepted biological and physical principles.

***: Reasonably reliable: The information presented is supported by generally accepted biological and physical principles and is partially supported in the literature.

**: Deductive: The information presented is supported by generally accepted biological and physical principles and is circumstantially supported in the literature.

*: Speculative: The information presented is consistent with generally

TABLE 6

GENERAL HABITAT TYPES AND ORGANISM GROUPS

Habitat Types	Organism Groups
Rock	Mammals
Sand	Birds: offshore feeders
Mud	Birds: shorebirds
Mixed - coarse	Birds: casual marine feeders
Mixed - fine	Fishes: shoreline
Eelgrass bed	Fishes: demersal
Kelp bed	Fishes: open water
Salt marsh	Echinoderms
Open water	Crustaceans
	Molluscs
	Annelid
	Algae
	Grasses

accepted biological and physical principles, and is suggested by information in the literature.

III. RESULTS - COMPUTER OUTPUT

A. Annotated Bibliography

The annotated bibliography has been organized as described in the preceding "Methods" section. Cross reference numbers relating data to the articles from which they were abstracted are listed on the composite fact sheets. At the end of each fact sheet, the author and date of publication of each article cited are listed according to reference number. An article can then be located by the author's last name in the annotated bibliography and a comparison of reference numbers will assure selection of the correct abstract.

B. Composite Species Fact Sheets

The composite species fact sheets were organized as described in the preceding "Methods" section. Information was taken from raw data sheets and compiled by the computer into a format which presents information on each species.

C. Composite Oil Impact Fact Sheets

The composite oil impact fact sheets were organized as described in the preceding "Methods" section. Information was taken from raw data sheets and compiled by the computer into a format which presents information on each oil impact.

D. Composite Habitat Fact Sheets

The composite habitat fact sheets were organized as described in the preceding "Methods" section. Habitat types were chosen to accomodate as many habitats occurring in Puget Sound as possible. The system has been constructed to allow access to data according to general habitat type for any species. Over 150 possible combinations of habitat characteristics have been condensed into nine basic habitat types. The basic habitats correspond to combinations of descriptors given in Table 7.

TABLE 7

General Habitat Types For Habitat Composite Sheets

General Habitats	Descriptors
Rock	Rock Boulder
Sand	Sand
Mud	Silt Clay Muck Detritus Fibrous peat Pulpy peat
Mixed-coarse	Cobble Mixed-very coarse Mixed-coarse
Mixed-fine	Mixed-medium Pebble-gravel Mixed-fine Mixed-very fine Shell fragments
Eelgrass Bed	Eelgrass bed
Kelp Bed	Kelp bed Periphyton
Salt Marsh	Salt marsh
Open Water	Pelagic Surface Midwater-photosynthetic Midwater-nonphotosynthetic Bottom

IV. RESULTS - TEXT: Probable Impact

INTRODUCTION

Certain general characteristics of oils and oil pollution apply to all habitats and all organism groups. An appreciation of these characteristics is necessary if specific impacts of oils and petrochemical products are to be understood.

Oils and petrochemicals display a wide variety of properties. In general, there are three factors governing the persistence of spilled oils in the environment and their toxicities to organisms living there. These are carbon number (the number of carbon atoms in each molecule), the degree of substitution (the number, size, and kind of chemical groups attached to each molecule), and the degree of aromaticity (the number of compounds in the oil or petrochemical having rings with resonating double bonds).

Persistence in the environment is highest in those oils or petrochemicals with low evaporation rates and those which tend to stick to or interact with the substrate. Large molecules (those with high carbon numbers) evaporate slowly, especially if they tend to interact with each other or the substrate because of complex molecular structures or attached groups. Aromatic compounds and, in some cases, highly substituted compounds, tend to be more soluble in water than most aliphatic (nonaromatic) compounds, and therefore enter the water column readily.

Rates of solublization, evaporation, emulsification, and natural dispersion of the various components of oils and petrochemical products are governed by temperature, wind conditions, and the amount of hydrological energy available. Higher air temperatures and greater air movement over a slick or contaminated substrate accelerate evaporation of light compounds. High water temperatures increase the rates of solublization of aromatic and substituted compounds, the rate of biological incorporation or degradation, and the rate of spread or dispersion of a slick. These effects are particularly evident in the early stages of a spill. Hydrological conditions are particularly important, especially regarding intertidal impacts. High energy conditions (surf or heavy surface chop) tend to increase the solublization and emulsification of toxic compounds, increasing the magnitude of impact. These same conditions, however, tend to favor the dissipation of the relatively nontoxic aliphatic compounds. Low energy (calm) conditions favor the evaporation of toxic compounds, thereby minimizing their incorporation into the marine environment. Heavy aliphatic compounds tend to persist for a very long time under low energy conditions, and their incorporation into the substrate is more likely.

There are many kinds of crude oils just as there are many classes of refined products. Biological impacts of crudes, whether chemical or mechanical, are governed primarily by the relative amounts of various components. So-called aliphatic or paraffinic crude oils have low concentrations of toxic materials, and their impacts are mostly mechanical. Aromatic crude oils have relatively high concentrations of toxic compounds and have both chemical and mechanical effects on organisms with which they come in contact. As these oils undergo the "weathering" process (evaporation of volatile, toxic compounds, selective leaching of metals, and biological degradation), impacts become more mechanical. "Naphthenic" crude oils have high concentrations of compounds related to naphthalene (a fairly stable double ring aromatic compound). These are moderately toxic and moderately persistent. Toxic effects in the case of these oils are less acute, but prolonged.

Toxicity is a function of reactivity; the more reactive a compound, the more likely it is to interfere with biological functions. Large aliphatic compounds do not tend to mix easily with water or biological tissues, and do not tend to react biologically. Therefore the toxicity of these compounds is almost always low. Highly substituted compounds can react more easily, and their toxicities cover a wide range depending on the nature of the substitutions. Aromatic compounds are very reactive in biological systems, and have extremely high toxicities. Small molecules, especially the more reactive varieties, can penetrate biological tissues easily and are the most damaging in terms of toxicity. However, these evaporate rapidly under most conditions and are the least persistent.

Besides chemical toxicity, oils and petrochemicals can have a mechanical impact on organisms. Animals or plants may become coated to the extent that gas exchange becomes impossible and suffocation takes place. Many animals are filter feeders and have evolved elaborate mechanisms for sorting and collecting tiny particles of food from the water. The same structures are frequently used for respiration. Oils may easily clog these structures causing starvation or suffocation. These effects are most severe with heavy, persistent oils. In the cases of birds and sea otters, feathers or fur may become matted or wetted to such an extent that flotation and insulation are drastically reduced and drowning or death from chilling takes place. These effects are probably most severe with mixtures of heavy aliphatic oils which mat the insulation, and aromatic compounds which allow water to penetrate. Mobility may be impaired by the coating of intertidal substrates with oil. Animals such as snails and sea urchins, cannot cling to oiled rocks and can be washed away and battered by even light wave action.

The total impact of an oil spill on organisms will always be a combination of many effects, although the spill of a particular type of petrochemical or oil may elicit the predominance of one type of effect over the others.

A. ROCK

1. General Impact

Rock surfaces exist where energy conditions are too high or the slope of the substrate is too great to allow sediment deposition. As oil moves inshore in high energy rocky areas, it can be emulsified by surf and spread over the intertidal and shallow subtidal rock surfaces. If the oil contains light, toxic fractions, they are more readily emulsified than in low energy environments where they can remain on the water surface and evaporate. Therefore the initial toxic effects to organisms can be higher in this environment than in low energy situations.

Once coating of rocks has occurred, the surf generally causes rapid flushing except in the high intertidal where oil coatings may persist for long periods. Remaining oil is subject to weathering, bacterial action and photochemical effects.

Vertical rock surfaces parallel to the direction of wave travel may not be subjected to active surf, so emulsification and initial impact may be less severe, and flushing comparatively slower. Subtidal rock faces are generally either vertical or swept by strong currents, and are protected by a water insulation from direct contact with oil.

Tidepools pose a particularly serious problem in the event of an oil spill in this habitat. Oil washed into upper or middle intertidal pools affects the residents in a complicated manner. The oil film tends to absorb infrared sunlight preventing natural evaporation of water and warming the system, thereby increasing the solubility of soluble fractions. Chronic toxicity elevates metabolic rates (oxygen consumption) of animals, and in many fishes it can increase over ten-fold with only moderate disturbance. The oil film also serves as an effective gas exchange block at the tidepool surface. The likely result in many instances would be suffocation of fishes and some invertebrates at oil concentrations well below acute toxicity levels. Greatly increased predatory activity by relatively resistant grapsoid crabs is also a possibility.

SUMMARY: In most cases rock is subjected to heavy initial coating of surf-created emulsions, but is also rapidly flushed. Tidepools in rocky habitats can be severely affected.

RELIABILITY: ***

A. ROCK

2. Mammals

As specific information concerning the impact of various oils and oil products on individual marine mammals is very limited, only a general discussion of oil impacts is possible. Seals, sea lions, and otters are mammals that come into contact with the rock habitat. Although such mammals do not depend on this habitat for their food supply, they do use rocky shores as loafing or resting grounds. And, since birth normally occurs on land, the rock habitat is commonly used for this purpose as well. The river otter (Lutra canadensis), sea otter (Enhydra lutris), and harbor seal (Phoca vitulina), known to breed in the Puget Sound and Washington coast areas, use the rock habitat as a rookery.

Seasonal occurrence and distribution within the study area varies among mammals. The Stellar's sea lion (Eumetopias jubata) and the sea otter may be found all year along the coast, while harbor seals (also permanent residents) are found throughout the study area. River otters occur all year in a quasimarine habitat in the San Juan Island area. Northern fur seals (Callorhinus ursinus) are offshore migrants (October to May) and use the rock habitat to a lesser extent.

Sea otters and river otters are by far the most susceptible mammals to oil pollution. Although the greatest threat of oil is in the water, otters may encounter oil washed up on the intertidal zones of rocky shores. Otters have no insulating fat layer but rely entirely on their dense, water repellent fur for warmth. Oil tends to mat the fur, causing a loss of buoyancy, destroying the insulative quality of the fur, and causing chilling. Otters cannot survive for long in this condition.

Seals and sea lions are probably less susceptible to oil pollution. Members of this group depend on a thick layer of blubber to insulate them from the cold water. External contact with oil has little known effect on these mammals other than possible eye irritation. Harbor seals may come into contact with oil washed onto rocks more frequently than other mammals since they have difficulty moving on land and cannot climb high on rocks to avoid undesirable conditions.

SUMMARY: Seals, sea lions, and otters use rock habitat primarily as resting grounds. Serious effects can result if the fur becomes coated with oil, especially with otters since they depend upon their fur for warmth and buoyancy in the water.

RELIABILITY: ***

A. ROCK

3. Birds: Offshore Feeders

The species representing offshore feeders in rocky habitats include gulls (*Larus* spp.), alcids (mainly Common Murres, *Uria aalge*; and Pigeon Guillemots, *Cepphus columba*), and cormorants (mainly Pelagic Cormorants, *Phalacrocorax pelagicus*). These birds, nearly all permanent residents, are generally restricted to the uppermost horizon of the rocky shore where they regularly rest and many nest. Pigeon Guillemots nest very close to the splash zone while the others occupy rocky ledges somewhat above the level of tidal spray. Guillemots and cormorants feed by diving for bottom organisms in the rocky intertidal and shallow subtidal zone.

Although data show that all these species are susceptible to oil pollution in varying degrees, very few data pertain to these species in rocky habitat. Since only the gulls forage extensively within the intertidal zone at low tide, they are susceptible to direct contamination. Contamination of feathers by oiled sea spray and wind-blown oil is a remote possibility for all these species, especially those nesting close to the spray zone. Diving for oil-contaminated food could result in serious effects for guillemots and cormorants. The effects of oiled feathers and ingestion of contaminated food on these species are similar for shorebirds in sandy habitat and are described in Section B.4. pp. IV 35-36. The high energy conditions occurring in this habitat result in relatively quick cleaning of oil from the area. However, the effects on food resources may be long lasting, forcing gulls, cormorants, and guillemots to forage elsewhere.

SUMMARY: Gulls, some alcids, and some cormorants are offshore feeders which sometimes occur in rocky habitats. All use the habitat for loafing and most forage either in the intertidal or subtidal zones. Pigeon Guillemots and Pelagic

Cormorants nest near the upper splash zone. Susceptibility to oil impact is expected to be moderate to negligible depending on how and what parts of the habitat are used. Loss of food source may be a more serious impact.

RELIABILITY: ***

A. ROCK

4. Birds: Shorebirds

Rocky intertidal is a characteristic habitat for Black Oystercatchers (*Haematopus bachmani*), Surfbirds (*Aphriza virgata*), Ruddy and Black Turnstones (*Arenaria interpres* and *A. melanochephala*), and Wandering Tattlers (*Heteroscelus incanus*). All use the habitat as a major foraging area. Oystercatchers are the only permanent residents; the others are winter residents and migrants.

Since very few data are available concerning oil impact on these species, it is assumed their exposure to direct impact from oil is low. The potential methods of oil contamination and its effects are assumed to be similar to those of shorebirds in sand habitat and are described in Section B.4, pp IV 35-36. The potential for contact with oil is likely short-lived in this high energy environment. However, the loss of local food resources may result in serious indirect impact on these species, forcing them to move to other areas.

SUMMARY: Five species of shorebirds can be expected in rock habitat. Only one is a permanent resident, the others being winter residents or migrants. This is a major foraging habitat for these species. Little is known of the impact of oil on these birds in this habitat, but it is assumed to be minimal. A loss of local food resources could result from spilled oil.

RELIABILITY: ***

A. ROCK

5. Birds: Casual Marine Feeders

The Northwestern Crow (Corvus caurinus) is the only species of casual marine feeders that can be expected regularly to occupy this highly productive habitat. Bald Eagles (Haliaeetus leucocephalus) may occasionally scavenge here.

No evidence was found in the literature of impact by oil on either species in this habitat, suggesting a low exposure to oil spills. The potential methods of contamination and their effects are similar to those of shorebirds in sand habitats and are described in Section B.4, pp IV 35-36. Since rocky intertidal areas are high energy situations, the habitat is quickly cleansed of oil residues, thereby lessening the duration of direct impacts. The indirect impact of loss of a highly productive food area may cause some adjustment in life style for foragers, especially crows. In the highly unlikely event of disruption of a breeding season for Bald Eagles due to loss of occasional feeding ground, there could be long-term consequences since they have a naturally low reproductive rate and breed successfully only in years when food and other conditions are optimal.

SUMMARY: Bald Eagles and Northwestern Crows may be found in this habitat. It is of moderate importance to crows as a foraging area. Neither species is susceptible to oil spills to any significant degree in this habitat. The methods and effects of oil contamination are the same as for shorebirds in sand habitat.

RELIABILITY: **

A. ROCK

6. Fishes: Shoreline

Of the 19 species of fish in this study commonly occurring along shorelines, five species, kelp greenling (Hexagrammos decagrammus), white-spotted greenling (Hexagrammos stelleri), tidepool sculpin (Oligocottus maculosus), crescent gunnel (Pholis laeta), and cabezon (Scorpaenichthys marmoratus) are commonly found in rocky habitats throughout the year in Puget Sound. Most of these species deposit demersal eggs (eggs on the substrate) in intertidal pools and shallow waters.

The impact of an oil spill is expected to be severe on shoreline fish, especially those which inhabit the intertidal zone, or those which spawn intertidally. Few direct laboratory investigations on the impacts of oil and refined products on these species have been conducted, however, and field observations are equally sparse.

Observations of mortality of tidepool sculpin caused by a spill of Canadian crude oil in intertidal pools were inconclusive. Concentrations of 100-400 ppm of diesel No. 2 heating oil in intertidal pools did not cause significant mortality in a 66-hour observation. In the laboratory, however, experiments with cabezon exposed to Louisiana crude and No. 2 fuel oil at various concentrations, showed that concentrations of 100 ppm produced significant mortality. Oil coatings on rock surfaces will undoubtedly have adverse effects on food items for shoreline fishes. It is expected that most shoreline fishes not trapped in pools would swim to new areas in the event of a spill, but disruption of this kind always leads to increased predation. If an affected area represents the only rock habitat for a considerable distance, local population declines can be expected.

Fishes in tidepools, especially in the upper and middle intertidal, are likely to sustain moderate to heavy impact due to temperature increases and the restriction of oxygen supplies, coupled with chronic toxicity from soluble fractions of oil washed into the pools. Most fishes which inhabit tidepools are intensely territorial and are very reluctant to leave their territory or "home tidepool." Predatory grapsoid crabs are generally less sensitive to toxic hydrocarbons, and have been observed preying heavily on partially narcotized fishes in affected tidepools.

Oil on the surface will tend to cover eggs deposited in intertidal pools and on shallow substrate causing them to suffocate, or preventing normal embryonic development. Most shoreline fishes which spawn in a rocky habitat do so between October and April, with peak activities between late December and March. Intertidal demersal egg masses would therefore be most susceptible during the winter months, with juvenile susceptibility highest in the spring and summer.

SUMMARY: The high energy rock habitat is one which cleans itself quickly, but which harbors tidepool and intertidal fishes which can be severely affected by spilled oil. Aromatic hydrocarbons anywhere in the rock habitat or heavy slicks of oils on tidepools are particularly serious pollutants. Polluted rock habitats may require long recovery periods if there are no similar areas nearby from which to recruit.

RELIABILITY: **

A. ROCK

7. Fishes: Demersal-epibenthic

Of 41 species of fish on the Significant Biological Resource List which inhabit the bottom (demersal) and near bottom (epibenthic), 20 species are commonly found on or associated with a rock substrate. These are the rockfishes (Sebastes spp.), lingcod (Ophiodon elongatus), rock sole (Lepidopsetta bilineata), Pacific tom cod (Microgadus proximus), and ratfish (Hydrolagus colliei). All of these species, except for the ratfish, are commercially important or have commercial potential in Puget Sound. They are found associated with rock substrate throughout the year. This habitat provides both prey and shelter and the habitat association is a strong one.

This fish group, especially those in deeper waters, such as halibut and most rockfish, are generally not vulnerable to the direct effects of spilled oils or refined products. However, 25 juveniles of this group tend to inhabit shallower waters, oil spills can have more direct and secondary impacts on them in the early stages of development. Heavy fractions can cover rock surfaces for extended periods of time in cold areas. Although most of the fish in this group broadcast pelagic (freely drifting) eggs or release live young in midwater, lingcod deposit eggs in inshore nests among rocks. The males guard the nest until the eggs hatch making them vulnerable for a longer time than females. Oil spills in inshore rocky habitats during spawning periods could have a moderate to light impact on lingcod eggs and fry through smothering by sunken sludges and poisoning by soluble fractions. Indirect impacts on invertebrate prey species, especially for the younger stages of demersal-epibenthic fishes, are more likely for this group as a whole, and tend to be more subtle.

SUMMARY: With the exception of lingcod eggs and fry, demersal and epibenthic fishes associated with rocky habitats are not likely to suffer significant impact due to spilled oil or petrochemical products.

RELIABILITY: **

A. ROCK

8. Fishes: Open Water

Of the pelagic (midwater) fish represented in this study, one species, Pacific herring (*Clupea harengus pallasi*), is closely associated with rocky habitat during spawning in Puget Sound. It is an important commercial fish and one of the most important food items of larger commercially valuable predators.

Herring spawn in winter and early spring in the rocky intertidal zone or in other habitats such as mixed-coarse, kelp, and eelgrass. Although there has been no oil-related mass mortality of herring eggs observed in Puget Sound, a spill of crude oil or refined products during the spawning season, especially near spawning grounds, could cause the depletion or deformity of the new recruits. In the laboratory, exposure of herring eggs to 5 ppm water soluble extracts of an unspecified oil caused 70% to 100% mortality. In addition, heavy fractions of oil (e.g. tar) which may cover rock surfaces in the intertidal zone and in shallow areas, can smother the eggs. Further, herring eggs exposed to 5 ppm of Venezuelan crude oil produced a large number of deformed fry. Finally, like salmon, herring home to particular areas to spawn. Because smell may be the homing cue, an oil spill in the path of a migrating school of herring could very likely interfere with the homing routine.

SUMMARY: The rock habitat is not used specifically by open water fishes with the exception of spawning herring. During the period of herring spawning, however, spills in or near rocky spawning grounds could devastate local runs.

RELIABILITY: **

A. ROCK

9. Echinoderms

Rock substrate is the preferred habitat of all the echinoderm species in this study. The sea cucumber (Parasticopus californicus) is occasionally found in both intertidal and subtidal areas. Of the three sea urchins, the purple urchin (Strongylocentrotus purpuratus) is most common in active surf on the outercoast, while in more protected waters the green urchin (S. droebachiensis) dominates intertidally with the red urchin (S. franciscanus) more common subtidally. Both the purple starfish (Pisaster ochraceus) and the sunstar (Pycnopodia helianthoides) occur from the middle intertidal to subtidal rocky bottoms.

Echinoderms in general are severely affected by oil. These animals maintain equilibrium between their internal salinity and the salinity of the external water, and have no adequate defense mechanisms to exclude oil. Urchins covered with crude oil suffocate, or become narcotized, and lose their ability to grip the substrate. They are subsequently broken by wave action, washed ashore or subject to easy predation. Refined products narcotize urchins, and cause them to lose their spines. Bunker C oil has been reported to cause tainting in green urchins.

Inconsistencies exist in the reported effects of spilled oil on starfish. Generally, either high mortality or no effects at all were reported. In many cases, however, the age of the spilled oil was not considered. As with other echinoderms, narcotization is to be expected.

No reports on sea cucumber responses were found, but these could probably be narcotization and death, similar to the other echinoderms. The characteristic sea cucumber response to undesirable chemicals is the expulsion of most internal organs. If the sea cucumber survives it can usually regenerate its vicera.

Oil exposure and damage is greatest in intertidal areas because of the potential of contacting floating oils. Soluble fractions can reach shallow subtidal animals and the heaviest fractions of crude oils will sink, contaminating deeper subtidal areas. Rock is generally well flushed and residual effects have not been noted, except for the possibility of predatory starfish concentrating oils from their prey. Replacement can be slow in areas of restricted circulation. In one case populations in a bay were depressed more than four years after a spill.

SUMMARY: All of the echinoderms in this study are common on rock substrate. They are sensitive to crude and refined oils, with narcotization causing loss of gripping ability thereby subjecting the animals to waves and predators. Spine loss and tainting also occur. Damage is greater intertidally than subtidally, and recovery can be slow.

RELIABILITY: **

A. ROCK

10. Crustaceans

A variety of crustaceans, including several commercially important species, live in rocky habitats. In the intertidal, this study includes the various barnacles (Balanus spp.), the isopod (Idothera wosnesenskii), and adult red rock crabs (Cancer productus). Barnacles are attached filter feeders, releasing planktonic larvae in winter which settle back on the rocks in mid-summer. Various isopod life stages appear to be associated with specific species of algae and mussels growing on the rocks. Females brood eggs in the summer. The red rock crab is a scavenger which does not reproduce in this habitat. It extends into the subtidal, where the dungeness crab (Cancer magister), more species of barnacles, and the Puget Sound king crab (Lopholithodes mandtii) also occur. The Puget Sound king crab migrates seasonally, occurring in shallow water in winter and spring. After the eggs, which the females have been carrying for a year, hatch in the spring, the females move offshore to depths greater than 30 meters, and are joined by the males and juveniles later in the summer. The related box crab (Lopholithodes foraminatus), both Cancer species, and four species of pandalid shrimp are found year-round in deep water. The various pandalid shrimp (Pandalus platyceros, P. danae, P. goniurus, and P. hypsinotus) feed on smaller crustaceans, worms, and detritus on the bottom during the day, and rise into the middle or upper water layers at night to feed on euphausiids, copepods, and other miscellaneous organisms. Panadalus goniurus, the shallowest living species, does more of its feeding on the bottom than the others.

Oil response data were found only for species of barnacles and crabs. Intertidal barnacles were killed by spills, but death was directly proportional to the percent coverage, and appears to have been caused by smothering, rather than chemical toxicity. An unspecified crude oil caused narcotization after six hours and 90% mortality after 70 hours in 20 ppt oil. This is a relatively high tolerance for invertebrates. The red rock crab showed 50% mortality only after more than 12 hours in undiluted No. 2 diesel oil. Tainting occurs, and is persistent. In a related Cancer species, residuals were shown to occur in the tissues for more than three years, and concentrations were higher in the second year than the first, suggesting that the crabs continued to concentrate oils from sediments or prey.

