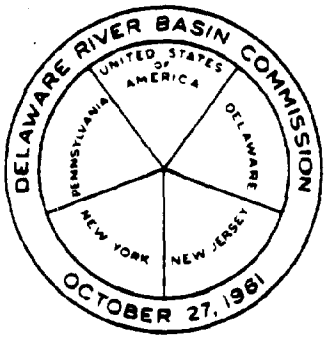
Fish Health and Contamination Study



DEL USA Project Element 10

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Delaware Estuary Use Attainability Project

Delaware River Basin Commission

West Trenton, New Jersey

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EXECUTIVE SUMMARY

A study of fish health (pathology) and fish tissue toxics was conducted in the October 1986 to December 1987 period. Target fish (catfish family and white perch) were collected at ten locations in Zones 2, 3 and 4 of the Delaware Estuary. Individual fish and composites of fish were examined for general health, pathogens, tumors and lesions, parasites, specific enzymatic compounds, and organic and inorganic toxics. The results of the study indicate that, while generally healthy, fish in the Delaware Estuary show the affect of various environmental stresses and have accumulated various toxic compounds in their tissue. Circumstantial evidence suggests that some toxic compounds are causing fish health problems in selected individuals or species. PCB concentrations were high enough in channel catfish to question their edibility from a human health viewpoint. Chlordane was found with PCBs but not quantified. DDT metabolites were also identified in every fish tissue sample but values did not exceed FDA Action Levels. Recommendations include the need for a systematic approach for identifying fish contamination problems and follow up studies.

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Study Design: The study was designed with assistance from the Delaware Basin Fish and Wildlife Cooperative, Ed Washuta with the NJDEP Division of Fish and Game, Mike Kauffman with the Pennsylvania Fish Commission, Cindy Rice with the U.S. Fish and Wildlife Service and Bruce E. Ruppel with the NJDEP Office of Science and Research.

Fish Collection: John C. O'Herron, II, Rutgers University researcher, was the primary fish collector. Fish were also collected by Cindy Rice, Dave Putnam, Phil Edmonds and Joe Miller with the U.S. Fish and Wildlife Service, and Art Lupine and Ed Washuta with the NJDEP Division of Fish and Game.

Fish Health Analyses: Ed Washuta, Bill Stansley, and Doug Roscoe with the NJDEP, Division of Fish and Game, conducted the fish pathological and toxicological studies.

Fish Tissue Analyses: Steve Friant, Senior Head Chemist with the Academy of Natural Sciences, Division of Environmental Research, and his staff performed the chemical analyses of the fish tissue composites.

Draft Report Review: Comments and suggestions on the draft report, received from ten different state and federal agencies, resulted in improvements to the final report.

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PART A - MAIN REPORT

INTRODUCTION

The Delaware River Basin Commission, on behalf of the four basin states and the federal government, initiated the Delaware Estuary Use Attainability (or DEL USA) Project in 1986. Federal regulations require use attainability analyses to be conducted on those water bodies where water quality standards and designated uses are less than the federal water pollution goals. These goals, contained in Section 101 (a)(2) of the Federal Clean Water Act Amendments of 1987 (and preceding acts), call for water quality which provides for the protection and propagation of aquatic life and recreation in and on the water (i.e., the so-called fishable and swimmable goals respectively). Also related is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited (Section 101 (a)(3)).

The objectives of use attainability studies, and the DEL USA Project in particular, are (1) to address what constraints, if any, prevent the attainment of the fishable and swimmable water quality goal and (2) to develop programs for attaining these goals where feasible. Currently 40 miles of the Delaware Estuary have designated uses which are less than fishable and 58 miles which are less than swimmable. Emerging as a concern as well are questions about toxics and their impact on aquatic life and human health. The two-year DEL USA Project is addressing these issues through a series of technical and policy studies. These studies and the project approach are outlined in the DEL USA Project Plan of Study dated May 1986.

PURPOSE OF STUDY

The Fish Health and Contamination Study was originally proposed for the DEL USA Project by the Delaware Basin Fish and Wildlife Cooperative Technical Committee. The objectives of the study were:

1. to provide needed data by location on fish pathological health (tumors, pathogens, etc.);
2. to provide needed data on the concentrations of various toxicants in fish tissue;

3. to develop, to the degree possible, inferences concerning the relationships between toxicants and fish health; fish tissue toxicants and toxics found in the estuary environment; and fish health and other water quality factors; and
4. to provide information concerning the edibility of fish.

RELATIONSHIP TO OTHER DEL USA PROJECT ELEMENTS

The Fish Health and Contamination Study, while an independent study, was designed to be an intrinsic part of the DEL USA Project. For example, various DEL USA elements are addressing the attainment of fishable water quality through the raising of dissolved oxygen standards. During the development of the DEL USA Plan of Study, concerns were raised that fish health, fish tissue toxics, and edibility considerations could jeopardize the potential fishery benefits derived from improved dissolved oxygen levels. The Fish Health and Contamination study is a response to this concern.

Because of the concern for toxics, the DEL USA Project conducted water and sediment toxics surveys in May and June 1986 in conjunction with a DEL USA study of sediment oxygen demand. The DEL USA report entitled Toxics Review Study contains the results of these surveys. The water and sediment toxics surveys and the Fish Health and Contamination Study were integrated by use of common parameters and sampling locations. These studies and a third study, the Chronic Toxicity Bioassay Study are the toxics elements of the DEL USA Project and the precursor to future toxics work in the estuary.

The Fish Health and Contamination Study is also interrelated to the fisheries-related elements of the DEL USA Project. The study adds to the fishery data base used by the DEL USA Project (see DEL USA report Fish Population Study) and will provide information to a DEL USA fish suitability assessment. This latter effort will attempt to assess water quality, habitat, toxics and other factors related to the restoration of fish in the estuary. The assessment of potential constraints to the estuary's fisheries and an assessment of the potential fisheries benefits of improved water quality will assist the decision-making process, particularly if new, potentially costly pollution controls are being considered.

STUDY DESIGN

Study Participants