These responses of high tolerance and tainting can probably be generalized to the other species in this study. Copepods, another crustacean group, have been observed to ingest some crude oils with no effect. The pandalid shrimp would contact oil only when feeding near the surface, from tainting prey, or if the oil was sunk with dispersants. The isopod is subject to indirect mortality if the algae on which it lives and feeds are destroyed. Crustaceans as a group are more mobile than most other invertebrates, and recolonization may be rapid. Crab populations on rock may be maintained by migration from sediments. Barnacles will not set on oiled surfaces but can be expected to return on the first breeding season after the surfaces are clean. Surviving barnacles would profit from the removal of the more sensitive snail (Thais), their major predator.

SUMMARY: Crustaceans on rocks are fairly resistant to oil effects, except for intertidal barnacles which are smothered by oil coatings, and isopods which require several algal species on which to live. Recolonization of affected areas would usually be rapid.

RELIABILITY: ***

A. ROCK

11. Molluscs

Rock surfaces are normally heavily populated with molluscs. Of the 31 mollusc species included in this study 14 utilize the rock habitat. Of these, 11 use the rock community almost exclusively, including several species of mussels, oysters, abalone, and chitons. All of these organisms have characteristic locations on rocks, relative to tidal level.

All mollusc species considered in this study release planktonic gametes or larvae, except for the snails, which attach eggs to substrates and hatch directly as small adults. The eggs of snails and newly settled larvae of other molluscs are susceptible to the mechanical and toxic effects of oil slicks that come in contact with them. Little data are available on the magnitude of these impacts.

In general, crude oils are not highly toxic to intertidal molluscs, although they can cause ripening gonads to atrophy. Species such as the California mussel (Mytilus californianus) which require active wave conditions, can be mechanically smothered. Refined products in low concentrations tend to narcotize molluscs and in high concentrations have been shown to be fatal. Narcotization is particularly detrimental to mobile species such as snails because it can cause them to lose their grip on the rock surfaces and be swept away to inhospitable habitats or be subjected to increased predation. Aromatic hydrocarbons can be selectively retained in tissue causing edible shellfish to remain tainted for many months.

Bivalves appear to be more resistant than other molluscs, especially to heavy aliphatic oils or aliphatic crudes. This is due, at least in part to their remaining closed for one or more tidal cycles, giving the more volatile toxic fractions of a spill a chance to evaporate and the spill a chance to drift away.

However, once drawn within the shells, aromatic hydrocarbons tend to relax the closing mechanism, thereby reducing the effectiveness of their defense mechanism.

The exposed position of molluscs on rocks generally leads to periodic flushing by waves, but also subjects them to a higher probability of at least some contact with spills. It has been shown that a No. 2 diesel spill can cause the death of bay mussels (Mytilus edulis), primarily in the uppermost horizon. At the same time, bay mussels in the middle intertidal remain largely unaffected. Bay mussels were unaffected by a direct, six hour application of Kuwait crude. The Santa Barbara spill had little noticeable immediate effect on mussels, but significant mortalities appeared three months later. This delayed effect has been observed in other crude and refined oil spills, perhaps due to the effect of chronic irritation. It is also possible that the initial contact may cause cancers or other incipient lethal conditions. These delayed deaths cast some doubt on short-term laboratory experiments which are interpreted to show no effects from crude oil applications. Observations of gonadal atrophy caused by single contacts with oils support the possibility of incipient lethal effects.

As previously mentioned, mobile molluscs are susceptible to narcotization. Most of the evidence for this is with exposure to No. 2 diesel fuel. It has been found that half of the wrinkled purple snails (Thais lamellosa) exposed to a 113 ppm concentration of diesel fuel could not attach to a substrate after 36 hours, but that 40-60% of the affected individuals recovered after 48 hours in clean water. In the field, the immobilized snails could be washed from their habitat by waves. The wrinkled purple snail, native drill (Urosalpinx), and the Japanese oyster drill (Ocinebra) do not recolonize for years once they are killed in a local area because they have no pelagic larvae, and do not crawl across large sediment areas. Effects can therefore be long lasting. Such an impact is desirable on commercial shellfish beds.

No data for scallop or octopus oil impacts were found. Scallop species related to those considered in this study show persistent tainting of flesh by fuel oils. Octopi are highly mobile and have been shown to avoid undesirable chemicals injected into their lairs. However, under certain circumstances, such as heavy mixing, they are probably also susceptible to narcotization and death.

SUMMARY: Rock substrates are the prime habitat for several mollusc species. The potential for impact is closely related to the tidal level occupied by an organism. Newly settled larvae of several species and the eggs of snails are subject to mechanical and toxic oil effects. The potential to remain closed is an effective defense mechanism for bivalves. Effects on adult molluscs include narcotization, acute toxicity, and possible incipient effects which appear long after exposure. Aromatic oils have the potential of tainting tissue.

RELIABILITY: **

A. ROCK

12. Annelids

The annelid polychaete worm *Nereis vexillosa* frequents intertidal and subtidal rock habitats, living in microenvironments at the base of mussel and barnacle growths. Here it is protected from waves, desiccation, and temperature stresses. Nereids are predators on other invertebrates, also eating organic detritus. Individuals live three to four years, undergoing a metamorphosis into a sexual form (epitoke). Adults leave the bottom in the spring to spawn, after which they die.

Few direct data were found on *Nereis* with respect to oil. A related species of nereid was among the more sensitive benthic organisms tested in one study. Highly aromatic, high sulfur content crudes were more toxic than other crudes. This same study indicated that nereids are absent in areas heavily polluted with industrial petroleum wastes. Nereids might also be sensitive to aromatics concentrated in prey organisms, and could be susceptible to poisoning from ingesting sediments containing oil or eating the remains of oil-killed organisms.

SUMMARY: Given certain conditions, significant mortalities would be expected from spills, particularly of highly aromatic oils. Repopulation would depend on recruitment from nearby populations. Repopulation would also depend on the recovery of mussels and barnacles which serve as a substrate for this annelid.

RELIABILITY: *

A. ROCK

13. Algae

The algal assemblage in subtidal and intertidal areas is generally diverse. Many important requirements of algal growth are provided in this habitat: clean and stable surfaces necessary for attachment; frequent exchange of nutrients in ambient water; and more moisture from surf action (spray) for intertidal species. Algal density may be quite variable on rock surfaces due to exclusion by species of barnacles and mussels (Mytilus-Balanus associations). In areas of heavy surf, the algae may be diverse but reduced in size, especially in the intertidal zone.

Seasonal fluctuations in the densities of species of algae in this habitat are characteristic. Dense kelp beds composed of Nereocystis luetkeana are found where tidal currents are strong (1-8 knots). Because these plants are annuals, beds are dramatically reduced in the late winter. Species of thin-bladed red algae such as Porphyra tend to grow in higher intertidal while Gigartina and Iridaea are found in both intertidal and subtidal. The thalli of these species are eroded back to a perennial basal attachment during winter months which produces new blades in spring. Thus the quantity of plant material that could be affected by exposure to oil will vary through the year with the greatest quantity being present from mid-July through October.

While quantities are less during periods of low water temperatures and decreased sunlight, stages of algal development occur at this time which may be especially sensitive to oil. The attraction of Nereocystis sperm to eggs, a probable hydrocarbon chemical phenomenon, may be obstructed by analogous hydrocarbons from a spill. The microscopic gametophyte filaments of Nereocystis and the sporophyte conchocelis stages of Porphyra, both subtidal, which develop at low temperatures and low light levels, may be damaged by oil spills in winter. Diminished standing crops of these species is a likely consequence. Oil spills in winter, usually accompanied by intense wave action which will disperse oil from this habitat, will also emulsify oil enabling it to intrude on subtidal surfaces where these winter life stages are found.

Changes in the relative amount of exposure to air and sunlight during low tide in the intertidal will affect the degree of stress on oiled thalli of Porphyra and other broad-bladed algae. Oil-covered Porphyra in the high intertidal have been observed heavily damaged because of reduced rinsing of thalli. Summer low tide exposures may be especially stressful in the presence of oil, though studies such as Schramm, 1971, show thin films of relatively nontoxic oil on Porphyra thalli retard water loss and thus increase length of photosynthesis time during exposure. The red algae genera Gigartina and Iridaea produce quantities of nonflagellated carpospores in late summer and early fall which require clean, rocky surfaces for their attachment and subsequent growth. These juvenile plants maintain population densities in the following summer's crop. Oiling of rocky surfaces during times of peak carpospore production may interfere with attachment mechanisms and reduce the quantity of these commercially valuable plants.

Field observations of oil spill effects on this habitat range from no mortality by residuals (bunker) on species of Gigartina and by dark diesel No. 2 (heating) on species of Porphyra to bleaching of thalli, brittleness of thalli and cessation of photosynthesis on species of Porphyra by various crude oils caused by continued adherence of oil to the thallus. Hydrocolloid (gelatinous) coatings on Gigartina and Iridaea provide protection lacking in Porphyra. If numerous observations of Macrocystis pyrifera, which does not grow in Puget Sound, can be applied, the less prevalent Macrocystis integrifolia and the abundant and closely related species Nereocystis luetkeana, few significant direct effects of oil on sporophytes are to be expected. An increase in sporophyte density of kelp beds following a spill has been reported for Macrocystis pyrifera due mainly to the death of natural predators such as Strongylocentrotus spp. (sea urchins). Since these are also predators of Nereocystis in Puget Sound, similar results can be predicted.

Studies of effects of oil-seawater emulsions of heavy products show that short-term exposure (1 day) of Macrocystis pyrifera blades frequently stimulate photosynthesis, while longer exposure (3 days) severely decreases photosynthesis. Light products at the same percent emulsion were found to be more toxic. Studies of the effects of aromatics on Macrocystis blades show such aromatics as toluene and benzene reduce photosynthesis 75% in 96 hours at concentrations as small as 100 ppm. In addition, 10-100 ppm of heavier aromatics such as phenol and cresol cause a 50% inactivation of photosynthesis in four days. Light aromatics therefore are likely to be much more damaging to Nereocystis than the heavier oils.

Studies of various crude oil films on Porphyra umbilicalis show persistent effects on photosynthesis from crudes with high naphthenic and aromatic contents (Venezuelan and Iranian) as compared with a high paraffin content crude (Libyan). However, high paraffin content crudes are more likely to obstruct gas exchange by the thallus, and will, if not removed by wave action, cause death by suffocation. These same effects can be predicted for the many species of Porphyra in Puget Sound.

Though the culture of Porphyra for human consumption is not underway in Puget Sound, studies of tainting of Porphyra by "oil" at concentrations of 1.5 ppm have resulted in imparting an offensive odor to the product.

SUMMARY: The most serious impact can occur during the peak growing season of summer and early fall. Many sensitive phases of algae growth have not been studied in relation to oil impact; effects can only be extrapolated. Major damage to algae with unprotected thalli in the middle and higher intertidal from highly aromatic or highly naphthenic crudes and light petroleum products can be expected. Subtidal kelp beds may become more dense due to oil-caused death of natural predators that tend to control the level of algal production.

RELIABILITY: ***

A. ROCK

14. Grasses

The preferred habitat of the common surf grass Phyllospadix scouleri is the exposed coast, rock-cobble substrate in the upper subtidal - lower intertidal. Vigorous wave action appears to be a prerequisite for its growth. Its attachment to cracks in rocks or corraline algae by horned seeds and subsequent growth there of roots and rhizomes enables it to accumulate and create its own substrate for growth. Both root-sediment and surfaces of leaves provide habitats for many animals. Leaves of surf grass are present throughout the year but in greater quantity during the summer. Flowering in early summer, seed formation and release in fall, and relatively large amounts of plant material make the period from May through October the period of greatest vulnerability to oil exposure.

No laboratory studies of oil effects have been done on surf grass. Field observations have been made, however, of oiling effects on surf grass. A die-off of outer blades immediately following a spill of bunker C fuel in winter was reported, with recovery and possible stimulation of growth in spring and summer. A spill of navy special fuel oil caused bleaching of blades which progressed to inner blades of turions and persisted for four months. Surf grass tends to strain oil from the moving water onto blades resulting in thick coating and matting of blades. Reports of a spill of California crude on a closely related species Phyllospadix torreyii showed extensive damage of exposed blades (40-100%) with continuing damage from oil redistribution due to cleaning of high intertidal rocks. Unlike gelatinous-coated genera of algae, oil is not washed off but adheres throughout the tidal cycle.

SUMMARY: Exposure of these grasses to heavy and light oils during winter months will damage blades, but because of the cleansing effects of wave action in this habitat, rhizomes and roots, especially if surrounded by sediments, are not likely to be damaged. A spill in early summer during flowering will likely have more serious results in preventing or retarding seed production for maintenance of the population.

RELIABILITY: ***

B. SAND

1. General Impact

Sand substrates can be divided into high energy exposed beaches, moderate energy subtidal, and protected intertidal areas. Exposed beaches are continually reworked by waves. There is usually a net transport of sand along the beach, with the top several feet of the surface normally transported offshore during winter and replaced in summer. Sands in moderate energy areas are much more stationary, although there may be minor onshore and offshore movements of sand. Currents and wave action may cause transport of subtidal sand.

Most oil on high energy beaches is rapidly flushed away. During summer, oil can be driven into the sediments by waves or washed high on the beach where it is more persistent; however, this oil is flushed away during the winter erosion period. A spill occurring in early spring could bury oil in sediments, but rapid flushing is far more likely. The sparse biological community found in this habitat is therefore only briefly subjected to oil, with the rapidly cleansed substrate allowing recolonization. Normal population levels of many species on exposed beaches may not be reestablished for years, since populations naturally vary widely from year to year. This factor complicates delineating the effects of oil pollution on exposed beach species.

Oil is more persistent on moderate energy sands. Wave action and burrowing organisms can mix oil into the sand, with small amounts of oil collecting in burrows. Water movement is generally sufficient to dilute soluble fractions rapidly and to provide moderate flushing of insoluble residues. Bacterial degredation occurs at the surface; however, some poorly flushed Puget Sound sandy beaches tend to develop subsurface anoxic conditions in late summer, thus retarding oil breakdown. Finally, oil can also be incorporated into the sand, to be released by later sediment disturbances, such as dredging.

As the biological community in sand is sparse to moderately dense, oil impact depends on the toxicity and quantity of oil introduced. Filter feeders and predators are more common than deposit feeders, so most ingestion of oil is incidental. Essentially all of the marine species here utilize some pelagic distributive life stage, facilitating repopulation from adjacent areas. The long-term retention of oil in sand may cause persistent tainting, and may increase the incidence of tumors or other naturally occurring pathologies.

SUMMARY: The overall effect of oil in sandy substrates depends on the energy conditions. High energy beaches suffer immediate effects, but rapidly cleanse themselves. Moderate energy beaches and subtidal sediments have denser populations, flush themselves more slowly, and may retain some oil for long periods, causing more initial and potentially more long-term damage.

RELIABILITY: ***

B. SAND

2. Mammals

The impact of oils on marine mammals occurring on sand, mixed-coarse, and mixed-fine shorelines are the same, based on available information. Specific information dealing with the impact of oil pollution on individual marine mammals is either very limited or does not exist. As a consequence, reliable assessments of oil pollution damage are difficult to make and only general conclusions can be drawn. The mammals that frequent this habitat type are the harbor seal (Phoca vitulina), Stellar's sea lion (Eumetopias jubata), sea otter (Enhydra lutris), and river otter (Lutra canadensis). The sea otter (reintroduced in small numbers in 1969 and 1970) and the Stellar's sea lion are restricted to the coast, although sea lions are known to enter protected waters during the winter months. Harbor seals are common permanent residents of the coast and the greater Puget Sound area. River otters, primarily residents of freshwater rivers, streams, and lakes, also occur on the San Juan Islands. The sand habitat is of secondary importance to marine mammals as it is used only as a resting ground as are rocky areas. No food is acquired or eaten in this area with the possible exception of food consumption by river otters.

The sea otter and river otter are the most susceptible to oil pollution. Otters have no insulating fat layer, but rely entirely on their dense, water repellent fur for warmth. Oil mats the fur which results in a loss of buoyancy in water and destruction of the insulative quality of the fur. Oil-soaked otters entering the water will experience hampered mobility, become chilled, and subsequently die under these conditions.

River otters may contaminate food brought onto an oil-covered shore. The specific effects of consumption of various oils and oil products are unknown, although varying degrees of poisoning by consumption of light petrochemical products is a strong possibility.

Seals and sea lions are probably less susceptible to oil pollution. Members of this group depend on a thick layer of blubber to insulate them from the cold water. External contact with oil is likely to have little effect on these mammals other than possible eye irritation.

SUMMARY: Otters, seals, and sea lions utilize this habitat as a resting or hauling-out area. The impact of oil pollution on seals and sea lions is probably minimal as external contact with oil has little, if any, effect. Oil impacts on otters are better known and can be serious. The pelage of an otter can become oiled resulting in a loss of the insulative quality of the fur. Food brought to shore also can be contaminated by oil or oil may be directly consumed in attempts to groom oil from the fur causing toxic effects.

RELIABILITY: **

B. SAND

3. Birds: Offshore Feeders

The literature for Puget Sound indicates the gulls (Larus spp.), Black Brant (Brant nigricans), and Common Terns (Sterna hirundo) use sandy beaches primarily as resting and loafing areas. The gulls also use the beaches for foraging. The habitat is of moderate importance to gulls, but is only occasionally used by the other species. Gulls are found in this habitat all year, Common Terns in fall and spring, and Black Brant in the winter.

These species, in general, have shown a low susceptibility to oil spills on a world-wide basis. The same situation should prevail in Puget Sound. The relatively quick cleansing nature of oil spills on the surfaces of high energy sand beaches reduces the potential impact to an even lower level. The potential does exist for loafing birds, which often sit flush with the sand surface, to come into contact with weathered heavy products and crudes, which mix for a time with the sand as clumps and tar balls. Loafing is usually done, however, on dry sand where any light products or volatile fractions of crudes that may have washed ashore are likely to have been evaporated. Ingestion of oil-contaminated refuse is possible. The methods of oil contamination and their effects on this group are very similar to those of shorebirds on sand habitat (see Section B.4- pp. IV 35-36).

SUMMARY: The offshore feeders in sand habitats are represented primarily by the gulls in Puget Sound. Their use of sand beaches is moderate and relatively constant throughout the year. Their susceptibility to oil is low owing to their limited use of the habitat and its quick cleansing nature in a high energy situation (see the section of Shorebirds on sand habitat for a more complete discussion).

RELIABILITY: ***

B. SAND

4. Birds: Shorebirds

Sandy beaches are generally thought of as typical habitat for most shorebirds. However, the literature for Puget Sound records only about half of the 23 species of shorebirds considered in this study. The recorded species include Great Blue Heron (*Ardea herodias*), Ruddy Turnstone (*Arenaria interpos*), two plovers and eight sandpipers. The remaining shorebirds use other coastal habitats more frequently and are rarely observed on sand. Because of the highly migratory nature of most shorebirds, peak occurrence of its members on Puget Sound sand beaches is during spring and fall.

Shorebirds which forage in sand are moderately dependent on it for food resources. Adaptations such as probing bills and wading-type feet have resulted in reduced susceptibility to direct impact from oil spills since shorebird bodies do not generally come in contact with oil-covered sand.

Should birds brush against oil-covered sand or preen with oil-covered bills, some oil could adhere to body feathers causing them to become matted and to lose their insulation. This would not likely be a significant problem for these birds since they spend almost all their time out of water, thus avoiding excessive loss of body heat. In time, the oil could be preened off and insulation restored. However, should a spill occur during the breeding season, oil from the breast feathers would readily be transferred to the eggs. This has been shown to reduce hatchability by as much as 90% due to insufficient oxygen transpiration.

In addition, preening birds may ingest as much as half the oil adhering to their feathers. Birds foraging on an oil-covered substrate can inadvertently ingest oil, either from their bills which have become covered with oil while probing, or from the contaminated food itself. Oil ingestion can delay egg laying for as much as two weeks.

Light oil products and aromatic crudes, being highly toxic, are especially injurious to digestive tract tissues sometimes causing inflammation and hemorrhages. Other effects include lipid pneumonia; kidney, liver, and pancreas degeneration; and loss of muscular coordination. Such disorders frequently are severe enough to cause death.

For migrating shorebirds, the loss of local food resources by oil contamination presents only moderate problems since sand beaches are usually not critical foraging areas. Further, their high mobility and transient use of the habitat allows them to move to a new area. The option of changing feeding grounds is not so readily available to nesting or wintering birds however, and may effect their reproductive success or chances for survival.

SUMMARY: Many shorebirds use the sand beaches of Puget Sound, especially in spring and fall. Because of the quick-cleaning nature of the substrate and their behavioral and anatomical adaptations, shorebirds are only moderately susceptible to oil spills. The most serious potential impacts they face are incidental ingestion of oil and oil-contaminated food, and the loss of local food resources forcing them to move on to other beaches and habitats.

RELIABILITY: ***

B. SAND

5. Birds: Casual Marine Feeders

This habitat is used year round by Northwestern Crows (*Corvus caurinus*) and occasionally by Bald Eagles (*Haliaeetus leucocephalus*) as foraging areas. It is of moderate importance to crows and less so for eagles.

The literature suggests that neither of these species, nor their close relatives, are susceptible to oil spills. It is reasonable to assume the same will apply for oil spills in Puget Sound. However, since both species often scavenge on sand beaches, a possibility exists for ingesting oil-covered material. The general methods of oil contamination and their effects on this group are very similar to those of shorebirds on sand habitat (see Section B.4, pp. IV 35-36).

SUMMARY: Little direct effect is expected on the casual marine feeders. A potential for digesting oil-contaminated food does exist with related side effects (see the section of shorebirds on sand habitat for a more complete discussion).

RELIABILITY: **

B. SAND

6. Fishes: Shoreline

Of 19 species of shoreline fishes, seven species, buffalo sculpin (Enophrys bison), red Irish lord (Hemilepidotus hemilepidotus), Pacific staghorn sculpin (Leptocottus armatus), shiner perch (Cymatogaster aggregata), striped sea perch (Embiotoca lateralis), walleye surf perch (Hyperprosopon argenteum), and white sea perch (Phanerodon furcatus) are found on or above sandy substrates of Puget Sound throughout the year. Buffalo sculpin, red Irish lord and staghorn sculpin usually inhabit the bottom, whereas other species prefer the water column above the sand. Most of these species are not commercially important, but they are important in food chains.

There have been no investigations conducted on the effects of oil and refined products on shoreline fishes either in the laboratory or in the field. Bottom species in shallow water and in tide pools would probably be most seriously affected by oil. Spilled oil would cover much of the substrate with which it comes in contact, and would be incorporated into the sediments, to be released as the sand shifts. Since harpacticoids, amphipods, mullosc spat, and polychaetes are heavily preyed upon by the shoreline fishes, the mortality of such macro and mieofauna in beach sand causes the depletion of essential food sources. Small fish trapped in tide pools may also be affected by the toxicity of soluble fractions. In addition, a layer of dark oil would raise water temperature by absorption of solar energy. Increases in temperature, especially during summer, combined with an oil slick on the water surface, could induce depletion of oxygen with suffocation as a result.

Most gunnels and sculpins deposit their egg masses in intertidal zones; thus, the contamination by oil of sandy intertidal zones during spawning will cause high mortalities of eggs and abnormal development of embryos. Most perch give birth to live young; the impacts of oils are less severe on them than on early life stages of egg-laying fishes. Juvenile perch usually form small schools and feed on zooplankton and epibenthos, which could become tainted by oils thereby affecting the perch food source.

SUMMARY: Although those shoreline species in deeper water are relatively free from the impact of oil, fish in the intertidal zone and on shallow sand bottoms can be seriously affected. The soluble fractions of freshly spilled oil can kill fish virtually on contact, while the heavy fractions can smother those in intertidal pools.

RELIABILITY: **

B. SAND

7. Fishes: Demersal-epibenthic

Thirteen species of flatfish, the rodfish, the midshipman, and two species of skates are commonly found associated with sandy substrates throughout the year in Puget Sound. Most of the 16 species of rockfish, in various stages of development, are occasional inhabitants. Sand dab, rock sole, starry flounder, and sand sole are the most abundant flatfish. Tom cod are probably the most abundant of the four species of cod-like fishes found in this habitat. Most of the cod-like fishes, rockfishes, and some of the flatfishes are commercially fished in Puget Sound, but the catch has been declining for economic reasons. These demersal and epibenthic fishes are distributed from the intertidal zone to great depths, where there is little possibility of oil impact.

Except for occasional strays, most of the larger fishes in this group inhabit the deeper water as adults and are relatively free from the impacts of spilled oils.

The great majority of flatfishes and cod-like fishes have pelagic eggs. Rockfish give birth to free swimming fry. Those eggs and fry near the water's surface may be affected by oil slicks and soluble fractions beneath them. In addition, the planktonic food organisms of pelagic juveniles may become tainted, narcotized, or killed by soluble fractions or emulsified oil. Fry and juveniles of these species are pelagic or inshore in distribution and are often found in shallower water. They can be easily narcotized by soluble fractions of oil if concentrations exceed a few parts per million.

Flatfish are often in direct contact with the substrate. Heavy fractions of oil (e.g., tar or oil-sand sludges) may sink and cover the substrate, causing localized habitat reductions or physiological disorders from direct contact with tars and sludges. Tumors in flat fish have been tentatively linked to contact with petrochemicals.

Both demersal and epibenthic fishes feed extensively on polychaetes, crustaceans, pelecypods, and other fish in or on the substrate which can become contaminated by hydrocarbons. Extensive consumption of these contaminated foods may produce disorders in fishes, but specific data are lacking.

SUMMARY: Except in shallower areas where starry flounder and some of the juvenile sole are common, oil impact on demersal and epibenthic fishes is expected to be light. There is some danger of serious local effects due to contaminated sediments and sludges.

RELIABILITY: **

B. SAND

8. Fishes: Open Water

The earliest life stages of most species of pelagic fish in Puget Sound are found in or on sandy substrates. Eggs of many species are laid in mud, and juveniles may swim over sandy bottoms feeding on vertebrates on the bottom or in mid-water. Both capelin (Mallotus villosus) and surf smelt (Hypomesus pretiosus) spawn in sandy beaches in Puget Sound from June to October at the edge of high tide. Juvenile pink and chum salmon utilize these beaches as nurseries in the spring. If an oil spill occurred at these times, the effects would be severe. Like other fishes in the intertidal zone, the impacts of oil on pelagic fishes take the form of narcotization and subsequent potentially heavy predation. Schools of Pacific sand lance (Ammodytes hexapterus) are usually found above the bottom, but they sometimes bury themselves in sandy substrate. The contamination of sand by sunken oil may tend to affect these fish by direct contact.

Although no mass mortalities of pelagic fishes due to oil have been observed in the past in Puget Sound, laboratory experiments have shown that the fry of herring are lethally narcotized by 5 ppm of mid-East mixed crude oil.

SUMMARY: Pelagic fishes in association with a sandy habitat can be affected severely by spilled oil during spawning periods, usually from June to October. Juveniles and fry including salmonids occur in relative abundance in this habitat and may be subject to narcotization and heavy predation.

RELIABILITY: *

B. SAND

9. Echinoderms

Although rock is a more preferred habitat, all of the echinoderms in this study are occasionally found on protected sands. The sea cucumber (Parasticho-pus californicus) and sunstar (Pyenopodia helianthoides) are very common on some subtidal sand habitats.

General responses to oil are narcotization and death, as reported for the rocky habitat (see Section A.9, pp.IV 16-17). Since most echinoderms on sand are found subtidally, they are more protected from heavy contact with oil than in the intertidal rock habitat. Narcotization alone would not be as dangerous as subtidal sands as on rock, since wave action and potential injury is usually less.

Oil is retained longer in sand than on rocks, so more tainting and other chronic effects could be expected. This could pose a special problem for sea cucumbers if repeated oil contact caused repeated eviscerations or prevented the growth of new internal organs. Repopulation would depend on the percent of the community affected, and on the potential of recruitment from other populations.

SUMMARY: As in rock environments, oil can cause narcotization and mortalities, but sea cucumbers and sunstars, which are common on sand, are primarily subtidal and therefore insulated by water from most heavy oil contact.

RELIABILITY: *

B. SAND

10. Crustaceans

Four crustacean species in this study are found on sandy substrates. The intertidal amphipod or sand flea (Orchestia traskiana) lives on and in the sand throughout its life under detritus on which it feeds. The red rock crab (Cancer productus) and dungeness crab (Cancer magister) are found subtidally, with red rock crabs occurring in coarser substrates than dungeness crabs. Mating occurs in May and June, with the later larval stages occurring on shallow bottoms, particularly in bay heads. Seasonal migrations occur both North-South and on and offshore. The pink shrimp (Pandalus borealis) occurs subtidally, often below 100 meters, on sandy substrates and, more commonly, on finer sediments. Eggs are brooded over the winter, and larvae begin to settle in shallower water by summer. They are bottom-feeders during the day, scavenging and preying on worms and small benthic and epibenthic crustaceans. At night, they are known to feed upon euphausiids and copepods.

The effects of oil vary inversely with the size of the individual crustacean. The red rock crab is very resistant to oil, with only 50% mortality in undiluted No. 2 diesel oil after more than 12 hours exposure. Sand fleas survived less than two hours when exposed to the same oil, while smaller individuals died much more rapidly. The shrimp is probably intermediate between the crab and the amphipod in its resistance to oil spills. Some smaller crustacean food species for fish, such as harpacticoid copepods, probably would be severely affected, especially in the shallower waters.

Oil tends to mix well into sand and may be retained indefinitely, particularly at the moderate energy levels at which these crustaceans live. No data on the possible effects of this chronic contact were found. Female crabs molt and bury themselves in the sand with males during mating, making them subject to tissue irritation at a vulnerable stage in their lives. Disruption of favorable breeding and juvenile growth areas could affect crab populations. Tainting of crab flesh by oil also could be a problem for a commercially valuable species or species utilized as food by other organisms.

SUMMARY: Crab populations could be affected by an oil spill, especially in shallow waters during their breeding season. Pink shrimp are more directly sensitive to oil, but occur deeper and would probably come into contact with oil only when feeding near the surface. Sand fleas could be severely affected locally, but could recolonize. Serious local mortalities on the smaller crustacea are possible.

RELIABILITY: **

B. SAND

11. Molluscs

Of the 31 molluscs included in this study, six species occur in the sand habitat with three species occurring in this habitat exclusively.

Sand-dwelling molluscs in this study are comprised of two groups: three clams and a scallop, which live in or on the sand and filter food from the water; and the moon snail (Polinices lewisii), which lives in the sand and feeds on clams. All five of these organisms occur in the intertidal, although moon snails are more common subtidally, while scallops are primarily subtidal. A distinction can also be made between the razor clam (Siliqua patula) which lives in high energy, surf-swept beaches, and other species, which live in lower energy, more protected areas. The moon snail lays egg cases in the sand which hatch into planktonic larvae. The bivalves release eggs or larvae directly into the water in the spring or summer.

Oil impact data for these species are scarce. The Santa Barbara incident caused no apparent effect on cockles (Clinocarbium), razor clams, or moon snails. However, refined oil products are generally more toxic than crudes. A spill of No. 2 diesel oil resulted in 50% mortality of cockles, razor clams, and moon snails. Another diesel spill caused 85% to 100% mortality of closely related species of molluscs. Acute local toxicities have been recorded for razor clams after spills of both gasoline and diesel truck fuel. In these latter cases the oils were volatile and the surf active. Apparently the oils were eventually dispersed, for there was a normal set of razor clams on the beach the following year. Scallops as a group are noted for susceptibility to tainting. The moon snail as a predator, probably concentrates containments from tainted clams, but it is rarely eaten by humans. As a group, these species are probably less susceptible to crude oils and more susceptible to toxic aromatic and naphthenic fractions than molluscs in general.

Cockles, razor clams, geoduck (Panope generosa), and horse clams (Tresus spp.) are unable to withdraw completely into their shells; the moon snail can do so for only a few minutes. This factor causes them to have more continuously exposed tissue than most molluscs. They will tend to be somewhat resistant to mild contaminants, but are generally unable to escape extensive exposures to toxic refined products. If the exposure causes only narcotization, geoduck, horse clams, and moon snails are safe under the sand. Being buried they are also somewhat sheltered from direct contact by oils occurring on the sand surface. However, cockles are often exposed or partly buried, and narcotized razor clams are rapidly uncovered by the surf if they are unable to readjust their positions in the sand. Consequently, these three organisms are vulnerable to crabs, birds, fish, or other predators if oil toxicity causes them to lose muscle control. Being exposed, they are also in direct contact with oils that occur on the sediment surfaces.

Oil tends to become mixed into the sediments to remain for lengthy periods. Since gonadal atrophy has been recorded for other molluscs in contact with oil, it is a likely event here, particularly for geoduck and horse clams which could be exposed to oils for long periods due to their sedentary nature.

SUMMARY: Data are scarce on the effects of oils on these organisms. The amount of tissue exposed to the oils can affect toxicity; thus, organisms that can withdraw into their shells or that are buried may be less affected than those with greater potential exposure. Light oils are apparently more toxic than crudes. the potential exists for impared reproductive efficiency after oil exposure.

RELIABILITY: **

B. SAND

12. Annelids

The annelid polychaete worm Nereis vexillosa, described in detail on page 23, cannot survive in high energy sand environments. It is found, however, in burrows in finer-grained protected intertidal and subtidal areas. The effects of oil spillage in this habitat are the same as for the annelids in the rock habitat (see Section A.12, p. IV-23).

RELIABILITY: *

C. MUD

1. General Impact

Mud substrates occur in areas of low energy, particularly in protected bays and over most of subtidal Puget Sound. Oil introduced into this habitat will initially spread over the mud surface. A limited amount will flow into animal burrows in the first foot or so of sediments, but water movement is too gentle to create any deep mixing into the mud (except for soluble fractions which will be dissolved). Oils will be adsorbed onto clay particles, binding them tightly to the mud, and flushing will be minimal. As the oil weathers over time, it will be worked through the upper two to three feet of mud by the active community of burrowing organisms. Subtidally it will be buried by the deposition of new sediments.

Oils on mud surfaces are subject to bacterial degredation. Adsorption onto clay spreads out the oil, greatly increasing the surface area available to attack by bacteria and enhancing the breakdown potential. As oil is mixed into muds, however, the common subsurface anaerobic conditions will retard or arrest bacterial degredation of the oil. Trapped oil could be released to the surface again by dredging, by major storms, or by other sediment disruption.

Oil will also be incorporated into the mud-dwelling organisms which filter food from the water above, gather it from the mud surface, ingest mud directly, or live as predators on or in the mud. The first two groups will contact oil at the sediment surface as they feed; the third cannot avoid eating oil if it is in the sediments; and predators will obtain oil from tainted prey. Toxic oil fractions will cause mortalities, but it is possible this will significantly interrupt burrowing activities which mix oil into mud, leaving toxic oils on the surface until they have weathered sufficiently to become nontoxic. Mud deposits are usually extensive, and it is doubtful that a single oil spill could destroy an entire community. Therefore, repopulation from surrounding areas would probably be rapid. Temporary removal of organisms would not affect the normal non-biological processes in mud. Effects of chronic oil presence are unknown, but some increase in naturally occurring pathologies, such as flatfish cancers, could be expected.

SUMMARY: Oils will be incorporated into muds and into the biological community on a long-term basis with initial mortalities depending on the toxicity of the oil. Oils will be adsorbed onto clay particles, and displayed for rapid weathering and bacterial action. They will subsequently be mixed deeply in the mud by the burrowing organisms, where degredation will be slow and chronic exposure to burrowing organisms will be persistent.

RELIABILITY: **

C. MUD

3. Birds: Offshore Feeders

The highly productive mud flats of Puget Sound are used by several species of offshore feeders, primarily gulls (Larus spp.) and some ducks and geese. The habitat is used at all times of the year as a loafing and resting area by all of these species and is used as a foraging area by gulls. It is of moderate importance to gulls but only of minor importance to ducks and geese.

The absence of reported effects of oil on these species in this habitat suggests a low susceptibility to oil pollution. However, 5,000 gulls and waders were killed in an estuary in England by an overnight oil spill on the rising tide. Presumably, much of the damage was done to birds roosting on mud flats. Thus, a potential does exist for impact on the birds of this group, especially gulls, who may roost on Puget Sound mud flats.

Under more normal circumstances, the methods of oil contamination and their effects on these birds are the same as those described for sand habitat (see Section B.4, pp. IV 35-36). The impacts are likely to be longer lived in this habitat since the oil is not washed away as quickly. In addition, because of greater food productivity and abundance, the damage to food resources is likely to be more extensive.

SUMMARY: Gulls, ducks, and geese represent the offshore feeders in this highly productive habitat. All use it occasionally as a resting area and gulls for a foraging area. Susceptibility to direct impact from oil spills is low here. Indirect food supply effects are more serious.

RELIABILITY: ***

C. MUD

4. Birds: Shorebirds

Nearly all of the 23 species of shorebirds listed in this study for Puget Sound occur on mud flats. This highly productive habitat is a major foraging area for these species, used most frequently during the fall and spring migrations. Winter use is also extensive and important.

Lack of applicable data suggests that susceptibility to oil spills in this habitat is low (owing to their minimal contact with the mud surface). However, an extensive kill of gulls and waders occurred in an estuary in England by an overnight oil spill on a rising tide. Presumably, much of the damage was done to birds roosting on mud flats. The methods of contact with oil and their effects are similar to shorebirds in the sand habitat and are further described in Section B.4, pp. IV 35-36. The indirect impact of a loss of food resources on this group is potentially severe, depending on the extent of the oil spill and the availability of other productive, uncontaminated mud flats.

SUMMARY: This highly productive habitat is used extensively as a foraging area by most of the shorebirds in Puget Sound. Their susceptibility to direct impact by oil spills is low for the same reasons described for sand habitat (see Section B.4, pp. IV 35-36). The loss of a major food resource area could be more serious.

RELIABILITY: ***

C. MUD

5. Birds: Casual Marine Feeders

Northwestern Crows (Corvus caurinus) are the only species of casual marine feeders that can be expected to occupy this habitat regularly. Bald Eagles (Haliaeetus leucocephalus) may occasionally scavenge here. Both are permanent residents and use mud flats as foraging areas.

No evidence was found in the literature of impact by oil on either species in this habitat, suggesting a low susceptibility to oil spills. The potential methods of contamination and their effects are similar to those of shorebirds in sand habitat and are described in Section B.4, pp. IV 35-36. Since mud flats are low energy situations, oil residues may remain for longer periods than in sandy areas, exposing birds to potential oil soaking for a longer time. The indirect impacts of oil spillage in this habitat are the same as for shorebirds in sand habitat (see Section B.4, pp. IV 35-36).

SUMMARY: Bald Eagles and Northwestern Crows may be found in this habitat. It is of moderate importance to crows as a foraging area. Neither species is susceptible to the effects of oil spills to any significant degree in this habitat. The methods and effects of oil contamination are the same as for shorebirds in sand habitat (see Section B.4, pp. IV 35-36).

RELIABILITY: **

C. MUD

6. Fishes: Shoreline

Of 19 species of fish found along the shoreline in Puget Sound, five species are more commonly found on mud substrate. They are buffalo sculpin (Enophrys bison), Pacific staghorn sculpin (Leptocottus armatus), tidepool sculpin (Oligocottus maculosus), cabezon (Scorpaenichthys marmoratus), and the penpoint gunnel (Apodichthys flavidus).

Only a few observations have been made of the effects of oil and refined products on these species. A spill of unspecified Canadian crude oil in tidepools did not affect tidepool sculpin to a significant extent. A spill of diesel No. 2 heating oil on the same species after 66 hours in the tidepool was inconclusive. A 50% mortality was observed on cobble substrate. In the laboratory, cabezon fry showed significant mortality at 100 ppm of both Louisiana crude oil and No. 2 fuel oil. The conflict in results between field and laboratory observations may be because age of oil was not taken into consideration. The degree to which oil mixes with water is also an important factor in observed toxicities.

Grunnel and sculpin can usually secrete a coat of mucus partially to protect themselves if they encounter unusual external stimuli. They also can tolerate relatively low oxygen for extended periods of time. However, oil mixed with mud due to heavy wave action can become incorporated into the substrate and prolong the release of toxic material. The shoreline fishes on or over mud substrate feed on polychaetes, crustaceans, mollusc larvae, and algae. Contamination of the substrate by oil can contaminate these organisms, causing tainting or reduction of the food supply through direct mortality, thus potentially causing reduced populations of shoreline fishes.

Most shoreline fishes in Puget Sound are not commercially important. However, they form an important part of the shoreline ecosystem. Although shoreline fishes prefer to live over higher energy sandy bottoms, a few perch species will occasionally be found over a mud bottom. These perch would probably abandon mud flats for a more suitable habitat in the event of an oil spill. They are easily narcotized, however, and in that condition are easily preyed upon.

SUMMARY: The effects of petrochemicals on shoreline fishes in mud habitats are not well established. Conflicting results in the literature suggest a higher toxicity for fresh oil or aromatic products. Embiotocids (perch) would be highly susceptible to narcotization and increased predation, but this is not their preferred habitat.

RELIABILITY: *

C. MUD

7. Fishes: Demersal-epibenthic

Black cod (Anoplopoma fimbria), midshipman (Porichthys notatus), four species of true cod and cod-like fishes, skate (Raja spp.), ratfish (Hydrolagus colliei), and 16 species of rockfish (Sebastes spp.) are found associated with mud substrates in Puget Sound, at least occasionally throughout the year. Dover sole (Microstomus pacificus), English sole (Parophrys vetulus), and arrowtooth flounders (Atheresthes stomias) are more abundant on this substrate than on any other.

The impacts of surface spills of oil and refined products of this group are most likely minimal. Those fish in shallower waters may be affected by water soluble fractions, but the depth of water to which the fishes may be affected is largely dependent on the type and age of the oil or refined product spilled and water conditions at the time of spill. Heavy waves or chop will tend to increase the mixing of water and oil, thereby increasing solublization and emulsification. Sinking of a heavy fraction of oil (e.g., tar or oil-mud sludges) may contaminate sediments and, subsequently, food organisms. Serious localized problems of tainting and possible skin disorders can be expected.

SUMMARY: Direct effects of oil on demersal-epibenthic fishes in a mud habitat are minimal. Contamination of food organisms and localized tainting are probably the most serious problems in this habitat.

RELIABILITY: **

C. MUD

8. Fishes: Open Water

Some open water fishes have juveniles which feed intertidally over mud substrates. Young salmon (*Oncornynchus* spp.), smelt (*Thaleichthys pacificus*), herring (*Clupfa harengus*), sand lance (*Ammodytes hexapterus*), and others frequent this habitat as a refuge from larger fish predators or in pursuit of epibenthic and planktonic invertebrates. As in other habitats without protective cover, the most severe impact of spilled petrochemicals occurs when these small fishes are slightly narcotized by soluble fractions and their erratic swimming behavior attracts predators. Moderate to heavy local losses may occur in this way. However, localized subpopulations probably represent a small fraction of the total populations of these highly transient fishes; thus, the net impact from a spill in this habitat is expected to be small. Frequent spills or chronic exposures could have a significant impact. Benthic invertebrates tainted by sunken oil could also present a local problem to the transient fishes preying on these organisms, but the net effect of this impact is also expected to be small.

SUMMARY: Oil spilled in a mud habitat is expected to have minimal net impact on juvenile pelagic fishes, since their presence is transitory and their overall populations are usually large.

RELIABILITY: ***

C. MUD

9. Echinoderms

Echinoderms are not common on mud, but sea cucumbers (Parastichopus californicus), some purple starfish (Pisaster ochraceus), and sunstars (Pycnopodia helianthoides) occur occasionally intertidally and subtidally on this substrate.

Effects of oil would be essentially the same here as in rock habitats (see Section A.9, pp. IV 16-17). Mud is poorly flushed, however, and retains oils for longer periods causing the possibility of delayed mortalities, tainting, and other chronic effects. The predatory starfish may be further affected by concentrating oil from tainted prey.

SUMMARY: Sea cucumbers and starfish are occasional inhabitants of mud substrates. Direct oil contact causes narcotization and mortalities, and, since mud retains oil, persistent tainting and other chronic effects can occur.

RELIABILITY: *

C. MUD

10. Crustaceans

Four crustaceans in this study live on subtidal muddy substrates. The dungeness crab (*Cancer magister*) scavenges here as it does on other bottom types. Ocean pink shrimp (*Pandalus jordani*) and pink shrimp (*Pandalus borealis*) are common on mud below 100 meters and sidestripe shrimp (Pandalopsis dispar) occurs to 600 meters. All three species feed on worms and detritus, and migrate into the water column at night to feed on copepods and euphausiids. Eggs are brooded over the water, and larvae are released in the spring. Later larval stages, particularly of the pink shrimp, occur near the bottom in shallower water. Juveniles return to deeper water and usually breed as males in their second year, after which they become females.

Crustaceans in general are fairly resistant to oil effects. Being subtidal, none of these species is likely to contact oil directly unless it is sunk with dispersants or dissolved due to wave action. In this instance, the soluble fractions would be greatly diluted. Crabs could consume oil-killed organisms, and the pandalid shrimp could eat copepods which have eaten oil. This could cause tainting of tissues of such commercial shellfish. Possible effects of food-chain concentrations of petroleum products and chronic toxicity effects have not been studied, but these are not likely to occur in deeper water.

SUMMARY: Other than for possible tainting of crab tissues, these mud-living crustaceans, being subtidal and relatively resistant to oil, are not likely to be greatly affected by spills.

RELIABILITY: ***

C. MUD

11. Molluscs

Of the 31 molluscs included in this study, six occur in the mud habitat. Of these, only the Atlantic soft shell clam (Mya arenaria) occurs in the substrate exclusively. The butter clam (Sacidomus giganteus) and the horse clams (Tresus nuttalli and Tresus capax) live in muddy shore sediments, while the common cockle (Clinocardium nuttalli), the geoduck (Panope generosa), and the Atlantic soft shell clam live in tidal and flats as well. All five also occur in subtidal muddy areas, and all filter their food from the water. The geoduck remains in its burrow for its entire life. The two horse clam species also have little mobility. Butter clams as juveniles and soft shell clams are more agile. The cockle moves easily in surface sediments. Soft shell clams spawn year-round, the others in the spring or summer; eggs and larvae are planktonic.

Except for the geoduck and the horse clams, which are deeply buried, all of the clams are preyed upon by the moon snail (Polinices) which is primarily subtidal, but extends into the intertidal. Characteristic moon snail egg cases left on the mud surface in spring and summer hatch into planktonic larvae. After the larvae settle, they first feed on algae and clam spat, and then exclusively on clams.

Moon snails and cockles were apparently unaffected by the Santa Barbara crude oil incident, but 50% to 100% kills of cockles from No. 2 diesel oil have been recorded. Residual oils have been shown to cause 100% kills of soft shell clams in the laboratory. Bunker C and No. 2 diesel oils have been shown to cause tainting in soft shell clams for more than six months. A study of long-term soft shell clam mortality, taken at invervals of several months following a bunker C spill, showed 12% to 22% mortality after 3, 9, and 18 months. In this case, contaminated clams tended to leave their burrows to escape the oil, and were eaten by predators. Data suggests that crude oils, at least low aromatic crudes, are not particularly damaging to the molluscs, but refined products cause both immediate and long-term mortalities. The long-term effects are particularly important since mud accumulates only where water movement is slight. Thus, flushing is poor, allowing oils to remain for long periods. Clay particles in the muds adsorb and retain oils. Oils can be incorporated into the sediments by wave agitation, and by mixing of sediments by animals possibly to a depth of 30 cm or more. Oil will then remain in the mud for extended periods of time. Some studies suggest that oils not subject to anaerobic biodegradation will remain in sediments indefinitely, and that future perturbation of the sediments (by dredging, for example) can release significant quantities of the trapped hydrocarbons. If they are returned to an aerobic environment in appreciable quantities, partially degraded oils could cause local effects.

SUMMARY: In a mud sediment habitat, crude oils, at least low aromatic crudes, do not appear particularly damaging to molluscs. However, refined products cause both immediate and long-term mortalities. Mud sediments tend to absorb and retain oils for long periods of time.

RELIABILITY: ***

C. MUD

12. Annelids

The annelid polychaete worm Nereis vexillosa described in detail on page IV-23, burrows in intertidal and subtidal muds. The effects of oil spillage in this habitat are the same as for annelids in rock habitat (see Section A.12, p. IV-23).

RELIABILITY: *

C. MUD

14. Grasses

Though the eelgrass Zostera marina is most often found growing on a mixture of sand and mud, it does grow in mud only and forms extensive beds in some areas. These beds of eelgrass are found in relatively sheltered locations with irregular wave action and currents of less than 3.0 knots throughout Puget Sound, covering an estimated 9% of the area. Patchy eelgrass beds occur in areas where wave action is greater. Though the quantity of plant material in an eelgrass bed is less in winter than in summer, blades are present for exposure to oil throughout the year. The rhizome-root matrix anchoring eelgrass beds is also potentially vulnerable throughout the year. Reproductive life stages occur during spring and summer in the most productive period of growth.

The sheltered locations in which eelgrass beds are often found, such as bays and lagoons, and relatively sheltered and more slowly flushing areas, such as Hood Canal, will tend to retain oil from spills for longer periods of time. During winter, when blades of eelgrass are being sloughed off and washed ashore, mats of drift blades will further capture and retain oil for later remobilization in the intertidal. The observation has been made of oil (bunker C) trapped in the sediments of eelgrass beds being gradually released by subsequent natural perturbation of these sediments, thus producing a longer exposure of the environment to spilled oil. The eelgrass beds appear to be unaffected by oiling of sediments, possibly because of the naturally occurring reducing environment of the detrital layer of eelgrass beds and the rhizome-root-sediment environment. Since root-rhizome respiration is both aerobic and anaerobic, the reducing environment produced by oil may not harm eelgrass beds. Oil may be toxic to blades, but no studies of this effect have been done except for an observation of patchy discoloration ("burning") from a diesel fuel spill. Oiling of blades, if not toxic to the grass, would likely make them unpalatable to natural predators such as Black Brant that depend on eelgrass for food during the winter months. Epiphytic biota, including sensitive species such as the red algae *Porphyra nereocystis*, could also be damaged by a thick coating of oil on leaves.

The spring and summer flowering (occurring in May in the Sound) and production of water-borne pollen are stages on which there has been no study of oil impact. A spill at the beginning of this period, with persistent dispersion of trapped oil from the bed itself, may disrupt the settling of pollen and fertilization and may result in a reduced maintenance of the eelgrass bed population.

SUMMARY: Though observations of eelgrass beds exposed to oil spills show little if any damaging effect, there is little known of the effects of oil on sensitive life stages where effects could be significant. Because of the oil retentive nature of eelgrass beds, the bed itself may have a subtle subsequent effect on the near intertidal and biota eelgrass by releasing small amounts of oil over a prolonged time period.

RELIABILITY: ***

D. MIXED - COARSE

1. General Impact

Mixtures of boulders, cobbles, and gravel are associated with high energy wave or current conditions. Heavy surf can emulsify oil in the intertidal zone causing initially heavy coats of oil. Light toxic fractions which would otherwise evaporate on the surface can be included in the emulsion causing the potential for high initial toxicity to organisms. Flushing can be rapid because of surf and current conditions but slower than on exposed rock faces. Heavy coatings may remain in high intertidal areas for long periods. These coatings are subject to weathering, bacterial degradation, and photochemical breakdown.

Subtidal mixed-coarse sediments are swept by strong currents and would not be severely affected except by an extremely severe spill. As in solid rock areas, tidepools can be expected to experience severe effects.

SUMMARY: Oil is emulsified by the surf associated with mixed-coarse sediments, causing initial heavy oil coating and potentially high toxicity. Flushing is rapid, except in the high intertidal. Subtidal oil effects are expected to be minimal.

RELIABILITY: ***

D. MIXED - COARSE

2. Mammals

Based on available information, the effects of oil spillage on marine mammals occurring on a mixed-coarse shoreline are the same as those occurring on a sandy habitat. See Section B.2, pp. IV 32-33.

RELIABILITY: **

D. MIXED - COARSE

3. Birds: Offshore Feeders

Gulls (Larus spp.) and cormorants (Phalacrocorax spp.) are often found in this habitat. Gulls use the area as foraging and roosting grounds, whereas cormorants restrict their use to roosting only. Since gulls are scavengers, consumption of tainted food is the most probable impact of oil pollution. Effects of oil on cormorants is minimal and confined to possible contact with feathers. It is likely that cormorants would avoid heavily oiled areas for roosting. Specific external effects of oil on these birds and effects of oil consumption are described under sand habitat (see Section B.4, pp. IV 35-36).

SUMMARY: Serious effects of oil on cormorants frequenting mixed - coarse habitat is improbable. Gulls, however, may be affected by consumption of contaminated food.

RELIABILITY: **

D. MIXED - COARSE

4. Birds: Shorebirds

Black Oystercatchers (Haematopus bachmani), turnstones (Arenaria spp.), surfbirds (Aphriza virgata), and Wandering Tattlers (Heteroscelus incanus) use mixed - coarse habitat for feeding and roosting. With the exception of the Black Oystercatcher, which is a permanent resident, the other shorebirds are migrants and winter visitors. Consumption of tainted food is the most serious threat to this group from oil pollution. Other oil impacts are described for the sand habitat (see Section B.4, pp. IV 35-36).

RELIABILITY: **

D. MIXED - COARSE

5. Birds: Casual Marine Feeders

Northwestern Crows (Corvus caurinus) are the only member of this group that frequent the mixed - coarse habitat. This species is primarily a scavenger and can be found in the area throughout the year. The greatest probable oil impact on crows is consumption of oil-tainted foods; however, crows are likely to avoid heavily oiled areas. For details of the effects of oil on this species, see the text under Sand Habitat (see Section B.4, pp. IV 35-36).

RELIABILITY: **

D. MIXED - COARSE

6. Fishes: Shoreline

Of the 19 species of shoreline fishes considered in this study, eleven are commonly found in a mixed - coarse habitat. These are the sculpins, the greenlings (*Hexagrammos* spp.), the gunnels, and the quillback rockfish (*Sebastes maliger*). All are intertidal species and most probably occur on or over this bottom type throughout the year. None are important commercially, but they are important to the ecology of the shoreline communities. Gunnel and sculpin deposit demersal eggs in the gravel; gunnel guard their nests under boulders until the eggs are hatched.

Oil spilled on the mixed - coarse habitat in inshore water will moderately contaminate the habitat of these species. Mixed - coarse habitats are generally characteristic of high energy areas where oil is likely to be removed quickly by wave and tidal action. Individuals not trapped in tidepools are capable of moving away from a polluted area, but most are somewhat territorial and would be reluctant to leave. The most severe effects are expected to be to tidepools from pollution by highly toxic materials (aromatics, highly soluble fraction products, etc.). Narcotization of individuals in tidepools or under intertidal rocks is likely to lead to predation by less susceptible grapsoid crabs causing significant mortalities.

SUMMARY: The high energy mixed - coarse habitat is not likely to retain oil for long periods of time. Significant impact is likely to result only during intertidal spawning of gunnels or in the case of a highly toxic spill.

RELIABILITY: **

D. MIXED - COARSE

7. Fishes: Demersal-epibenthic

Most of the 41 species of demersal and epibenthic fishes included in this review are found on or above mixed-coarse substrates; rockfishes (Sebastes spp.) are probably the most common. Ratfish (Hydrolagus colliei), midshipman (Porichthys notatus), cod and cod-like fishes, as well as starry flounder (Platichthys stellatus), C-O sole (Pleuronichthys coenosus), and curl-fine sole (Pleuronichthys decurrens) are also found on this substrate. As in the case of other types of substrate, the fish on mixed-coarse bottoms are not seriously affected by spills of oil or refined products as long as they are in deeper waters. Those in relatively shallower water, especially pelagic larvae and juveniles, can be seriously affected by soluble fractions. Rockfish give birth to live young in midwater. These fry migrate vertically, rising to the surface to feed at night, or take up residence in intertidal pools. Therefore, they can come into contact with soluble fractions or emulsified oil from intertidal spills or from floating patches of oil. Judging from the results of experiments performed with salmonids, soluble fractions may cause narcosis and death, probably through the disruption of gill membrane permeabilities. These latter potential effects would be localized, with the overall impact relative to the volume of spill. An extensive sinking of heavy fractions of oil may cause a limited reduction of habitat plus mortality and contamination of food organisms.

SUMMARY: Oil impacts on demersal and epibenthic fishes are expected to be light except in shallow regions where juvenile rockfish and some of the sole and flounders are frequently found. Impacts in these areas could be moderate to locally heavy, depending on the nature of the spill. Some local pelagic effects could be expected associated with patches of floating oils.

RELIABILITY: **

D. MIXED - COARSE

8. Fishes: Open Water

Of 17 species of pelagic fishes in Puget Sound, four species (Pacific herring, Clupea harengus pallasi; surf smelt, Hypomesus pretiosus pretiosus; eulachon, Thaleichthys pacificus; and capelin, Mallotus villosus) require mixed-coarse and mixed-fine habitats in the intertidal zone for spawning during the spring and fall. Oil spills in the intertidal zone during the spawning season will cause high mortality of eggs from suffocation and poisoning. These species are commercially harvested or are preyed upon by larger commercially important predator fish, such as salmon and rockfish. Oil of any kind is likely to have severe effects if spilled or washed up onto spawning grounds. Juvenile pink and chum salmon reside in shallow mixed-coarse and mixed-fine habitats for an early period of their development. They would be highly susceptible in this early stage of development to an oil spill through direct toxicities, narcotization, and increased vulnerability to predation. Severe indirect effects could result from a reduced food supply of invertebrate prey. Limited shallow beach areas with reduced food supplies would force the juveniles into deeper water with greatly increased predation.

SUMMARY: Four important food fish use the mixed-coarse habitat for spawning in spring and fall so that spills during spawning could devastate local runs. Two juvenile salmonids use this habitat as a refuge from predators and as a nursery in the spring. Limited alternative habitats increase the severity of impact on this group.

RELIABILITY: **

D. MIXED - COARSE

9. Echinoderms

The mixed - coarse environment is functionally similar to rock faces for echinoderms, and is a preferred habitat for all species, second only to rock. The distribution of the various animals and their responses to crude and refined oils are identical to those observed in the rock habitat (see Section A.9, pp. IV 16-17), except that mixed - coarse sediments will not be flushed as rapidly as rock, causing longer exposure to oil, more tainting, and other chronic effects.

SUMMARY: Echinoderms are common in a mixed - coarse habitat. Their responses to the environment and oil impacts are similar to those indicated under rock habitat in Section A.9, pp. IV 16-17).

RELIABILITY: **

D. MIXED - COARSE

10. Crustaceans

A variety of crustaceans inhabit mixed - coarse sediments. In the intertidal zone, filter feeding barnacles (Balanus spp.) live attached to rock surfaces. The beach isopod (Idothea wosnesenski) lives among and consumes several species of algae which grow on the larger sediments, while the sand flea (Orchestia traskiana) lives under and feeds on detritus, particularly algae. Small red rock crabs (Cancer productus) can be found foraging for food in the lower intertidal. Red rock crabs, dungeness crabs (C. magister), and barnacles extend into the subtidal with the dungeness crab becoming more common in finer substrates. In the near shore subtidal, the Puget Sound king crab (Lopholithodes mandtii) moves from deeper water in winter to spend spring at 6-10 meter depths. Males and juveniles remain through summer, but females return to sediments below 30 meters after eggs hatch in May. Dock shrimp (Pandalus danae), coonstripe shrimp (P. hypsinotus), and spot shrimp (P. platyceros) do not exhibit such seasonal movement, but later juveniles and young adults are found closer to shore than the main populations. All three species are most common below 60 meters, with spot shrimp having the deepest range and coonstripe shrimp being intermediate. Pandalids hunt and scavenge on the bottom during the day, and swim up, often near the surface at night, to feed on euphausids and copepods. Puget Sound king crab females, found below 30 meters in summer, join the box crab (Lopholithodes formaminatus) in deeper water in the fall. The shallower mixed-coarse beach areas harbor good populations of amphipods and harpacticoids, important prey for some juvenile fish.

The red rock crab, the largest crustacean for which oil data were found, is quite resistant to oil. Tainting of tissue occurs, however, and has been found to persist for more than two years in other Cancer species. Sand fleas, which are considerably smaller than crabs, are much more susceptible. Barnacles showed high local mortalities in intertidal spills; the evidence suggests they were smothered rather than poisoned. In the laboratory, barnacles show narcotization at high oil concentrations. The beach isopod would be affected by oil spills if the algal it feeds upon were killed. Pandalids and other deep water species are not likely to encounter oil, unless they feed near the surface at night, or if oil is brought to the bottom by dispersants. The shoreline epibenthic crustaceans would probably be severely affecting by direct toxicity and smothering.

SUMMARY: Other than some local mortalities, an oil spill would not likely affect the larger crustaceans, except for probable tainting of tissues. Localized barnacle kills can be expected from smothering, while only minor impact on the pandalid shrimp is suspected. Serious local impacts on beach area epibenthic crustaces are expected.

RELIABILITY: ***

D. MIXED - COARSE

11. Molluscs

Of the 31 molluscs included in this study, 14 occur in the mixed - coarse sediment habitat. Three species prefer this substrate extensively - the northern abalone (Haliotis kamtschatkana) and the two species of octopus (Octopus spp.).

Mixed - coarse sediments, indicative of strong currents and moderately strong wave conditions, present a combination of solid surface and sedimentary mollusc habitats. In intertidal and shallow subtidal areas, the rock surfaces are occupied by the bay mussel (Mytilus edulis), wrinkled purple snail (Thais lamellosa), and the Olympia oyster (Ostrea lurida). From low intertidal areas into deep water, northern abalone, Pacific pink scallops (Chlamys hastata), and chitons (Mopalis lignosa) are present. Octopi nest between and under boulders in the subtidal zone. Butter clams (Saxidomus giganteus), manila clams (Venerupis japonica), and the rock cockle live in the sediments, particularly where there is an inclusion of finer silts or clays. Species of the oyster (Crassostrea) are found on the sediment surface. They and other bivalves are filter feeders. Abalone and chitons are algal grazers. The wrinkled purple snail and the two species of octopus are predators on molluscs and crustaceans. The wrinkled purple snail lays benthic eggs which hatch as small adults. Octopi guard a clutch of attached eggs until the larvae hatch and disperse in the water. The other molluscs release planktonic eggs or larvae directly into the water.

These organisms appear to be relatively resistant to aliphatic crude oils. Aromatic components are selectively retained and cause tainting. Heavy mortalities in the clam species have been caused by No. 2 diesel fuel oil spills. Fifty percent of the wrinkled purple snails in a 113 ppm concentration of No. 2 diesel were unable to reattach after 36 hours. Chitons, abalone, and octopi may be similarly affected. In this relatively high energy environment, narcotized animals could be battered to death by waves or currents or become vulnerable to predators. Sublethal quantities of diesel fuel (as low as 17 ppm) inhibit byssus formation in immature mussels, thus preventing spat from settling successfully. Oysters are apparently more resistant to petrochemical toxicity than other species, but they easily become tainted. Because of the high volume of water movement, molluscs in this environment can experience rapid population rebound by seeding from other areas, except for the wrinkled purple snail which has no pelagic larval form.

Mixed - coarse sediments are not likely to become contaminated for long periods because of constant flushing. Mortality in the intertidal is higher on the upper portions of the beach than in the more continuously wave-swept lower portions.

SUMMARY: Oil impacts on mixed - coarse sediments can produce a fairly rapid mortality of clams, and paralysis and subsequent death of snails, chitons, abalone, and octopi. There should be little long-term incorporation of oils in sediments, and, during the next spawning season, new individuals could be introduced into the area.

RELIABILITY: ***

E. MIXED - COARSE

12. Annelids

Nereis vexillosa, the only annelid worm in this study, is described in detail on page IV-23. These nereids live in mixed - coarse sediments in microenvironment at the base of beds of mussels and barnacles, where they are protected from waves and temperature stress. The effects of oil spillage in this habitat are the same as for the annelids in the rock habitat (see Section A.12, p. IV-23).

RELIABILITY: *

D. MIXED - COARSE

13. Algae

This habitat is intensely populated with diverse algae in both its intertidal and subtidal range. Representatives of the red algae genera Gigartina, Iridaea, Porphyra, and the kelps Nereocystis and Macrocystis are found here. A clean, rocky substrate and moving water with low particulate content are necessary to maintain these surfaces and are essential to the growth of both the red algae and the kelps in this habitat. The effects of oil spillage in this habitat are the same as for algae in the rock habitat (see Section A.12, pp. IV 24-27).

Laboratory observations of the effects of various kinds of oils on marine algae have largely been confined to species of Macrocystis and Porphyra. Generally, toxicity of hydrocarbons increased in this order: straight-chain alkanes, aliphatics (paraffins), alkenes (olefins), cycloalkanes, and aromatics.

SUMMARY: The diverse algal assemblage in this habitat may be affected in many ways by oil. The most serious impact will occur during the peak growing season of summer and early fall. Many sensitive phases of algae growth have not been studied in relation to oil impact, and effects can only be a matter of conjecture. In the middle and higher intertidal, major damage to algae with unprotected thalli from highly aromatic or highly naphthenic crudes and light petroleum products can be expected. On the other hand, subtidal kelp beds may become more dense due to oil-caused death of natural predators that tend to control the level of algal production.

RELIABILITY: ***

E. MIXED - FINE

1. General Impact

Mixtures of mud, sand, and gravel are extremely common on Puget Sound beaches because of the protected waters and the mixed glacial sediments which feed the beaches. In general, oil interacts with these beaches in a manner similar to mud sediments. Oil is adsorbed onto clay particles and can be retained for long periods. It flows into burrows of animals and is mixed into the surface sediments to a limited extent by waves. Water movement is moderate to slow, and flushing is proportional. Gradually, some mixing of oil into sediments is caused by burrowing organisms, but not to the same extent as in mud. Bacterial degradation of oil occurs, facilitated by increased surface area as oil is spread over clay particles. Mild subsurface anoxic conditions may occur in summer, retarding oil breakdown. Cleansing occurs due to a combination of flushing and degradation, and some residual amount of oil can be permanently incorporated in the sediments, where it may be exposed by later sediment disturbances, such as dredging.

Mixed - fine habitats support a dense and diverse community, particularly of clams. Quantity and toxicity of oil will determine the impact of a spill, but moderate to poor flushing suggests the probability of both initial mortalities and chronic effects, such as persistent tainting. Deposit feeders, which ingest sediments, can continually introduce residual oils into the food web. Speed of repopulation depends on recruitment from adjacent mixed - fine sediment areas.

SUMMARY: Oil is adsorbed onto clay, and mixed into surface sediments initially by waves and later by organisms. Cleansing is slow to moderate, a result of a combination of flushing and bacterial action. Residues can remain for long periods in the sediments, and are introduced into the biological community by deposit feeders. Mortalities may occur from the initial incident; chronic effects are also possible.

RELIABILITY: **

E. MIXED - FINE

2. Mammals

Based on available information, the effects of oil spillage on marine mammals occurring on a mixed-fine shoreline are the same as those occurring on a sandy habitat. See Section B.2, pp, IV 32-33.

RELIABILITY: **

E. MIXED - FINE

3. Birds: Offshore and Pelagic Feeders

Dabbling ducks (*Anas* spp.) and gulls (*Larus* spp.) frequent mixed - fine habitat during the fall, winter, and spring months. Oil impact on ducks is minimal as they primarily use this habitat for roosting. Gulls, however, could be more seriously affected as a potential exists to consume oil-tainted food. Specific effects of various oils and oil products are described under Sand Habitat - Shorebirds (see Section B.4, pp. IV 35 - 36).

RELIABILITY: **

E. MIXED - FINE

4. Birds: Shorebirds

Shorebirds such as sandpipers (Calidris spp.), yellowlegs (Tringa spp.), and dowitchers (Limnodromus spp.) commonly utilize mixed - fine habitat during the spring and fall months. Great Blue Herons (Ardea herodias) are permanent residents in this habitat. Because these birds are highly mobile, mixed - fine habitat is only partially depended upon for food and roosting sites. The most serious threat to this group from an oil spill would be consumption of food contaminated by oil. Details of the effects of oil on these species can be found in the description of shorebirds in sand habitat (see Section B.4, pp. IV 35-36).

RELIABILITY: **

E. MIXED - FINE

5. Birds: Casual Marine Feeders

Bald Eagles (Haliaeetus leucocephalus) and Northwestern Crows (Corvus caurinus) may be found scavenging on mixed - fine habitat throughout the year. In case of an oil spill, it is unlikely that oil would come into contact with the birds' feathers; however, consumption of oil-contaminated food is possible. For details on the effects of oils on birds, see the discussion under Sand - Shorebirds (see Section B.4, pp. IV 35-36).

RELIABILITY: **

E. MIXED - FINE

6. Fishes: Shoreline

Crescent gunnel (Pholis laeta) and penpoint gunnel (Apodichthys flavidus) are two of 19 species commonly found on mixed - fine substrate in Puget Sound. They commonly inhabit the intertidal zone and tidal pools throughout the year, most likely completing their life cycle here. Five species of perch are also commonly found over mixed substrate: the redtail surf perch (Amphistrichus rhodoterus), shiner perch (Cymatogaster aggregata), stripe sea perch (Embiotoca lateralis), walleye surf perch (Hyperprosopon argenteum), and white sea perch (Phaeradon furcatus). Neither gunnel nor perch are commercially important in Puget Sound. Gunnel are usually found directly on this substrate, while small schools of perch are found above it.

The impacts of alaphatic crude oils on perch in deeper water are minor. Those in shallower water are easily narcotized by soluble fractions in the upper layer of water. High concentration of this fraction may cause suffocation of the fish, while low concentrations produce erratic swimming behavior which attracts predators. Large numbers of embiotocid perches are vulnerable to predation under these circumstances.

Gunnel spawn and lay demersal eggs in intertidal gravel. Egg masses are particularly susceptible to smothering by oil. In addition, embryonic development may be altered either by a restricted oxygen supply or through chemical activity of soluble fractions. Wave action will cause some mixing of oil, water, sand, and mud, effectively forming a sludge. Aromatic hydrocarbons contained in the sludge can be released to the surrounding water over an extended period of time exposing resident territorial fishes to prolonged chronic toxicity.

SUMMARY: Shoreline fishes in the mixed-fine habitat are likely to be affected most severely in the winter during the spawning of gunnel and when wave and temperature conditions favor the formation of sludge deposits. Warmer temperatures favor the solublization of aromatic fractions which would have severe impact on schools of perch.

RELIABILITY: *

E. MIXED - FINE

7. Fishes: Demersal-epibenthic

Various life stages of the demersal and epibenthic fishes in this study occur in a mixed - fine habitat. Juvenile rockfishes and flatfishes are quite common on these sediments. Ratfish, cod and cod-like fishes, and skates are also found on or above this substrate, feeding on polychaetes, crustaceans, gastropods, and other fishes near the bottom.

The impacts of oils on this group are expected to be minimal in deeper water. The effects of spills will be felt more strongly in relatively shallow water if soluble fractions are well mixed with water by strong wave action. The depth of penetration of contaminants is dependent on the age of oil as well as on the extent of surface mixing. Aliphatic crude oils are much less toxic to fish than highly aromatic oils and refined products.

Flatfish and cod and cod-like fish broadcast pelagic eggs, whereas rockfish give birth to live young. Flatfish larvae will seek the bottom as soon as they complete metamorphosis; prior to metamorphosis, they inhabit surface waters. Larvae of cod and rockfish occur near the bottom and migrate to the surface at night where they may become exposed to soluble fractions of spilled oil; narcosis and suffocation may result. Heavy fractions of spilled oil may sink to the bottom and contaminate the sediments which may cause tainting of food organisms such as polychaetes. This may in turn cause tainting of demersal and epibenthic fishes. In addition, direct exposure to sunken oils (Particularly in the case of flatfish) may cause skin irritation and tumors.

SUMMARY: Significant oil impacts on demersal or epibenthic fishes are restricted to juveniles in shallow waters or locally to those areas where heavy fractions sink and contaminate sediments.

RELIABILITY: **

E. MIXED - FINE

8. Fishes: Open Water

Pacific herring (Clupea harengus pallasi), surf smelt (Hypomesus pretiosus pretiosus), eulachon (Thaleichthys pacificus), and capelin (Mallotus villosus) are found over the mixed - fine habitat in Puget Sound. Spawning in the intertidal zone between early spring and fall, their eggs adhere to gravel and sand. If petrochemicals are spilled on the beach or an oil slick is washed ashore during spawning, extensive mortalities will result, effectively destroying replacement crops of fish. Eggs covered by oil are smothered or develop abnormally.

Very sandy mixed substrates are inhabited by the Pacific sand lance (Ammodytes hexapterus), an important food fish. Often they swim in schools in midwater, but they sometimes bury themselves in sand or mixed substrate. Sand covered with heavy fractions of oil or sand-oil sludges can be expected to interfere with the normal behavior of the sand lance.

The shallow mixed-fine shoreline habitat is critical for the onshore stage of development of juvenile pink and chum salmon. Thus any spill reaching this shallow habitat is likely to have serious effects on them. Direct toxicities and narcotization are probable. Forced emigration is equally probable and is serious because of limited alternative habitats. Migrations through deeper waters dramatically increase predation mortalities. Reduction of the invertebrate prey is also highly probable due to smothering by the heavier oil fractions and direct toxicity. This prey reduction further limits suitable nursery areas.

SUMMARY: Oil spills on or over mixed - fine habitats could result in serious impacts on seven pelagic fishes, four of which use this habitat extensively in the spring and summer for spawning, and two for critical nursery areas. Limited alternative habitats increase the severity of potential impact.

RELIABILITY: **

E. MIXED - FINE

9. Echinoderms

Sea cucumbers (Parastichopus californicus) are found on subtidal mixed - fine sediments, although it is not a preferred habitat. Occasional sea urchins (Strongylocentrotus spp.) and sunstars (Pycnopodia helianthoides) also occur on this substrate.

The responses of echinoderms to oil have already been described in the rock habitat (Section A.9, pp. IV 16-17). However, since mixed - fine sediments hold oil for longer periods than rock substrates, even more tainting and other chronic effects are to be expected. Most echinoderms in this habitat are subtidal; hence, they are insulated from the heavy oil coating that can occur in the intertidal region. Repopulation, depending on current and adjacent populations, could be slow.

SUMMARY: Echinoderms are found on mixed - fine substrates, but it is not a preferred habitat. Responses to oil impact is similar to those indicated under rock habitat (Section A.9, pp. IV 16-17).

RELIABILITY: *

E. MIXED - FINE

10. Crustaceans

Five of the crustaceans in this study occur on mixed - fine sediments. Barnacles (*Balanus* spp.) occur on oyster shells and other hard surfaces on top of the sediments in the intertidal and shallow subtidal areas. The sand flea (*Orchestia traskiana*) is abundant intertidally, particularly under algal debris, and in burrows high on the beach. The dungeness crab (*Cancer magister*) is common subtidally, while red rock crabs (*Cancer productus*) occur occasionally, especially where silt content is low. In deeper water, ocean pink shrimp (*Pandalus jordani*) are common, particularly from 100 to 200 meters. This is an important habitat for many prey species of juvenile fish (i.e., amphipods and harpacticoids), especially in the shallows. Barnacles are filter feeders and release larvae in winter which set in June and July. The sand fleas feed on detritus, brood their eggs, and have no planktonic life stage. The *Cancer* species are scavengers, migrating into shallow water in summer to mate and molt, and moving to deeper water during the winter. Off the coast, they move to the north during summer and south in winter. Ocean pink shrimp feed on organic detritus and smaller invertebrates on the bottom during the day, and rise to mid-water or the surface at night to feed on euphausiids and copepods. They brood eggs over winter, releasing larvae in the spring. These larvae return to the bottom in summer in shallower water. Most mature as males at two years, and become females at three years.

The barnacles are apparently fairly resistant to oil poisoning, but can be smothered by heavy direct coating. Red rock crabs reached 50% mortality after more than 12 hours in undiluted No. 2 diesel oil, while sand fleas survived less than two hours. This may be a result of the greater surface/volume ratio of sand fleas, since smaller individuals also died more rapidly than larger ones.

Local populations of the smaller crustacea would be severely affected in the shallow beach areas. Crabs showed tainting which persisted for more than two years in some studies. Crabs are probably most susceptible to oil effects during the summer mating period when pairs may remain buried in the surface sediments in shallow water for several days while the female molts and is fertilized. No information was found, however, concerning oil effects on molting crabs. Panalid shrimp live in deeper water and would have contact with oil only in very diluted states. The probability of contact is increased somewhat during vertical migrations. Copepods have been observed to ingest oil in the water; shrimp could then concentrate oil from this food source, thus becoming tainted indirectly from oil on the surface. Effects of chronic oil pollution or concentration of minor oil constituents are unknown.

SUMMARY: The available evidence suggests oil spills will cause severe local mortalities in smaller crustaceans. Larger crustacea will probably not suffer significant mortalities, but commercially important shellfish may become tainted. Molting adult crabs may be more susceptible, though chronic effects are unknown.

RELIABILITY: **

E. MIXED - FINE

11. Molluscs

Of the 31 molluscs considered in this study, 14 occur in mixed - fine sediment habitat. Of these, 10 frequent this habitat extensively. Mixed - fine sediments harbor a profuse and diverse community of molluscs, particularly bivalves. Ten of the bivalve molluscs under consideration in this study and the moon snail (Polinices lewisii) occur in a band between the upper intertidal and eelgrass beds. Some, like the geoduck (Panope generosa) and the horse clams (Tresus nuttalli and Tresus capax), live in permanent burrows, while others move about. Oysters and some cockles (Clinocardium nuttalli) lie on the sediments; most others are within a foot of the surface. Larger geoducks and horse clams may be two or three feet below the sediment surface. The mixture of species on a given beach will depend on salinity, temperature, and energy conditions. All are filter feeders, and all release planktonic eggs or larvae, except for the moon snail. This snail is predatory on clams and lays eggs on the sediment surface which hatch into planktonic larvae. At any time during the year some species of molluscs will be spawning, although most do so between late winter and mid-summer. Spawning success is variable, depending on physical conditions, and a large year-class may dominate the population of a species for three to six years. In the intertidal, the surface and shallow bivalves are stressed by large changes in salinity and temperature. A severe winter freeze can decimate the community. Beyond the intertidal, the Pacific coast squid (Loligo opalescens) lays its eggs in late summer on mixed - fine sediment on the bottom of gently sloping bays in depths of 3 to 40 meters. The eggs hatch in 20 to 25 days. In deeper areas of 90 to 110 meters, the sea scallop (Pecten caurinus) lives on the sediment surface filtering food from the water.

Considering the effects of oil on intertidal molluscs other than oysters, the Santa Barbara incident had no apparent effect on sedimentary mollusc communities. Spills of refined products, however, have caused significant local mortalities. A spill of No. 2 diesel oil caused 100% mortality in the clam (Venerupis) over a 39 square meter study area near Anacortes, Washington. Effects tend to be proportional to temperature (higher temperatures increase mortality rates). Spills in fine sediments also tend to have long-term effects, because the oils can be incorporated into the top portion of sediments. This subjects the animals to chronic low-level exposure and tainting, and to more severe effects if the sediments are disturbed by storms or by dredging. Bivalves selectively and persistently retain aromatic hydrocarbons in lipids, causing long-term tainting. There is no evidence of effects on reproduction by gonadal atrophy due to oil pollution as has been noted in other molluscs. If spawning were disrupted following a series of less favorable spawning seasons, a population could be severely depressed for years.

More data exist for oil effects on oysters, particularly Crassostrea virginica, than for effects on other bivalves. Oysters appear to be more resistant than other species, particularly to crude oils. Concentrations of thousands of parts per million of crude oil are required to cause significant mortality. Lower concentrations of both crudes and diesel fuels can cause tainting and suppression of pumping rates and ciliary activity, but do not cause death. Aromatics are selectively retained, causing persistent tainting. Several studies show concentrations of hundreds of parts per million of crude oils causing increased growth and improved survival as compared to laboratory controls, possibly due to digestion of aliphatic compounds. However, these are studies of Louisiana oysters, which are normally exposed to low-level oil concentrations in their environment. Sufficient levels of enzymes necessary to degrade oil will probably not be maintained in oysters unless they are continuously exposed to oil.

In deeper water, mating squid and squid eggs are not likely to be directly exposed to oil unless dispersants or sinking agents are used. Squid are highly mobile and do not cease feeding during breeding season. Adults which are contaminated at the surface, or eat contaminated fish could introduce oils into the lipids in the eggs. Pacific coast squid live only three years (a short life span for a mollusc), breed once, and then die. If a spill occurred over a large enough area, a single breeding disruption could depress every third-year class for several cycles thereafter. Scallops, the other deep water mollusc in this study, are noted for selective retention of aromatics and persistent tainting.

SUMMARY: Based on available data, low aromatic crudes are not particularly threatening to molluscs. Refined products can cause severe mortalities and probably can disrupt reproduction. Oils incorporated into sediments for long periods can lead to persistent tainting, and can raise the possibility of mortalities at a later time if sediments are disturbed.

RELIABILITY: ***

D. MIXED - FINE

12. Annelids

The annelid polychaete worm *Nereis vexillosa*, described in detail on page IV-23, burrows in intertidal and subtidal mixed - fine sediments. The effects of oil spillage in this habitat are the same as for annelids in a rock habitat (see Section A.12, p. IV-23).

RELIABILITY: *

E. MIXED - FINE

13. Algae

The algae are confined to larger gravel in this low to moderate energy habitat because of their requirements for the larger and more stable substrate. Various species of the red algae genera *Porphyra*, *Gigartina*, and *Iridaea*, in addition to forms of green algae, attach to gravel in the subtidal and intertidal. *Iridaea* and *Gigartina* are primarily present in the subtidal range but only where tidal currents are present to keep surfaces clean. *Porphyra* species will inhabit the entire range of the intertidal. The effects of oil spillage in this habitat are the same as the algae in the rock habitat (see Section A 13, pp. IV 24-27).

RELIABILITY: ***

E. MIXED - FINE

14. Grasses

A misture of sand and mud is the preferred habitat of the eelgrass Zostera marina, as described in detail in Section C 14, pp. IV 63-64. The effects of oil spillage in this habitat are the same as for grasses in a mud habitat (see Section C 14, pp. IV 63-64).

RELIABILITY: ***

F. EELGRASS BED

1. General Impact

The eelgrass (Zostera marina) forms extensive beds in Puget Sound. Other marine grasses are found throughout the Sound, but, with the exception of the suft-grass (Phyllospadix scouleri), are patchy in occurrence. Surf-grass grows in high energy (surf) conditions in solid rock and rock-boulder habitats. Roots and rhizomes of this grass form their own substrate by retaining bits of detritus, sand, and gravel.

Eelgrass beds are found throughout Puget Sound covering an estimated 9.0% of the bottom area below mean low low tide. They are found in sheltered bays and coves and along beaches, primarily in the subtidal from +5 feet mean low low tide down to -20 feet mean low low tide, where currents do not exceed 3.5 knots and wave action is moderate and irregular. Coasts fringed with eelgrass beds 200 feet wide and a mile in length are not uncommon. These beds tend to be widest in relatively shallow depths.

An extremely complex web of life forms is supported by the eelgrass bed habitat, with food chains deriving from eelgrass detritus feeders, from eelgrass herbivores, and from eelgrass epiphytes. The principal microhabitats in eelgrass beds consist of animals and plants (a) growing on the blades, (b) swimming among plants, (c) living on the mud surface, and (d) burrowing or living below the surface, such as various bivalves (clams), worms, and burrowing shrimp.

Eelgrass beds function to conserve particulate matter providing an environment in which organic matter moves into higher trophic levels. In relation to probable oil impact on this habitat, eelgrass beds will function similarly as strainers and retainers of oil spilled in their vicinity. The location of these beds in low energy situations will increase the effectiveness of this function in the presence of an oil spill. Observations of oil effects on eelgrass beds are few. Observations of eelgrass blades affected by spilled diesel fuel showed that patchy discoloration ("burns") occurred. It also has been noted that oil (bunker C in this case) became entrapped in eelgrass beds and incorporated into the sediments. Droplets of oil are subsequently released over a prolonged time period into surrounding areas by gradual seepage out of the substrate during tidal fluctuations or as the result of natural perturbations of the detritus layer. The eelgrass itself appears to be resistant to the effects of crude oils and some heavy petrochemical products. This is probably due to the naturally reducing sediments around the rhizome-root matrix and the capability of eelgrass to respire anaerobically. However, the effects of oil on sensitive life stages of eelgrass, particularly developing reproductive stages (necessary for the maintenance of this habitat), are not known.

SUMMARY: Detritus from the decomposition of eelgrass blades serves as the most important energy source in this habitat. The effects of oils on the bacterial decomposition of dead eelgrass blades into detritus suitable for consumption by detritus and filter feeders are unknown. It is presumed that effects would be adverse, particularly with respect to oils with high aromatic or naphthenic content.

RELIABILITY: ***

F. EELGRASS

3. Birds: Offshore Feeders

Eelgrass habitat offers an abundant food supply for loons (*Gavia* spp.), grebes (*Podiceps* spp.), Black Brant (*Branta nigricans*), most ducks, Whistling Swans (*Olor columbianus*), and gulls (*Larus* spp.) in the Puget Sound area. All of these birds frequent the habitat during the fall, winter, and spring months, except for Western Gulls (*Larus occidentalis*) and Glaucous-winged Gulls (*Larus glaucescens*) which are permanent residents. Black Brant feed almost exclusively on eelgrass making this habitat-type of utmost importance to them. Since other species also obtain food from other habitats, the eelgrass habitat is on moderate importance to them.

Eelgrass is resistant to most oils and oil products. Therefore, oil pollution will not appreciably alter the availability of food to Black Brant. However, Brant may consume oil adhered to eelgrass blades or may become oil-covered.

The rhizome-root matrix of eelgrass traps oil sediments, creating anaerobic conditions. Since natural degradation of oil is primarily aerobic, an oil spill can have a long-term effect on food organisms (e.g. worms, clams, crabs and other crustaceans) inhabiting eelgrass beds. As a consequence, the food supply of these birds may decrease or the birds may consume oil-tainted food. Feather damage by oil is also probable. Specific impacts of oil and methods of contamination is detailed in the open water habitat section.

SUMMARY: Black Brant are most susceptible to oil impacts in this habitat due to its nearly exclusive diet of eelgrass. Other birds that occur in the eelgrass habitat may be affected by loss of food supply, by consuming tainted food, or by oiling of plumage.

RELIABILITY: ***

F. EELGRASS

4. Birds: Shorebirds

Eelgrass beds extend into the intertidal zone where most shorebirds (e.g. sandpipers *Calidris* spp.; yellowlegs, *Tringa* spp.; dowitchers *Limnodromus* spp.; and the Great Blue Heron, *Ardea fannini* can be found feeding. Herons are permanent residents while the others utilize eelgrass beds primarily during the fall, winter, and spring months.

The greatest probable impact of oil pollution here is loss of food supply or consumption of tainted food. These birds are likely to avoid areas of heavy oil impact. Specific effects of oil and methods of contamination are described for Sand Habitat - Shorebirds (see Section B.4, pp. IV 35-36).

RELIABILITY: **

F. EELGRASS

5. Birds: Casual Marine Feeders

Northwestern Crows (*Corvus caurinus*), permanent residents of the Puget Sound area, can be found foraging on exposed eelgrass beds. This habitat is of minor importance, however, as crows obtain food from many other habitats. A possibility exists that oil-contaminated food will be consumed. Heavily oiled areas are likely to be avoided.

RELIABILITY: **

F. EELGRASS BED

6. Fishes Shoreline

Eelgrass beds in Puget Sound extend from the intertidal zone to a depth of 10 meters. All of the 19 species of shoreline fishes as well as various early stages of pelagic and demersal fishes can be found in eelgrass beds. Eelgrass provides shelter for juvenile fish as well as a highly suitable habitat for food organisms. As this habitat is attractive to all species of shoreline fishes, the potential oil spill impact is severe to them.

Buffalo sculpin (Enophrys bison), red Irish lord (Hemilepidotus hemilepidotus), Pacific staghorn sculpin (Leptocottus armatus), tidepool sculpin (Oligocottus maculosus), cabezon (Scorpaenichthys marmoratus), penpoint gunnel (Apodichthys flavidus), saddleback gunnel (Pholis ornata), and crescent gunnel (Pholis laeta) are usually found on the bottom, while quillback rockfish (Sebastes maliger), sea-run cutthroat trout (Salmo clarki clarki), kelp greenling (Hexagrammos decagrammus), rock greenling (Hexagrammos lagocephalus), and white spotted greenling (Hexagrammos stelleri), are usually found above the substrate.

Since eelgrass beds do not extend to great depth, the impacts of oil are significant. Although cutthroat trout and greenling can swim away rapidly from a contaminated area, abandonment of a protective habitat can lead to predation. Sculpin and gunnel in the intertidal zone and shallow water are affected by both soluble fractions and heavy fractions of oil. They are not as mobile as cutthroat trout and greenling, and can be trapped in the polluted area. Heavy fractions of oil often sink, coating eelgrass and the substrate and smothering epiphytes and benthic organisms. The rhizome-root matrix of eelgrass has a tendency to trap sunken oil or oil deposited in the mat at low tide. Oil is subsequently released to surrounding water over long periods of time. The eelgrass itself tends to be very resistant to oil pollution and will often remain alive and apparently healthy while presenting an alluring but dangerous habitat to a wide variety of other organisms. Long-term chronic exposure to slowly released hydrocarbons may result in a wide variety of functional disorders, such as reproductive failure, as well as direct mortality.

SUMMARY: Oil pollution of an eelgrass bed represents a very serious immediate and long-term impact on shoreline fishes and other residents of this habitat. Since almost all shoreline fishes are commonly found in eelgrass beds, a spill in this habitat is regarded as potentially very damaging.

RELIABILITY: ***

F. EELGRASS BED

7. Fishes: Demersal-epibenthic

Juveniles of a variety of demersal and epibenthic fish frequently occur in or near eelgrass beds throughout the year. They are seldom found in growths of surf grass. With their luxuriant growths of long blades and abundant populations of small fishes and invertebrates, eelgrass beds provide attractive shelter and an abundant food supply for juvenile flatfishes, rockfishes, skates, rays, and other representatives of this group. This habitat serves as an important rearing area for demersal and epibenthic fishes.

Oil spills in eelgrass beds can have important consequences for all associated biota. The shallowness of the habitat and the tendency for eelgrass to retain oils, encourages the solublization of aromatic fractions of crude oils or of refined products. These soluble fractions have been shown to have very high toxicities, and their effect on demersal and epibenthic fishes follows this pattern. Narcotization is followed by suffocation, or predation by the less sensitive crabs on the affected fishes. If the rhizome-root matrix is exposed to oil during low tides, or if heavy fractions sink, oils become trapped in the mat of organic matter. These are held in large quantities for extended periods of time, to be released gradually as natural seepage or with agitations of the substrate. The results of this protracted, steady, low-level exposure of fishes to oils can only be speculated upon, but tainting is almost a certainty. Increased oxygen consumption is likewise a strong probability as it usually accompanies chronic poisoning. Less certai but probable results are reduced general fitness from the consumption of tainted food and long-term reproductive difficulties. Flatfishes are highly susceptible to tumors, especially on their ventral surface, in areas where the sediments are contaminated with various industrial and municipal wastes. There is circumstantial evidence linking these neoplasms with hydrocarbons or petrochemicals in the substrate.

SUMMARY: The pollution of eelgrass beds by oil is likely to have serious consequences for the juveniles of many demersal and epibenthic fishes which use this habitat for rearing. Impacts may be direct mortality, increased predation, poisoning from tainted food, and possibly long-term reproductive failure and increased incidence of tumors. We judge these potential impacts to be among the more serious ones within one specific habitat.

RELIABILITY: ***

F. EELGRASS BED

8. Fishes: Open Water

Young herring (Clupea harengus), Salmon and smelt (Oncornynchus spp.), adult smelt (Thaleichthys pacificus), and sand lance (ammodytes hexapterus), are frequently found in eelgrass beds throughout the year. Alternative habitats are available, but eelgrass is attractive to these fishes. The beds, commonly extending to 10 meters in depth, provide abundant invertebrate prey and good shelter.

An oil spill reaching this habitat will have serious effects on open water fish. The vegetation and structure of the bed will tend to hold the spill, while immediate leaching of the more aromatic fractions will cause direct toxicities and narcotization. The invertebrate food supply will be reduced significantly and, probably more important, the fish will tend to leave the area for more exposed habitats, increasing the probability of predation. Partial narcotization will further increase predation on out-migrating fishes.

Long-term chronic impacts to this group in an eelgrass habitat are also probable as fishes may immigrate continually into the contaminated beds. The root-rhizome complex can retain the heavier oil fractions for long periods, with extended gradual releases of toxic compounds. Food chain contamination is certain; tainting may also be expected. Long-term chronic exposure effects are not well documented, but general weakening and reduced viability are possible. Reduced future reproductive capacity has been suggested.

SUMMARY: Eelgrass beds are important for some economically important juvenile and adult pelagic fishes throughout the year. Spills reaching eelgrass beds will have short-term and long-term effects on this group.

RELIABILITY: ***

F. EELGRASS BED

9. Echinoderms

Two species of echinoderms, sea cucumbers (Parasticopus californicus) and green urchins (Strongylocentrotus droebachiensis), are occasionally found in eelgrass beds.

The effects of oil on these animals are described in the rock habitat section (Section A 9, pp. IV 17-18). Eelgrass traps and retains oil, whereas rock is rapidly flushed. Thus, more tainting and possible delayed mortalities are to be expected here. Intertidal areas will be more severely affected than subtidal ones through contact with floating oils.

SUMMARY: Sea cucumbers and urchins are occasionally found in eelgrass beds. Oil spills in the intertidal zone and shallow water can cause suffocation, narcotization, and death.

RELIABILITY: *

F. EELGRASS BED

10. Crustaceans

Three of the crustaceans in this study live in eelgrass beds. The beach isopod (Idothea resecata) ranges over the blades, eating detritus and eelgrass. Both dungeness and red rock crabs (Cancer magister and C. productus) hunt and scavenge in this habitat (commonly up to 10m deep), although the red rock crab is more common where sediments have little silt or mud, and the dungeness crab where the finer sediments are common. All three species brood their eggs; the isopod has no planktonic larvae.

From the limited available laboratory evidence, crabs are very resistant to immediate oil spill effects. Field spill reports are either inconclusive or show no effect. Persistent tainting does occur and would be a problem with the commercially harvested crabs. Isopods are probably more sensitive, having a greater surface/volume ratio and in general the smaller the crustacean, the more severe and immediate the effect.

Significant water soluble extracts from oil on the surface are not likely to reach the bottom dwelling crabs in damaging concentrations. Some direct mortalities can be expected to smaller crustaceans. If dispersants bring oil to the bottom, the crabs will be more directly exposed, but they are quite resistant. Long-term effects of low, chronic oil exposure are unstudied. The mobility of dungeness and rock crabs suggests rapid recolonization if the eelgrass itself is not seriously damaged.

SUMMARY: Sparse available written evidence suggests that larger crustaceans are fairly resistant to oil spills. Persistent tainting has been found to occur. Smaller crustaceans are more directly affected by oil with some mortalities expected. This will secondarily affect fish inhabiting these beds. Because of the mobility of those crustaceans occurring in eelgrass habitats, recolonization would be rapid if the eelgrass itself were not severely damaged.

RELIABILITY: **

F. EELGRASS BED

11. Molluscs

Molluscs in eelgrass beds are primarily the lower edge of clam communities extending into the intertidal. These molluscs include the rock cockle (Protothaca staminea), manila clam (Venerupis japonica), soft shell clam (Mya arenaria), common cockle (Clinocardium nuttalli), butter clam (Saxidomus giganteus), and geoduck (Panope generosa). Sediment type will determine which species dominate a given location. These bivalves are all filter feeders, and all have planktonic larvae. Soft shell clams spawn year-round, the rest primarily in the spring and summer.

Very little work has been done on the effects of petrochemicals on molluscs living in eelgrass. These clams are apparently relatively unaffected by crude oils with low aromatic content. Highly aromatic crudes and refined products cause paralysis and death. The soft shell clam will leave their burrows and try to avoid oil. On the surface they and narcotized cockles are eaten by crabs and other predators. Oil can be incorporated into the sediments of eelgrass beds, and can possibly cause long-term tainting and mortality of clams, particularly after sediment disturbance. The chronic presence of oil can possibly cause reporductive failure since oil has caused gonadal atrophy in other molluscs.

SUMMARY: Refined products in general and aromatics in particular can cause paralysis and death of the clams in eelgrass beds. The oil can remain as a chronic pollutant, causing long-term tainting and possible reporductive failure.

RELIABILITY: **

F. EELGRASS BED

12. Annelids

The annelid polychaete worm Nereis vexillosa, described in detail on page IV 23, burrows in the sediments and in the rhizome-root complex of eelgrass, particularly where silt content is high. The effects of oil spillage in this habitat are the same as for annelids in the rock habitat (see Section A 12, pp. IV 23).

RELIABILITY: *

G. KELP BED

1. General Impact

Two prominent types of kelp beds are found on the West Coast of North America: the commercially valuable *Macrocystis pyrifera* off the coasts of California and the kelp beds of *Nereocystis luetkeana* off the Oregon and Washington coasts. No kelp beds of *M. pyrifera* have been observed in Puget Sound. A closely related species *M. integrifolia* has been observed growing in beds exposed to open water in the Straits of Juan de Fuca. Differences between the development and growth of *Nereocystis* and *Macrocystis* relative to the effects of exposure to oil result in two different environments for other life forms. The body of the kelp itself as substrate is suitable for attachment of many plants and animals. *M. pyrifera* beds are perennial, with individual fronds and blades (from bottom to surface) persisting up to nine months to be continually replaced by new fronds produced from holdfasts. In contrast, *Nereocystis*, with its long stripes and surface fronds found at the same site over periods of many years, are annuals.

From January through March the site of a *Nereocystis* kelp bed will usually be without the mature sporophyte. Coupled with low water temperatures this cyclical presence-absence phenomenon of Puget Sound kelp beds results in their having less highly developed communities of life forms associated with them. The colonization of *Nereocystis* beds by epiphytes and epifauna is slow until mid-summer. Such growth proceeds rapidly, in addition to invertebrate infestations of forms burrowing into holdfasts. However, there is much less time for development of complex food chains before fall and winter low temperatures, storms, and natural weakening of holdfasts reduce the bed to few or no sporophytes. This process can begin as early as September. In light of these differences between *Macrocystis* and *Nereocystis* beds, the general impacts of oil on the kelp beds in the Puget Sound area should be considerably less when compared to those on the perennial beds in California waters.

Kelp beds are generally found in areas where currents may range from 1-8 knots. This is especially true for Puget Sound. In such currents the self-cleaning ability of the habitat is greatly enhanced. The gelatinous coating of Macrocystis and Nereocystis plant bodies reduces the amount of oil that will adhere to parts of the algae. Nevertheless, the flotation tissues (pneumatocysts) of kelps cause a large amount of the plant to float on the surface where it can intercept spilled oil. This interference and trapping of oil will have differing effects on the kelp bed community depending on the relative toxicity of the oil spilled and on the tidal level. Oil that would narmally be washed onto shores will occasionally be delayed, giving time for the light, more toxic oil fractions to be volatilized.

Since kelp beds are located offshore at some distance from the surf where oil can become emulsified, there is a tendency for oil effects to be limited to the upper level of the kelp community. Exceptions to this have been noted for Macrocystis where emulsified oil has intruded into the lower portion of kelp beds in a cove where oil (heavy diesel) was confined for an extended period of time. Where this intrusion has occurred, natural predators which control total wuantity of kelp through grazing have been killed, permitting marked increase in the size of kelp beds.

SUMMARY: Puget Sound kelp beds as habitats will be most vulnerable to damage from oil exposure from late June through October or November. Because of the gelatinous coating of the kelp, the habitat as substrate will resist harmful oil effects. Since beds are located where there are strong currents, the expected reduced contamination time of oil in the kelp habitat will reduce this impact on plant and animals living there. The greatest harm from oil spills will be sustained by inhabitants of the kelp canopy due to interception and trapping of floating oil.

RELIABILITY: ***

G. KELP BED

2. Mammals

The mammals that occur in kelp beds are harbor seals (Phoca vitulina), Stellar's sea lions (Eumetopias jubata), river otters (Lutra canadensis), and sea otters (Enhydra lutris). The Stellar's sea lion and the sea otter are restricted to the coast although sea lions are known to enter protected waters during the winter months. Harbor seals are common permanent residents of the coast and the greater Puget Sound area. River otters, primarily residents of freshwater rivers, streams, and lakes, also occur on the San Juan Islands. Kelp beds are of great importance to sea otters as a preferred habitat. Any protected, shallow, coastal waters with a good benthic invertebrate food supply can offer sea otters favorite food items such as sea urchins (Strongylocentrotus spp.), abalone (Haliotis spp.), mussels (Mytilis spp.), crabs, and some small fish, sea otters will also drape kelp over themselves during feeding and sleeping to keep from drifting. River otters, harbor seals, and Stellar's sea lions also acquire food from this habitat.

Sea otters, formerly native to the Washington coast, have been considered extinct from the area until recent attempts to reestablish populations in 1969 and 1970. Where they are present, sea otters play a significant role in controlling the number of sea urchins, an important predator of kelp. Removal of an established population of otters from a kelp bed may result in an explosion in the population of sea urchins followed by extensive damage to kelp.

The external effects of oil in this habitat are the same as the mammals in the rock habitat (see Section A 2, pp. 6-7). In addition, marine mammals may be affected indirectly by contamination of their food supply. This can occur by consumption of tainted food or by loss of a food source (for example, contamination of sea urchins or abalone in the case of sea otters). Impact of oil on food supply is likely to be the most serious threat to marine mammals, with the possible exception of the otters where oiling of the pelt is paramount.

SUMMARY: The probable impact of oil pollution on harbor seals and Stellar's sea lions can only be speculated. Oil impact on otters, however, is more conclusive. Evidence indicates that certain oils seriously damage otter pelage to the extent that insultation is lost and subsequent death occurs.

RELIABILITY: ***

G. KELP BED

3. Birds: Offshore Feeders

Of the 51 species of offshore and pelagic feeders on the resource list, cormorants (Phalacrocora spp.), scoters (Melanitta spp.), gulls (Larus spp.), Common Tern (Sterna hirundo), Parasitic Jaeger (Stercorarius parsiticus), and the various alcids come into contact with kelp bed habitats. As an annual, kelp is absent from October through March. Therefore, most gulls, scoters, Parasitic Jaegers, and Common Terns frequent kelp areas only during early fall and late spring migration. Western Gulls (Larus occidentalis) and Glaucous-winged Gulls (Larus glaucescens) can be found in this habitat during the entire kelp growing season. Kelp beds provide an abundant supply of fish for cormorants, scoters, alcids, and terns, and resting areas for gulls and jaegers.

Kelp is highly resistant to oil pollution, as it occurs in relatively swift currents. Occasionally oil may be retained in the canopy of the bed. Should this occur, contamination of feathers is a strong possibility. Birds roosting in kelp beds at night are not likely to detect oil in the vicinity until daylight and could, therefore, be susceptible to contamination. Details on the effects of oil and oil products and methods of contamination may be found in the open water habitat section. (Section I 3, pp. IV 137-140).

SUMMARY: Permanent and summer residents of the Puget Sound area frequent kelp beds to the greatest extent. The most probable effect of oil pollution in this habitat is contamination of the bird's plumage.

RELIABILITY: ***

G. KELP BED

6. Fishes: Shoreline

The kelp beds of Puget Sound are populated by a number of shoreline fishes such as kelp greenling (Hexagrammos decagrammus), rock greenling (Hexagrammos lagocephalus), white spotted greenling (Hexagrammus stelleri), and kelp perch (Brachyistius frenatus). Kelp beds are the most important habitat to these species although they are found near other habitats such as rock, sand, and eelgrass beds. In addition to these four species, there are juveniles of many demersal and pelagic fishes which seek shelter and food in kelp beds. Kelp beds usually extend into much deeper water than eelgrass beds (probably up to 30 meters). Because of this, oil spills pose a moderate rather than severe threat to shoreline fishes frequenting this habitat. Kelp beds in Puget Sound are usually located in areas with resaonably strong currents, precluding persistence of spilled oil. As the variety of kelp occurring in Puget Sound in an annual, the beds disappear in the winter. Effects on residents of this habitat are therefore restricted to the late spring, summer, and fall. The kelp itself can be expected to be resistant to all but the most severe and toxic spills.

In some cases, where current and wind conditions are suitable, the relatively dense canopy of kelp may retain floating oil, thus exposing near-surface organisms to a somewhat prolonged exposure to soluble fractions. Fry and juveniles of shoreline fishes in kelp beds are most vulnerable to the oil toxicity. If they fail to move away from the polluted area, soluble fractions of the oil can lead to narcotization and heavy mortalities due to predation. If water temperatures are high, solublization as well as volatilization of aromatics is accelerated Oil slicks remaining on kelp beds in calm conditions may produce a greenhouse effect increasing the temperature of surface waters (especially during the summer) and accelerating the solubilization of aromatics.

SUMMARY: If conditions favor the retention of oil, juveniles of shoreline fishes which inhabit the canopies of kelp beds are moderately affected by soluble fractions of aromatic crude oils or refined products. Since these conditions do not often apply, average effect is expected to be light. The kelp beds are only present in the Sound in late June to October or November.

RELIABILITY: ***

G. KELP BED

7. Fishes: Demersal-epibenthic

Some demersal and epibenthic fishes are frequently found in or near kelp beds. For many species the foliage offers a good habitat for food organisms and suitable protection from predators. Shoals of juvenile rockfish (Sebastes spp.) are common, and young cod, black cod (Anoplopoma fimbria), ling cod (Ophiodon elongatus) and tom cod (Microgadus proximus) may also be found.

Because of the depth at which Nereocystis grows (usually 30 feet or more), oil spilled in kelp beds is likely to have direct effects only on juvenile rockfish or young cod and black cod occupying the upper layers of water just beneath the canopy. Narcotization following by predation is by far the most likely effect. Effects in deeper waters may result from eating tainted fish and invertebrates.

SUMMARY: The effects of oil spilled in kelp beds on demersal or epibenthic fishes are likely to be slight, with the most serious impact being on schools of juvenile rockfish which frequent this habitat. Because Nereocystis is an annual, complete recovery is virtually assured by the next growing season.

RELIABILITY: ***

G. KELP BED

8. Fishes: Open Water

In general, pelagic fishes are not usually associated with kelp beds; however, various life stages may be found in kelp in Puget Sound from late June through October or November. White sea bass (Cynoscion nobilis) lay their eggs in kelp beds from March to August. Young shad (Alosa sapidissima), Pacific herring (Clupea herengus pallasi), all species of salmon (Oncornynchos spp.), and steelhead (Salmo gairdneri) can be found in this habitat at one time or another as kelp beds offer shelter and feeding areas. Large schools of Northern anchovy (Engraulis mordax mordax) and Pacific sand lance (Ammodytes hexapterus) can occasionally be found in kelp beds. Spills coming into this habitat could have locally severe but unpredictable effects upon this group of fishes.

Oil pollution of kelp beds may force young pelagic fish away from shelter, thus subjecting them to the predation of larger pelagic and demersal fishes. Because of their surface association, spills coincidental with the occurrence of schools of anchovys could have serious results, but probabilities of concurrence are small.

SUMMARY: Pelagic fishes occur in moderate to sparse numbers in kelp beds. Spills in this habitat are likely to have local effects on these species but overall, only minor potential impacts are probable.

RELIABILITY: **

G. KELP BED

9. Echinoderms

The adults and juveniles of all three groups of echinoderms (sea cucumbers, Parasticopus spp., urchins, Strongylocentrotus spp., and starfish) are found on or in kelp beds. Although there has been no study made to assess the relative abundance of each group, it is probable that sea urchins are the most abundant group in this habitat.

General responses of these organisms to oil are described in the rock habitat section of this report (Section A 9, pp. IV 16-17). As kelp is normally subtidal, oil effects on echinoderms in kelp would not be as severe as in intertidal habitats. However, kelp-devouring urchins may climb into the canopy where oil has been trapped, and contact higher concentrations of oil. Narcotization can cause them to lose their gripping ability and fall to the bottom. Kelp blooms have been reported after high urchin mortality caused by a spill of dark diesel oil, probably because of reduced grazing pressure. Urchins are probably the primary food source for starfish in this habitat; depletion of urchins could thus cause a reduction in local starfish populations.

SUMMARY: All six echinoderms included in this study occur in kelp, with urchins the most common. Since kelp is subtidal, only a severe spill would significantly affect the populations. Depletion of the urchin population could reduce starfish numbers and promote kelp bloom.

RELIABILITY: **

G. KELP BED

10. Crustaceans

Three of the crustaceans considered here occur in kelp beds; however, this is not the major habitat for any of these organisms. Dungeness and red rock crabs (Cancer magister and C. productus) are predators and scavengers living on the sediments and rocks under the kelps, while the isopod Idothea resecata ranges over the plant surface, eating detritus and the kelp itself. The isopod broods its eggs; there are no pelagic larvae.

The effects of oil spillage in this habitat are the same as for crustaceans in the eelgrass habitat (see Section F 10, pp. IV 109-110).

RELIABILITY: **

G. KELP BED

11. Molluscs

Abalone, ranging from the low intertidal to the kelp beds, are the only species of molluscs in this study which regularly appear in kelp beds. They graze from rock surfaces near the holdfasts of the plants. The Northern abalone (Haliotis kamtschatkana) normally eats only smaller algae, but the red abalone (Haliotis rufescens) grazes on the kelps Nereocystis and Macrocystis as well. Both species prefer active surf or strong currents, an association common only in the northern parts of the study area.

Few data were found on the response of abalone to oil. A severe spill of No. 2 diesel oil caused high local mortality as did the Tampico Maru spill of the same oil in Baja, California. In the latter case, the population had not returned to original levels after four years. This may reflect limited recruitment from adjacent areas rather than continued oil effects. Abalone mature at three to four years; recovery would be slow until a resident spawning population could be established. Molluscs in general are narcotized by oil in sublethal quantities. This can be indirectly fatal to abalones since they tend to lose their grip on the rock faces and can then be battered by waves and exposed to predators. Oil can also indirectly affect abalone by depleting algae which form their primary food source.

SUMMARY: The molluscs in kelp beds are vulnerable at least to No. 2 diesel oil, and probably to refined products in general. Low concentrations can cause narcotization and subsequent deaths; higher concentrations cause direct mortality. Recovery depends on recruitment of larvae from other areas, and may require several years.

RELIABILITY: ***

G. KELP BED

12. Annelids

Nereis vexillosa, the only annelid worm considered in this study, is described in detail on page IV 23. These nereids are not common in kelp beds, but a few live in kelp holdfasts, among mussels or barnacles on rocks in the base on the kelps, or burrowing in the sediments. The effects of oil spillage in this habitat are the same as for annelids in the rock habitat (see Section A 12, p. IV 23).

RELIABILITY: *

G. KELP BED

13. Algae

The kelp beds of Nereocystis in Puget Sound serve as substrates for a wide variety of green, brown, and red algae. Among the red algae, Porphyra nereocystis is a prominent epiphyte which is found attached to the stipes of Nereocystis. Because of its position below the surface of the water and in a bed where currents are usually vigorous, little if any damage would be predicted.

RELIABILITY: ***

H. SALT MARSH

1. General Impact

The effects of oil pollution on salt marshes depend on the amount and type of oil involved. As with most organisms, light oil products are more toxic than heavy crudes. Oils of low viscosity enter stomata of plants and are distributed in the intercellular spaces, disrupting transpiration and damaging cell membranes. Low boiling point hydrocarbons at high concentrations are known to injure plant cell membranes which in turn cause irreversible increased permeability of the cell. As a result, the cells leak their contents, the plant wilts and subsequently dies. Polycyclic aromatics are known to penetrate slowly plant cell membranes and to damage chloroplasts resulting in inhibition of photosynthesis.

Small spills have little affect on salt marsh vegetation as the oil remains trapped above the soil. Large spills, however, can penetrate to the plant base, killing new growth and inhibiting oxygen exchange between roots and micro-organisms. Natural decomposition of oil is largely aerobic. Under the anaerobic conditions of a heavy spill, salt marsh recovery is greatly reduced.

Seasonal variation also influences the vulnerability of salt marshes. Seedlings and annuals rarely recover from an oil spill. Therefore, salt marshes are most susceptible during the growing season of spring and summer months.

On a community level salt marshes may tolerate isolated areas of oil pollution without serious injury. The texture of the vegetation mat also acts as a filter, retaining oil brought in by the tides, thus protecting more vulnerable estuarine organisms such as commercially valuable fish and bivalves.

SUMMARY: The most important feature of salt marsh habitat in view of this study is its interrelationship with estuaries. Although salt marsh vegetation and many of the animals of the marsh are not included on the resource list, effects of oil pollution on salt marshes must be considered in order to assess accurately its impact on estuaries partially dependent on this habitat for food and nutrients.

RELIABILITY: ***

H. SALT MARSH

3. Birds: Offshore Feeders

Dabbling ducks (e.g., Mallard, *Anas platyrnynchos*; Pintail, *Anas acuta*; Wigeon, *Anas americana*), Coots (*Fulica amerciana*), and most gulls on the resource list are regular visitors to salt marshes. With the exception of Mallards, Coots, Western Gulls (*Larus occidentalis*), and Glaucous-winged Gulls (*Larus glacescens*) all are migrants and winter visitors to the Puget Sound area. Salt marshes are primarily used as a feeding ground, secondarily as a resting area.

The greatest impact of oil pollution in this habitat is likely to be a loss of abundant food supply, affecting birds indirectly. Contaminated food may also be consumed with some toxic effects. Methods of direct oil contamination and its specific effects are the same as those discussed for sand habitat (see Section B 4, pp. IV 35-36). Heavy oil products and crude oils are retained by marsh vegetation and are not easily washed away. Oil pollution here will have long-term effects in contrast to spills in other areas, such as open water.

SUMMARY: The greatest threat to the ducks and gulls that occur in salt marshes is an indirect impact on their food supply. Consumption of tainted food is probable. Effects would be more long-term than in other habitats.

RELIABILITY: ***

H. SALT MARSH

4. Birds: Shorebirds

Sandpipers (Calidris spp.), dowitchers (Limnodromus spp.), yellowlegs (Tringa spp.), Whimbrels (Numenius phaeopus), and Great Blue Herons (Ardea herodias) are common visitors to the salt marsh habitat. The Great Blue Heron is a permanent resident of the area, whereas other shorebirds are fall and pring migrants. The habitat provides an abundant food supply for these species.

The vegetative mat of the marsh serves as a filter, retaining oil brought in by the tides. Oil contamination is not easily removed and is likely to have long-term effects. Since herons and shorebirds primarily rely on salt marshes for food, indirect impact is most probable. These birds may also consume contaminated food items. Specific methods of impact and effects of oil on birds is discussed under the sand habitat (see Section B 4, pp. IV 35-36).

SUMMARY: Herons and shorebirds are more susceptible to oil pollution by loss of food supply rather than direct contact.

RELIABILITY: ***

H. SALT MARSH

5. Birds: Casual Marine Feeders

Northwestern Crows (Corvus caurinus) are the only members of this group to come into frequent contact with salt marshes. A permanent resident, the Northwestern Crow is a scavenger along the marsh, and oil impact is likely to occur by the consumption of contaminated food items. Specific effects of oils and oil products are discussed under the sand habitat (see Section B 4, pp. IV 35-36).

RELIABILITY: ***

H. SALT MARSH

11. Molluscs

Marine molluscs in general are not well equipped to cope with low salinities. Thus, of the molluscs in this study, the only normal resident of salt marshes is the soft shell clam (Mya arenaria), which has an unusual tolerance of low salinity, low temperature, and low oxygen conditions. This clam lives in burrows, filters food from the water, and spawns year-round.

Soft shell clams have been noted to leave their burrow to avoid oil, thus exposing themselves to predators on the surface. They are also subject to direct toxic effects of oil. A spill of residual oil has been observed to cause extensive, long-term mortality of this species. Oils can be retained by salt marshes and can be more or less permanently incorporated into sediments; long-term mortalities and tainting can therefore result. In a laboratory study, filtration rate was affected by an emulsion of bunker C No. 6 fuel oil, but not by soluble extracts of the same oil, suggesting that mortality in a spill may be limited to clams which directly contact this oil.

SUMMARY: Oil in a salt marsh can cause soft shell clams to expose themselves to predators, and can cause mortalities on direct contact. Because the oil can become a chronic pollutant, continued mortality and long-term tainting are possible.

RELIABILITY: **

I. OPEN WATER

1. General Impact

By far the most serious impacts to open water marine ecosystems are posed by the collisions of tankers when large amounts of crude oil or refined petrochemical products would be spilled onto surrounding waters.

Other potential major sources of crude oils and refined petrochemical products in the open water environment are offshore drilling, natural seepage, accidental tanker spills, barge collisions, discharged ballast water, spilled fuel oils, and offshore terminals. Discharges of oils from rivers and land sources will also contribute. The fate and effect of oils introduced onto open water are dependent on many factors including the physical and chemical properties of the oil, hydrographic conditions, weather, the nature of the source, the method of introduction, and the biota present.

Crude oil spilled in the open water habitat will spread rapidly over the surface until a relatively uniform critical thickness (depending on the physical properties of the oil; about 8 mm for most crudes) is reached. After this, surface tension becomes more important than gravity in promoting the spread. As the oil spreads, it loses volatile or water soluble fractions (which have been shown to be the most toxic to marine organisms). The rate at which oils tend to lose these soluble fractions depends on temperature, wind conditions, and surface mixing phenomena. Oil slicks may persist for more than two months if ocean conditions are calm, but in rough conditions, oil will become emulsified with the water. The dispersed phase will then exist as droplets in a continuous dispersion with diameters of less than 10^{-4}cm. Usually within 40-100 hours, spilled oil will spread to a film with a thickness of about 10^{-4}cm and will disappear from the surface within another 24 hours. Films with thicknesses up to 7 x 10^{-6}cm do not persist for more than about five hours.

The strength and direction of winds and currents are important factors in determining the movement of a slick. Oil moves with the wind at about 3 to 4% of wind speed. Strong winds will whip an aerosol of oil droplets from whitecaps or the tops of breakers in open water which may hasten the volatilization of light fractions. The residuals remaining after volatilization, dissolution, and other physical and chemical processes tend to be very dense and to sink when their densities exceed that of sea water. Oils may coat and agglutinate suspended particles of silt or sand in the water and sink because of the density added by these collected particles. Oil is also subjected to photo-oxidation, bacterial degradation, and consumption by plankton. Refined products such as gasoline, aviation fuel, fuel oil, and heating oil (generally more toxic to organisms) spread out and evaporate much faster than crude oils.

SUMMARY: Oil spilled in the open water habitat is expected to have minor impact on most biota, with the exception of birds attracted to the slick where impacts can be severe. Oils and petrochemical products are dispersed naturally into films thin enough to be broken up and degraded biologically. Local toxic effects are expected to be insignificant, in all but the most extreme cases, when compared to the productivity of the entire study area.

RELIABILITY: **

I. OPEN WATER

2. Mammals

Specific information dealing with the impact of oil pollution on individual marine mammals is either very limited or does not exist. The habitat in which these mammals live often makes collection of accurate data very difficult. All the mammals included in this study come into contact with the open water habitat. Except for occasional excursions into bays and inlets, cetaceans (whales and porpoises) depend exclusively on this habitat type, whereas Pinnipeds (seals and sea lions) and otters also utilize rocky shores, kelp beds, and beaches. All the mammals in question may be found in the Puget Sound area throughout the year except the Northern fur seal (Callorhinus ursinus), an offshore migrant (October to May). Because explicit data on the effects of various crude oil and oil products are unavailable, only a general discussion is possible.

Whales, porpoises, seals, and sea lions are probably less susceptible to oil pollution. Members of this group depend on a thick layer of blubber to insulate them from the cold water. Therefore, external contact with oil will have little known effect of these mammals other than possible eye irritation. There is no known evidence currently available of internal damage caused by oil, however, poisoning from consumption of light petrochemical products is a strong possibility.

Marine mammals may be affected indirectly by contamination of their food supply. This can occur by consumption of tainted food or by loss of a food source (for example, contamination of sea urchins or abalone in the case of sea otters). Impact of oil on food supply is likely to be the most serious threat to marine mammals, with the possible exception of otters where oiling of the pelt is paramount.

SUMMARY: The probable impact of oil pollution on whales, porpoises, seals, and sea lions in this habitat is probably minimal. Oil impact on otters is better known and can be serious. Evidence indicates that certain oils damage otter pelage to the extent that insulation is lost and subsequent death occurs.

RELIABILITY: **

I. OPEN WATER

3. Birds - Offshore Feeders

The offshore feeders in this study are composed of 51 species including gulls (*Larus* spp.), grebes (*Podiceps* spp.), cormorants (*Phalacrocorax* spp.), ducks, geese, and alcids (e.g. murres (*Uria aalge*), puffins (*Lunda cirrhata*), etc.). Of these, the alcids and cormorants are most characteristic of offshore marine waters. These permanent residents forage exclusively in this habitat by diving. Other species of offshore feeders use marine open water extensively but are not totally dependent on it. For all species, this habitat represents a food resource and resting area of major importance.

By sitting on the water, all offshore feeders are at least partially immersed. The divers, which include all but the gulls, some ducks and geese, become completely immersed. These factors make them vulnerable to intensive effects of oils. Most literature on oil pollution and birds concerns impacts on offshore feeders in open waters; ample evidence indicates the alcids are the most susceptible of all marine birds. Most of this evidence comes from countries bordering the English Channel and North Sea where oil pollution incidents have been studied for decades. Very little data on the effect of oil on Puget Sound birds exist, but extensive information from other areas is applicable.

For a time following a spill, most oils remain at the air-water interface allowing birds to come into contact with the slick in a variety of ways. While large visible oil slicks are usually avoided, light or dispersed slicks can often drift into floating birds undetected. For those species that roost on the water at night, such as alcids and grebes, a drifting slick generally has a greater impact since they may be in contact with the oil for hours before it is light enough to see the oil and move away. Diving birds are especially susceptible to oil because they pass through the slick twice during each dive, potentially covering their entire body with oil. Evidence exists suggesting some birds may actually select oil slicks on which to land because of their smooth appearance.

The most immediate effect of an oil slick on floating birds is the coating of feathers, most often with heavy products and weathered crudes. In heavier spills, this destroys the natural waterproofing character of the feathers allowing water to penetrate to the skin. With its insulation gone, the bird's body loses heat rapidly causing a rapid increase in metabolic rate and uptake of reserves, especially fat. Concurrently, buoyancy is lost, and the bird begins to sink. Since its flight feathers are matter, it cannot fly and the bird is forced to swim to keep from drowning. This further aggravates the heat balance problem by burning up additional energy reserves. These reserves are not replenished because the bird, under these stresses, usually does not feed. The rapid utilization of fat reserves causes the release of chlorinated hydrocarbons (if the bird has any accumulated) into the blood stream. The nervous disorders that may result further complicate the bird's attempts to stay afloat. Birds which eventually drown have about a 10% chance of washing ashore. The bodies of others are lost at sea. Attempts at rehabilitation of those living birds which wash ashore have been generally unsuccessful; less than 10 percent of the treated birds survive.

Other effects, especially from lighter products and crude oils, include irritation and burning of the skin and eyes. Minor contamination during the breeding season can result in eggs being covered with oil from breast feathers of brooding adults. Oil reduces the transpiration of oxygen through the egg shell and may suffocate the embryo. Substantial reductions in hatching success of oil treated eggs have been reported. In some ducks, oil may cover their nasal salt glands leading to an imbalance in ion concentration of the blood.

If an oil-soaked bird attempts to preen or drink, it may swallow oil with serious consequences. Light products and aromatic crudes, being highly toxic, are especially injurious to digestive tract tissues, causing inflammation and hemorrhages. Other effects include lipid pneumonia, kidney, liver and pancreas degeneration, and loss of muscular coordination. Such disorders frequently are severe enough to cause death. Smaller quantities have been shown to result in a variety of ailments, including the delay or cessation of egg laying.

Estimations of the effect of oil spills on the food supply of offshore feeders is difficult. Narcotized prey are generally more vulnerable to predation, but many narcotized prey will sink beyond the diving range of the birds.

One of the most potentially serious impacts of open-water oil spills is the probability of long-lasting effects on the population dynamics of alcids. Because of their extremely low reproductive potential, recovery is very slow. After the elimination of only half of a colony of murres, it may take over 50 years to recover to former levels, even under ideal circumstances. Because of this, it has been suggested that preventive measures and, if necessary, rehabilitation efforts, should be directed toward this highly susceptible family.

SUMMARY: Evidence from the literature, especially from Europe, suggests offshore feeders in open water are highly susceptible to oil spills. Those species which roost on the water at night are particularly vulnerable to floating oil. Diving birds can be completely covered. Oil, especially heavy products and crudes, destroys the natural waterproofing character of feathers which subjects the bird to excessive heat loss and drowning from loss of buoyancy. Exhausted, starved,and cold birds rarely recover even if they reach shore. Ingestion of oil injures digestive tract and other tissues, often leading to death. A temporary increase in the oil contaminated food supply may increase the uptake of oil. Oil spills during the breeding season can result in delayed egg laying or contamination of eggs which reduces reproductive success (often in species that can ill afford it). Birds with long generation times, such as murres, are especially vulnerable to short-term events such as oil spills because of their long recovery time.

RELIABILITY: ****

I. OPEN WATER

4. Birds: Shorebirds

Most shorebirds migrate over open water but rarely land on it. Only two species, Wilson's Phalarope (Stepanopus tricolor) and Northern Phalarope (Lobipes lobatus), can be expected to occur on the open waters of Puget Sound. Wilson's Phalarope breeds in the Sound, while the Northern Phalarope migrates through it. Since this is not their preferred habitat, used only as a resting area, the potential for oil impact is very low. No information on oil impact on either of the phalaropes was found in the literature.

In the unlikely event these species were to come into contact with an oil slick, they could be expected to suffer some of the same impacts as offshore feeders in open water. The foremost danger would be covering and matting of feathers by oil, the loss of insulation and buoyancy, excessive drain on energy reserves, and hypothermia, exhaustion, and eventual drowning. Accidental swallowing of oil could cause digestive disorders. Reproductive success could be reduced by oil ingestion or transfer of oil from breast feathers to eggs.

SUMMARY: Estuarine and shorebirds do not frequent the open waters of Puget Sound, except for the two phalarope species. Neither species is expected to suffer from oil slicks to an appreciable extent. Should they come into contact with oil, a loss of insulation and buoyancy would result which could lead to exhaustion and drowning. Lighter oiling could reduce reproductive success.

RELIABILITY: **

I. OPEN WATER

5. Birds: Casual Marine Feeders

Three of the casual marine feeders, Bald Eagle (Haliaeetus leucocephalus), Osprey (Pandion haliaetus), and Belted Kingfisher (Megaceryle alcyon), can be expected to use the open water habitat of Puget Sound. Eagles and Kingfishers are permanent residents, while Ospreys are summer residents only. All three use the habitat, on a casual basis, to capture food, mainly fish, by dropping from the air and briefly touching the surface waters. No data from the literature are available indicating any contact by these species with oil spills. Their potential for impact by oil is assumed to be low.

RELIABILITY: *

I. OPEN WATER

6. Fishes: Shoreline

Of the shoreline fish included in this study, six species, sea-run cutthroat trout (Salmo clarki clarki), redtail surf perch (Amphistichus rhodoterus), shiner perch (Cymatogaster aggregata), striped sea perch (Embiotoca lateralis), walleye surf perch (Hyperprosopon argenteum), and white sea perch (Phanerodon furcatus) are occasionally found in the open waters of Puget Sound. Most of these species are usually associated with certain substrates such as sand, kelp, or eelgrass.

If individuals of these species were exposed to a spill in open water, it is expected that they would leave the area.

SUMMARY: Oil spills in open water are not likely to affect shoreline fishes to an appreciable extent unless the slick is blown or moved by currents onto the intertidal.

RELIABILITY: *

I. OPEN WATER

7. Fishes: Demersal-epibenthic

The probability of direct oil effects on this group of fish is judged to be minor. However, nearly all 41 species of demersal and epibenthic fish do migrate vertically to the surface waters, especially at night. Associated with deep mud substrates, the juveniles of black cod (*Anoplopoma fimbria*) normally are often caught near the surface. Flatfish are occasionally taken by surface gill nets. Thus, some narcotizing effects could be expected, but these would be isolated in space and time.

Flatfishes and cod-like fishes broadcast pelagic eggs. Depending on their buoyancy, these eggs will float near the surface or in midwater, and if exposed to oil will be killed or develop abnormally. Some flatfish eggs have been found to exhibit 100% mortality after two or three days exposure to as little as 10 ppm of Russian crude oil. At lower concentrations, eggs will hatch, but some portion of them will produce deformed fry which will be unable to complete their life cycles. Except locally, this effect is not expected to be serious to populations in Puget Sound because of the size of the Sound and the wide distribution of eggs.

SUMMARY: The effect of oil on demersal-epibenthic fish in the open water habitat is limited. Exposure to the soluble fraction of oil near the surface may cause narcosis and mortality. Some eggs and larvae found in surface waters are vulnerable to spills; heavy or complete local mortalities can be expected.

RELIABILITY: ***

I. OPEN WATER

8. Fishes: Open Water

The open water habitat is important to all 19 species of pelagic fishes in this study occurring in Puget Sound. Salmon (Oncornycnos spp.), herring (Clupea harengus), smelt and shad (Alosa sapidissima), all pelagic fishes, are among the most important commercial and food fishes in the Northwest. The northern anchovy (Engraulus moroax) is the only representative of the pelagic group in this study to broadcast pelagic eggs. All subsequent life stages of all species of the pelagic group, as well as their food organisms, are distributed over a wide expanse of open water.

Pelagic fish in open water are probably the least affected by the impacts of oil spills and refined products. Most occur deep enough to be unaffected or can move to deeper water to avoid contaminated areas. Petroleum spilled in open water usually spreads rapidly over the surface as the water soluble fractions are continuously evaporated. Although oil spills tend to smooth waves and swells, their major direct impact is the intoxication of smaller surface fish by the soluble fractions just beneath the slick. An indirect impact is the killing of zooplankton, the primary food for many juvenile pelagic fishes, salmon and adult anchovy. However, in open water the zooplankton populations as a whole will probably not be seriously affected.

No mass mortalities of any pelagic fish by spills of crude oils or refined products have been reported. Laboratory exposure of herring fry to Venezuelan crude oil induced hyperactivity, narcosis, and mortality at concentrations of 100 ppm. The exposures to Prudhoe Bay crude oil of silver salmon fry in the laboratory tend to show that mixed oils are less toxic than those which are unmixed. Concentrations of 1250 ppm of mixed oil did not produce mortality in four days at 6°C whereas 100 ppm of unmixed oil produced 80% mortality.

These results are indicative of the toxicity of volatile fractions of the oil which are ameliorated by the mixing procedure. Aromatic compounds, such as benzene, naphthalene, xylene, toluene, and ethylbenzene are very toxic to silver salmon fingerlings, whereas normal and mono-cyclic aliphatic hydrocarbons, such as cyclohexane and heptane, are generally non-toxic. The degree of toxicity increases with the aromatic character, the degree of unsaturation and the number of side groups. These results support the idea that the more reactive a compound, the higher its toxicity. It has been observed, however, that non-toxic oil emulsions can remove the protective mucous layer, thus affecting the fish.

SUMMARY: The majority of pelagic fish are not seriously directly affected by the spill of crude oil or refined products as long as they can move away from the affected area. The extent of the pelagic zone in Puget sound further lessens any potential impact. The soluble fractions of oil near the surface and relatively shallow water may affect those smaller fish which fail to move away. The toxicity of soluble fractions to plankton communities near the surface may affect fish indirectly by some reduction of food supplies.

RELIABILITY: ***

I. OPEN WATERS

9. Echinoderms

Echinoderms are represented in open water by eggs and larvae. Spawning occurs between late winter and early summer. Development of eggs and larvae may take two to three months. Oil and refined products spilled in open waters will affect the eggs and larvae to varying degrees, depending on temperature, oil concentration, age of the oil, degree of mixing and solubility, weather conditions, etc.

No field observations were found for eggs or larvae of any of the echinoderm species. Laboratory studies of the purple urchin (Strongylocentrotus purpuratus) showed that soluble fractions of most crude oils and many refined products did not affect unfertilized eggs and sperm. However, some refined fractions prevented fertilization, and even low concentrations of soluble fractions of most crude and refined oils prevented development of fertilized eggs. Spills of either crude oils or refined products in spring could prevent development of fertilized eggs given certain conditions. Effects on larvae are not known.

SUMMARY: Unfertilized eggs and sperm are resistant to oil, but soluble fractions of both crude oils and refined products in low concentrations prevent the development of fertilized eggs. Eggs are present from late winter to early spring; effects of spills during that time would depend on factors which promote mixing of oil extracts through the water column.

RELIABILITY: **

I. OPEN WATER

10. Crustaceans

Open water is inhabited by various life stages of crabs, barnacles, pandalid shrimps, and euphasiids. Zoea and megalops of the crab species (Cancer spp.) occur in mid and surface waters from January to June. Barnacle (Balanus spp.) nauplii and cypris larvae are most common from late spring to midsummer in surface waters.

Pandalid shrimp zoea are released in spring and remain in deep water below the thermocline while seasonal currents carry them shoreward. After about six weeks, zoes have become mastrgopus, which become associated with the bottom. In fall and winter, northward, offshore bottom currents assist the juveniles as they move back into deeper water. All of the larvae prey on phytoplankton and smaller larvae.

The euphausiid (Euphausia pacifica) is strictly a planktonic organism. Its population is minimal during the winter, rises rapidly with early spring spawning, and declines again in late fall. They rest at 60-100 meters during the day, and rise to or near the surface at night, where they feed on algae and small zooplankton. Adult pandalid shrimp show a similar pattern of diurnal migration.

The only data found on the effects of oil on crustacean larvae indicate that barnacle naupli are rather intolerant. In one study, one hundred percent mortality occurred after 12 hours in 0.5% solution of No. 2 diesel oil. This, however, is a 200 to 1 dilution of oil, and represents a high, sustained concentration for open water, an unlikely occurrence.

Many dead euphausids and mysids were reported on the beach in a cove following the Anacortes spill of No. 2 diesel. However, no comparison was made between the observed mortalities and the remaining population. This spill occurred in April, when the euphausiid population is large. Euphausiids are small crustaceans, which molt every four or five days during spring and summer, probably increasing susceptability to oil toxicity. Some mortality would be expected following a spill, but the bulk of the population, occurring in deep waters, would likely encounter concentrations too low to be toxic. Pandalid shrimp would be less affected in that they are not as near the surface at night.

SUMMARY: The open water crustacean community is likely to suffer limited, local damage from an oil spill. More damage will be sustained by early larval forms than by later ones, and absolute mortality will be higher for all the crustaceans in spring and summer when populations are higher. Euphausiids and pandalid shrimp would probably encounter oil only at night when the population rises to the surface to feed. Otherwise the vastness of the ocean insulates these organisms from toxic oil concentrations.

RELIABILITY: **

I. OPEN WATER

11. Molluscs

With the exception of the predatory snails, all of the molluscs in this study have planktonic larvae. Most also have planktonic eggs. The majority of larvae appear in the spring, but mussels spawn in fall and winter. The horse clam (Tresus capax) and the native little-neck clam (Protothaca staminea) begin spawning in late winter and continue into spring, while soft shell clams (Mya arnaria) spawn throughout the year. The larvae remain in the water two weeks to two months, depending on the species and temperature. Horizontally, larvae float passively with the currents and tides. They are heavily preyed upon and are vulnerable to variations in physical conditions. Natural mortalities range from 90-99% and the spawning success of any mollusc species varies from year to year. A successful year-class can dominate the population for several years.

Most information on larval mollusc reactions to oil concerns the imported Japanese oyster (Crassostera gigas). The Northwest is colder than this animal prefers, and wild populations spawn successfully only once every three to four years. These data therefore must be applied cautiously. Data indicate that crude oil concentrations up to 1,000 ppm do not affect either eggs or larvae, but 100,000 ppm is fatal to eggs. Aromatic crudes are probably less toxic than those with high paraffinic content. Refined products are more toxic, with 5,000 ppm of No. 2 diesel causing 100% larval mortality in 24 hours. Since larvae typically occur one to two meters below the surface, it is probable that crude oil from a spill would not reach the larvae in sufficient quantity to cause serious mortaltiy. Oils with high soluble fraction content could have significant impact if surface mixing were sufficient to entrain the oil.

Contamination of spawning adults and of larvae as they are released is more apt to be a problem. In concentrations as low as 17 ppm, No. 2 diesel has been shown to cause inhibition by byssus thread formation in mussels. Larvae which are contaminated prior to settling may be unable to attach to rocks. Various oil products also inhibit ciliary action in adult molluscs possibly reducing their ability to maintain position in the water column.

The only mollusc in this study which spends its adult life in open water is the Pacific coast squid (*Loligo opalescens*). No data were found concerning oil reactions of either adults or larvae. The highly mobile adults will probably avoid a single spill incident, but chronic contamination causing narcotization could make squid susceptible to predators or could cause tainting.

SUMMARY: Molluscs are represented in open water by their eggs and larval forms. These forms could be affected by oils that were introduced into the water column, but this would occur only under certain circumstances. Based on sparse data, the level of toxicity to larvae is not expected to be great. Squid, which live in open water, could be affected, but the magnitude of such effects is not known.

RELIABILITY: *

I. OPEN WATER

12. Annelids

The only annelid worm considered in this study is Nereis vexillosa. Sexually mature individuals (epitokes), three to four years old swarm at the water surface on certain nights in the spring. Males shed sperm spontaneously as females release eggs in the presence of sperm. The adults then die. Eggs, trochophores, and later larval stages are usually found near the bottom. After about three weeks the larvae are several segments long and settle to the bottom. Pelagic larvae feed on plankton.

In one study on Nereis, trochophores were found to be among the most oil resistant of invertebrate larvae. Complete mortality occurred after 48 hours in 5,000 ppm of No. 2 diesel oil. In another study, adults were found to be among the more sensitive benthic animals. Since spawning occurs on relatively few nights out of the year at the very surface of the water, a coincidental spill could cause mortality and a reduced year-class. Trochophores would be relatively unaffected, being tolerant and near the bottom.

SUMMARY: The life stages of Nereis which occur in open water are not likely to be affected by oil except during the brief periods of spawning. The larvae of this species is probably considerably more resistant to oil then the adults.

RELIABILITY: *

V. DISCUSSION AND CONCLUSIONS

A. General

The species, oil, and habitat fact sheets are summaries and reorganizations of information from reviewed articles which could be incorporated in a composite format. The ordered format of the composite sheets was developed to accommodate the accumulation, condensation, and sorting of a very large volume of factual material into an organized, accessible output. The purposes of the textual portion of this report are: 1) the interpretation of composited material and 2) the formulation of practical, general conclusions. To accomplish these objectives, the textual material has always relied on specific information in the composite sheets for a base (including occasional specific examples of oil impacts). In addition, inferences and extrapolations have been made from applicable sources. Judicious extrapolation of impact data across phylogenetic lines helped develop generalities and partially filled in large information gaps. All examples of oil impact on specific organisms or other pieces of information in the text which would normally have references cited in a technical document are taken directly from composite species or oil impact fact sheets, where references (with ratings) are given. Citations were not included in the text because they might be mistakenly applied to accompanying inferred material.

B. Assessment of the Information Base

The information base from which data were taken for this project varied considerably in usefulness, quality, and completeness. When uncertainties or contradictions arose from the literature regarding the impact of oils on an organism, the benefit went to the species concerned. Sources were necessarily limited in most cases to those which directly applied to organisms on the Department of Ecology's Significant Biological Resources List. Along with the great quantity of directly incorporated data, there was as much (or more) relevant information which could be inferred from the consulted sources or which could be contributed by experienced professional biologists. Some of this information did not lend itself well to a computerized system, but was always considered in writing the text.

The variability of the entire information base is substantial. Based on the review experience constructive criticism of the information base is warranted. Data on distribution, habitat associations, and life history are only very complete or reliable for a few life stages (usually adults) of a few organisms in certain geographic locations. Inconsistencies in completeness of data, sampling techniques, methods of reporting results, and particularly in the times of year for sampling, have made a clear, complete picture of Puget Sound biota impossible to attain at this time. It is likely that the primary reasons for these difficulties rest on the traditional ways in which biological research is carried out: individual investigations tend to operate relatively independently, and a coordinated plan for investigation has not existed. Nevertheless, a reasonable overview of most organisms studied could be obtained.

Information on the biological effects of oil pollution is even more variable and, on the whole, inferior to that on general ecology and distribution. Most work has been done on highly visible, easily obtainable organisms of immediate economic or recreational value. Serious ecological effects due to oil pollution can certainly affect less obvious plants or animals. (However, the very real, practical constraints of time and available funds help to put this criticism into perspective.) The selection of indicator organisms should definitely be reviewed. Very few studies were concerned with other than immediately apparent effects; second order, subacute, or delayed effects were virtually never considered in field studies, and laboratory studies have largely ignored these problems. Many studies failed to consider key parameters of impact. The large number of criteria used for assessment of oil impacts often entirely precludes the comparison of results. Adequate controls in either field or laboratory experiments were rare. Field sampling techniques are almost completely without standardization. Most field studies failed in conceptual design. (For example, cause and effect relations were not adequately considered, or hypothesis testing was carried out improperly.) Field studies of oil spill incidents tended to ignore mechanisms of impact and concentrate instead on counting organisms. Usually these studies tried to measure too much with insufficient depth (sample size) and lack of design, and, because of this shotgun approach, failed in their objectives. It would be far more productive to have standardized sampling and impact assessment techniques very well thought out, and a sampling program planned in advance of a spill, so that they might be applied efficiently, and provide useful results.

The following paragraphs summarize some of the influences of variable or inconsistent information on the ability to assess oil impacts on various major organism groups.

The habitats in which marine mammals live, particularly whales and porpoises, make the collection of sufficient data for projecting effects on this group difficult. This is reflected by the small volume of information in the composite sheets for marine mammals. The sparse, generalized information available indicates little direct effect. However, the variable methodology and sparsity of concrete observations render any conclusions reached on this group mostly educated speculation.

Data on the distribution and abundance of Puget Sound marine birds are also sparse and very general in nature, similarly limiting predictions of effects. The bulk of literature on the effects of oil pollution on birds involves descriptions of the numbers and kinds of birds washed ashore after major spills.

Nearly all of the data are from the English Channel and North Sea. In addition, the few laboratory studies recorded used oils that probably would not be encountered by marine birds in Puget Sound. Thus, many conclusions were reached on the mechanisms of oil contact and related effects with a minimum of critical data. Where doubt existed as to the degree of vulnerability to oil pollution to a particular species, the greater degree of vulnerability was assumed. The importance of delayed and second order effects due to substrate contamination remains to be explored.

There is considerable variety in the volume and quality of abundance and distribution data for fishes. As a rule, commercially important fishes have received much attention, while other species, regardless of their ecological importance, have been largely neglected. Habitat information is fair to good for most species, especially those inhabiting intertidal and shallow subtidal areas. Reliable assumptions and extrapolations can be made in many cases to fill holes in the information base. Several good investigations using various petrochemicals have been made concerning the effects of oils on commercially important species of fish. The relative toxicities of these compounds can be induced. Virtually no data exist on long-term or second order effects.

Field data on invertebrates in general exhibit considerable variation but little contradiction. The variation occurs principally in postspill field reports, and is coupled with incomplete recording of physical parameters, such as temperature, wave conditions, type of oil, and degree of weathering. Variations did not appear to extend beyond those which could be accounted for by physical conditions. Some long-term oil effects are reported for marine invertebrates, but the results are complicated by natural population fluctuations. Data from laboratory studies show less variation and reflect the importance of the accompanying physical and biological parameters.

Information on the general ecology and distribution of the dominant life stages of plants in Puget Sound is fairly good, although many of these organisms have extremely complex life cycles, not all of which are thoroughly understood. Contradictory interpretations of effects of an oil spill on certain algae exist. Few field observations of oil spill effects have been made on Significant Biological Resource species growing in Puget Sound. Observations made elsewhere, whether on members of the same family (e.g., Laminarialies, Macrocystis and Nereocystis) or on members of the same genera (e.g., Porphyra), have had to be applied to Puget Sound species. Observations from field and laboratory investigations are numerous and uniform enough to be useful. However, as with other organisms, extrapolations from laboratory results to interpretations of field conditions were done carefully.

Although a surprising number of generalities and conclusions could be reached regarding the effects of oil pollution on particular organism groups, much of this information came from extrapolations from related organisms and other areas. Very few studies concerned other than immediately apparent reactions. Also, many inconsistent parameters have been measured and a confusing variety of criteria for impact evaluations has been used. Adequate controls were rare.

As a result of such difficulties, this study has defined a critical need for standardization of field and laboratory techniques, as well as for a standardized selection of impact judgment criteria. Most significantly, this study's synthesis of available literature suggests that the more important ecological consequences of major oil spills could involve second order effects. This suggestion is circumstantially supported by published data. The possibilities for cyclic oscillations and other instabilities in populations or communities due to different relative sensitivities to oil pollution of predators and prey should be investigated. Long-term effects and interhabitat feedbacks are definite candidates for further serious study.

C. Relative Habitat Vulnerability

The effects of hydrologic and wind conditions (energy levels) on oil solubilization, removal, evaporation, disbursement, and emulsification have been discussed in the introduction to the results section (pp. IV 1-3). High energy (surf) conditions favor the disbursement of heavy aliphatic oils and the reduction of their impact, while encouraging the solubilization and emulsification of the more toxic light soluble fractions. The reverse conditions are true for low energy situations.

In general, the more porous or rough the surfaces of a given habitat type, the greater will be the tendency to absorb or hold oil. In this regard, the mixed-coarse habitat will hold more oil for a longer period of time than solid rock. Among the sedimentary types of substrates, the finer the sediments, the more tightly oils are bound. Eelgrass and kelp present unusual cases for oil retention. Kelps have a gelatinous coating which allows oil to slide off and drift away. Although surface areas in the canopy can be large, oil is not readily retained. Eelgrass beds retain large amounts of crude oils and heavy products in the rhizome-root matrix, leading to potential long-term chronic impact on this habitat.

In general, the higher the energy level of a given habitat, the more quickly it will become cleansed. In some cases, sedimentary habitats can have sufficient rates of deposition of new sediments to effectively bury oil-contaminated surfaces within a relatively short time.

Biological cleansing of spills is usually bacterial in nature. Optimum conditions for bacterial action are aerobic, with much surface area and a moderate flushing rate. Contaminated muds and clays can become anaerobic, increasing the persistence of oils. The rhizome-root matrix of eelgrass beds is frequently anaerobic to begin with; thus oils may persist for a very long time. Mixed-fine and open water habitats offer somewhat better conditions for aerobic bacterial degradation.

Although any habitat vulnerability ranking system will have exceptions, this study suggests two sets of rankings, based on whether the expected impact is primarily mechanical or a function of toxicity. From highest to lowest vulnerability the habitats are as follow:

Physical Impact	Toxicity Impact
Salt marsh	Mixed-coarse
Eelgrass bed	Solid rock
Silt	Salt marsh
Mixed-fine	Eelgrass bed
Mixed-coarse	Kelp bed
Sand	Mixed-fine
Solid rock	Mud
Kelp bed	Sand
Open water	Open water

D. Relative Organism Group Vulnerability

Several factors complicate the problem of assessing relative organism group vulnerability. The structural and functional diversity of organisms, especially with plants and invertebrates, often produces a wide range of sensitivities within a group. Different life stages of the same organism display dramatically different sensitivities. Because modes of impact among groups may vary significantly, no consistent criterion of impact is available. In many cases any attempt to rank groups according to vulnerability is severely hindered by a critical lack of knowledge about oil impact.

Mammals, except for otters which are very vulnerable to direct physical impact, are likely to be affected only by the loss of food supply due to oil pollution or direct consumption of oil. For this reason, they are likely to be less affected by spilled oil than most other organism groups. Extensive damage to food supplies, however, may alter marine mammal distributions. Although specific evidence is unavailable, consumption of oil or oil-covered food may cause some internal damage. This is especially true for light petrochemical products and aromatic fractions of crudes. Marine mammals are essentially restricted to the open water habitat throughout the year with secondary utilization of rock, sand, and kelp beds by seals, sea lions, and otters. Alternative habitats cannot be considered due to specialized adaptations and dependence on the open water habitat for food; however, since this habitat is very large, effects would be local.

Birds are extremely vulnerable to oil impact when they become covered with oil in a cold aquatic environment. In terms of physical impact, birds are much more vulnerable than any other organism group. Adverse conditions exist most frequently for offshore feeders as indicated by the large body of data concerning oil impacts on this group. Most offshore feeders are diving birds and would pass through an oil slick upon entering the water, coating their bodies with oil. Further, the most adversely affected members of the group, such as alcids, grebes, and some ducks, roost on the water at night increasing the potential for contact with a slick. In general the more highly adapted a bird is to the aquatic environment, the higher its vulnerability to oil impact. All groups of birds in most habitats face the hazard of swallowing oil after a spill, either directly or by eating oil-contaminated food. Severe digestive ailments can result, often leading to death. Several of the alcids and cormorants breed in colonies, primarily in the San Juan Island area, but most of the bird species that face potential oil impact in Puget Sound do not breed there. Some alcids (such as Common Murres) have semiprecocial young who for several days after leaving the nest are flightless and could not easily avoid an oil slick. Since these birds have low reproductive rates, several years might be required to recover their numbers after a spill.

Adult fishes are less vulnerable to the mechanical impacts of oil spills than sedentary and slow-moving invertebrates such as molluscs, echinoderms, and polychaetes. The majority of fish inhabit midwater or benthic habitats and would seldom come into direct contact with spilled oils. Intertidal fishes such as sculpins and gunnels, and shoreline fishes in shallow water such as greenling, perch, and the young of some of the salmonids, are extremely vulnerable to the toxic effects of water-soluble fractions from spills near the intertidal, along beach areas, or in protected waters. Toxins enter the gills rapidly, causing narcotization and dramatically increasing susceptibility to predation. Pelagic eggs and larvae of many fishes are also vulnerable to the toxic effects of water-soluble fractions of oils. Herring and smelt are most susceptible to the impacts of oils during their spawning seasons. Since these species spawn in intertidal zones, a spill at the time of spawning or before the eggs are hatched could seriously affect a local year class. Sparsity of data makes it difficult to assess the indirect impacts of oils on fishes from records of past spills. Depletion of food organisms due to oil pollution could be a significant factor in the success of local populations, another area where delayed and secondary effects must be further explored.

Almost all invertebrates have early life stages which are pelagic. Even though individuals of these stages can be quite susceptible to oils and petrochemical products, they are widely disbursed in large numbers throughout the marine environment. Oil spill effects on pelagic eggs or larve should have relatively minor effects and because of high fecundity, population rebound potential is high. In general, inshore populations of invertebrates are more vulnerable. The integument of most invertebrates offers little protection against the effects of oil spills with the exception of the chitinous exoskeleton of adult crustaceans. The crabs in particular seem to exhibit very high resistance to toxicity of petrochemicals. Mullusc shells provide very high resistance to toxicity of petrochemicals, but they provide a very temporary protection, since they must open for the animal to respire, thus exposing the internal tissues to direct contact with oil. Invertebrates buried in mud or sand can frequently be protected from excessive impact by their environment. In general, most invertebrates are affected by toxins to a greater extent than by mechanical action.

Algae vary in their ability to withstand effects of an oil spill. Those with highly gelatinous thalli (many red and brown algae) will be more resistant to prolonged contact with oil. Those algae lacking such thalli will be more susceptible, especially if they grow in the intertidal. The sea grasses, also lacking a gelatinous coating, will resist damage by oil to the extent that their leaves are covered by a dense layer of epiphytes and epifauna (such as eelgrass, *Zostera*) or to the extent that they are washed by wave action (such as surf grass). In some red algal genera, such as *Porphyra*, a perennial life stage exists on rocks of the subtidal which continually produces spores to colonize the intertidal substrate. With such species, the death of all intertidal individuals would not affect the ability of that species to rapidly recolonize the same area. Some species in the same genera, however, lack this more secure stage and could be more seriously affected. Continuous production of spores which generate the gametophytic life stage, by the kelp *Nereocystis* from late spring through fall, makes this kelp very resistant to long-term damage by oil. Populations of grasses appear to be vulnerable to oil in spring during the once-a-year flowering period. Since surf grass and eelgrass are both perennials persisting through growth of rhizomes, prevention of one season's seed production would set back population maintenance and development but not eradicate the population. Repeated spills during these more sensitive stages of the life cycle would have very serious effects.

Exceptions will occur in any ranking system depending on a multitude of prevailing environmental conditions. Nevertheless, this study suggests two useful rankings, again based on whether the expected impact is primarily mechanical or a function of toxicity. Ranked from highest to lowest vulnerability, the groups are as follows:

Physical Impact	Toxicity Impact
Birds	Fishes
Molluscs	Annelids
Echinoderms	Molluscs
Grasses	Echinoderms
Algae	Birds
Crustaceans*	Mammals
Annelids	Crustaceans
Mammals **	Grasses
Fishes	Algae

* The outstanding exception is barnacles which are highly susceptible to physical impact.

** The outstanding exception is otters which are highly susceptible to physical impact.

E. Relative Impacts of Oils and Petrochemicals

A preliminary discussion of the relations among aspects of chemical structure of oils and petrochemicals and their toxic and mechanical impacts was presented in the Introduction to Section IV (pp. IV 1-3). Although any petroleum spill will have both mechanical and toxic impacts, these can assume widely differing relative importance depending on the petrochemical spilled and the physical and biological conditions surrounding the incident. As has been indicated, relative habitat and organism group vulnerabilities depend heavily on the nature of the oil or petrochemical under consideration.

An interesting dichotomy in the analysis of oil impact exists between toxicity and persistence, a dichotomy reminiscent of similar problems with pesticide impact analysis. The most acutely toxic materials tend to be those which disappear from the environment the fastest; those with lower toxicities tend to persist and have potential long-term effects.

It is virtually impossible to generalize as to which kinds of oils or petrochemical products pose the greatest threat to the environment. There are too many variables which depend directly on conditions surrounding a particular case. In any case, a consideration of the principles set forward in the Introduction to Section IV (pp. IV 1-3) along with the nature of the affected habitat should help in the assessment of a probable impact.

APPENDIX A

The following tables list organisms included in this study by scientific and common name. Separate tables are given for each organism group.

MAMMALS

Scientific Name	Common Name
Lutra canadensis	River otter
Eumetopias jubata	Northern sea lion
Phoca vitulina	Harbor seal
Callorhinus ursinus	Sea otter
Orcinus orca	North Pacific fur seal
Globicephala scammonii	Pacific killer whale
Phocoena phocoena	Pacific blackfish
	Pacific harbor porpoise

BIRDS: Offshore Feeders

Scientific Name	Common Name
Gavia immer	Common Loon
Gavia arctica pacifica	Pacific Arctic Loon
Gavia stellata	Red-Throated Loon
Podiceps grisegena holbollii	Holboel Red-Necked Grebe
Podiceps auritus cornutus	Horned Grebe
Podiceps nigricollis californicus	American Eared Grebe
Aechmorphus occidentalis	Western Grebe
Phalacrocorax auritus cincinatus	White-Crested Cormorant
Phalacrocorax auritus albociliatus	Northwestern Double-Crested Cormorant
Phalacrocorax auritus	Double-Crested Cormorant
Phalacrocorax penicilatus	Brant's Cormorant
Phalacrocorax pelagicus resplendens	Baird Pelagic Cormorant
Olor columbianus	Whistling Swan
Branta canadensis occidentalis	Western Canada Goose
Branta nigricans	Black Brant
Anser albifrons frontalis	Pacific White-Fronted Goose
Chen caerulenscens caerulescens	Lesser Snow Goose
Anas platyrhynchos platyrhynchos	Mallard
Anas acuta	Pintail
Anas crecca coralinensis	Green Winged Teal
Anas americana	American Wigeon
Anas clypeata	Northern Shoveler
Aythya valisinera	Canvasback
Aythya marila neararctica	Greater Scaup
Aythya affinis	Lesser Scaup
Bucephala clanqula americana	Common Goldeneye
Bucephala islandica	Barrow's Goldeneye
Bucephala albeola	Bufflehead
Clanqula hyemalis	Oldsquaw
Histrionicus histrionicus	Harlequin Duck
Melanitta deglandi dixoni	Western White-Winged Scoter
Melanitta perspicillata	Surf Scoter
Melanitta nigra	Black Scoter
Mergus merganser americanus	Common Merganser
Mergus serrator	Red Breasted Merganser
Fulica amerciana americana	American Coot
Stercorarius parsiticus	Parasitic Jaeger
Larus glaucescens	Glaucous-Winged Gull
Larus occidentalis occidentalis	Western Gull
Larus argentatus	Herring Gull
Larus californicus	California Gull
Larus delawarensis	Ring-Billed Gull
Larus canus	Mew Gull
Larus philadelphia	Bonaparte's Gull
Larus heermanni	Heermann's Gull
Larus thayeri	Thayer's Gull
Sterna hirundo hirundo	Common Tern
Uria aalge californica	Common Murre
Cepphus columba	Pigeon Guillemot
Brachyramphus marmoratus marmoratus	Marbled Murrelet
Ptychoramphus aleutica	Cassin's Auklet
Cerorhinca Monocerata	Rhinoceros Auklet
Lunda cirrhata	Tufted Puffin

BIRDS: Shorebirds

Scientific Name	Common Name
Ardea herodias fannini	Northwestern Great Blue Heron
Numenius phaeopus	Whimbrel
Actitis macularia	Spotted Sandpiper
Heteroscelus incanus	Wandering Tattler
Tringa melanoleucuc	Greater Yellowlegs
Tringa flavipes	Lesser Yellowlegs
Calidris canutus rufa	American Knot
Calidris melanotos	Pectoral Sandpiper
Calidris minutilla	Least Sandpiper
Calidris alpina	Dunlin
Limnodromus griseus caurinus	Short-Billed Dowitcher
Limnodromus scolopaceus	Long-Billed Bowitcher
Calidris mauri	Western Sandpiper
Calidris alba	Sanderling
Steganopus tricolor	Wilson's Phalarope
Lobipes lobatus	Northern Phalarope
Haematopus bachmani	Black Oystercatcher
Charadrius semipalmatus	Semipalmated plover
Charadrius vociferus vociferus	Killdeer
Pluvialis squatarola	Black-Bellied Plover
Aphriza virgata	Surfbird
Arenaria interpres	Ruddy Turnstone
Arenaria melanocephala	Black Turnstone

BIRDS: Casual Marine Feeders

Scientific Name	Common Name
Megaceryle alcyon	Belted Kingfisher
Corvus caurinus	Northwestern Crow
Haliaeetus leucocephalus	Bald Eagle
Pandion haliaetus	Osprey

FISHES: Shoreline

Scientific Name	Common Name
Salmo clarki clarki	Sea run cut throat trout
Hexagrammos decagrammus	Kelp greenling
Hexagrammos lagocephalus	Rock greenling
Hexagrammos stelleri	White spotted greenling
Enophrys bison	Buffalo sculpin
Hemilepidotus hemilepidotus	Red irish lord
Leptocottus armatus	Pacific staghorn sculpin
Oligocottus maculosus	Tide pool sculpin
Scorpaenichthys marmoratus	Cabezon
Amiphistichus rhodoterus	Redtail surf perch
Brachyistius frenatus	Kelp perch
Cymatogaster aggregata	Shiner perch
Emriotoca lateralis	Striped sea perch
Hyperprosopon argenteum	Walleye surf perch
Rhacochilus vacca	Pile perch
Phanderodon furcatus	White sea perch
Apodichthys flavidus	Penpoint gunnel
Pholis ornata	Saddleback gunnel
Pholis laeta	Crescent gunnel
Sebastes maliger	Quillback rockfish

FISHES: Open Water

Alosa sapidissima	American Shad
Clupea harengus pallasi	Clupea pallasii
Engraulis mordax mordax	Northern anchovy
Oncorhynchus tshawytscha	Chinook salmon
Oncorhynchus kisutch	Coho salmon
Oncorhynchus gorbuscha	Pink salmon
Oncorhynchus nerka	Sockeye salmon
Oncorhynchus keta	Chum salmon
Oncorhynchus masu	Masu salmon
Salmo gairdneri	Steelhead
Hypomesus pretiosus pretiosus	Surf smelt
Spirinchus thaleichthys	Longfin smelt
Thaleichthys pacificus	Eulachon
Mallotus villosus	Capelin
Cynoscion nobilis	White sea bass
Ammodytes hexapterus	Pacific sand lance
Squalus acanthias	Spiny dogfish

FISHES: Demersal-epibenthic

Scientific Name	Common Name
Anoplopoma fimbria	Black cod
Ophiodon elongatus	Lingcod
Citharichthys sordidus	Pacific sand dab
Atheresthes stomias	Turbot
Eopsetta jordani	Petrale sole
Glyptocephalus zachirus	Rex sole
Hippoglossus stenolepis	Pacific halibut
Isopsetta isolepis	Butter sole
Lepidopsetta bilineata	Rock sole
Microstomus pacificus	Dover sole
Parophrys vetulus	English sole
Platichthys stellatus	Starry flounder
Pleuronichthys coenosus	C-O sole
Pleuronichthys decurrens	Curlfin sole
Psettichthys melanosticus	Sand sole
Hippoglossoides elassodon	Flathead sole
Lyopsetta exilis	Slender sole
Porichthys notatus	Plain fin midshipman
Gadus macrocephalus	Pacific cod
Merluccius productus	Pacific hake
Microgadus proximus	Pacific tom cod
Theragra chalcogrammus	Walleye pollock
Anarrhichthys ocellatus	Wolf eel
Sebastes alutus	Pacific Ocean perch
Sebastes brevispinis	Short spine rockfish
Sebastes caurinus	Copper rockfish
Sebastes emphaeus	Puget Sound rockfish
Sebastes flavidus	Yellowtail rockfish
Sebastes malanops	Black rockfish
Sebastes paucispinis	Bocaccio
Sebastes ruberrimus	Red snapper
Sebastes pinninger	Orange rockfish
Sebastes goodei	Chili pepper rockfish
Sebastes babcocki	Flag (red banded) rockfish
Sebastes aleutianus	Rough eye
Sebastes diploproa	Rosefish
Sebastes elongatus	Greenstriped rockfish
Sebastes auriculatus	Brown rockfish
Sebastes proriger	Redstripe rockfish
Raja binoculata	Big Skate
Raja rhina	Long nose skate
Hydrolagus colliei	Rat fish
Acipenser transmontanus	White sturgeon
Acipenser medirostris	Green sturgeon

ECHINODERMS

Parastichopus californicus	Sea cucumer
Strongylocentrotus droebachiensis	Green urchin
Strongylocentrotus franciscanus	Red urchin
Strongylocentrotus purpuratus	Purple sea urchin
Pisaster ochraceus	Purple starfish
Pycnopodia helianthoides	Sunflower starfish

CRUSTACEANS

Pandalus jordani	Ocean pink shrimp
Pandalus borealis	Pink shrimp
Pandalopsis dispar	Sidestripe shrimp
Pandalus platyceros	Spot shrimp
Pandalus danae	Dock shrimp
Pandalus goniurus	Coonstripe shrimp
Pandalus hypsinotus	Coonstripe shrimp
Lopholithodes formaminatus	Box crab
Cancer magister	Dungeness crab
Cancer productus	Red rock crab
Lopholithodes mandtii	Puget Sound king crab
Orchestia traskiana	Sand flea
Idothea resecata	Beach isopod
Euphausia pacifica	
Balanus sp.	Barnacle
Idothea Wosnesenskii	Beach isopod

MOLLUSCS

Scientific Name	Common Name
Crassostrea virginica	Eastern oyster
Ostrea lurida	Olympia oyster
Crassostrea gigas	Japanese oyster
Crassostrea gigas kumamoto	Kumamoto oyster
Mytilus edulis	Blue mussel
Mytilus californianus	California mussel
Haliotis rufesceans	Red abalone
Haliotis kamtschatkana	Northern abalone
Saxidomus giganteus	Butter clam
Clinocardium nuttalli	Common cockle
Panope generosa	Geoduck
Tresus nuttalli	Horse clam
Tresus capax	Big neck
Mya arenaria	Soft shell clam
Venerupis japonica	Japanese little neck
Zirfaea pilsbryi	Piddock
Siliqua patula	Razor clam
Protothaca staminea	Rock or native little neck
Chlamys hastata hericia	Pacific pink shrimp
Pecten caurinus	Sea scallop
Hinnites multirugosus	Rock scallop
Chlamys hindsi	Hinds' scallop
Polinices lewisii	Moon snail
Thais lamellosa	Wrinkles purple snail
Cryptochiton stelleri	Giant gunboat chiton
Mopalia lignosa	Chiton
Urosalpinx cinerea	Native drill
Ocinebra japonica	Japanese oyster drill
Loligo opalescens	Pacific Coast squid
Octopus hongkongensis	Octopus
Octopus dofleini	Octopus

ANNELID

Nereis vextillosa Pile worm

GRASSES

Scientific Name	Common Name
Zostera marina	Eelgrass
Phyllospadix scouleri	Surf grass

ALGAE

Gigartina papillata	Red algae
Gigartina exasperata	Red algae
Iridaea cordata	Algae
Nereocystis Luetkeana	Bullwhip kelp
Macrocystis pyrifera	Kelp
Porphyra perforata patens	Nori
Porphyra perforata perforata	Nori
Porphyra miniata	Nori
Porphyra san juanensis	Nori
Porphyra abbottae	Nori
Porphyra porphyra nereocystis	Nori

APPENDIX B

The following page is a matrix of the expected general impacts of oils and petrochemicals on organism groups in general habitat types. Both mechanical and toxic impacts are designated. The designation of effect is a function of both vulnerability and occurrence. For example, "*" (minor impact potential) may indicate that the organism group exhibits low vulnerability, or that the organism group occurs in this habitat type infrequently, or both.

These predictions are first-order estimates, and true effects may vary under varying conditions.

APPENDIX B: THE EFFECTS OF PETROCHEMICALS ON ORGANISM GROUPS IN GENERAL HABITATS

Organism \ Habitat	Rock	Sand	Mud	Mixed-Coarse	Mixed-Fine	Eelgrass Bed	Kelp Bed	Salt Marsh	Open Water
Mammals	M: ** (otters) T: ?	M: ** (otters) T:	X	M: ** (otters) T: ?	M: ** (otters) T: ?	X	M: *** (otters) T: ?	X	M: *** (otters) T: ?
Birds - Offshore feeders	M: * T: *	M: * T: *	M: * T: *	M: * T: *	M: * T: *	M: ** T: **	M: *** T: ***	M: ** T: **	M: *** T: ***
Birds - Estuarine and shorebirds	M: * T: **	M: * T: **	M: * T: **	M: * T: **	M: * T: **	M: * T: **	X	M: * T: **	M: *** (phalaropes) T: * (phalaropes)
Birds - Casual marine feeders	M: ? T: ?	M: ? T: ?	M: ? T: ?	M: ? T: ?	M: ? T: ?	M: ? T: ?	X	M: ? T: ?	M: ? T: ?
Fishes - Shoreline	M: ** (tidepool) T: **	M: 0 T: **	M: 0 T: **	M: ** (tidepool) T: **	M: 0 T: **	M: * T: **	M: 0 T: **	X	M: * T: *
Fishes - Demersal	M: * T: *	M: 0 T: **	M: 0 T: *	M: * T: **	M: 0 T: **	M: * T: **	M: 0 T: *	X	M: 0 T: 0
Fishes - Open Water	X	M: ** (spawning) T: *** (spawning)	M: 0 T: * (juvenile)	M: * (juvenile) T: ** (juvenile)	M: *** (spawning) T: *** (spawning)	M: 0 T: ** (juvenile)	M: 0 T: * (juvenile)	X	M: * (surface) T: ** (surface)
Echinoderms	M: *** (intertidal) T: ***	M: * T: *	X	M: *** (intertidal) T: ***	M: * T: *	M: * T: **	M: 0 T: **	X	M: 0 T: * (larvae)
Crustaceans	M: *** (barnacles) T: *	M: * T: *	M: * T: *	M: *** (barnacles) T: *	M: * T: **	M: * T: **	M: 0 T: *	X	M: ? T: **
Molluscs	M: *** (intertidal) T: ***	M: ** T: **	M: * T: ***	M: *** (intertidal) T: ***	M: ** T: ***	M: *** T: ***	M: 0 T: ** (abalone)	M: * (soft clam) T: * (soft clam)	M: ? T: ?
Annelids	M: ? T: **	M: ? T: **	M: * T: **	M: ? T: **	M: ? T: **	M: ? T: **	M: ? T: *	M X	M: ** T: ***
Algae	M: ** T: *	X	X	M: ** T: **	M: ** T: **	M: * (epiphytes) T: ** (epiphytes)	M: * (epiphytes) T: * (epiphytes)	X	X
Grasses	M: ** T: ***	X	M: * T: ?	X	M: * T: ?	—	X	X	X

LEGEND: M = mechanical impact potential; T = toxic impact potential; X = group rare in this habitat; * = minor impact; ** = moderate impact; *** = severe impact; 0 = insignificant impact; ? = insufficient data; () = indicated impact applied particularly

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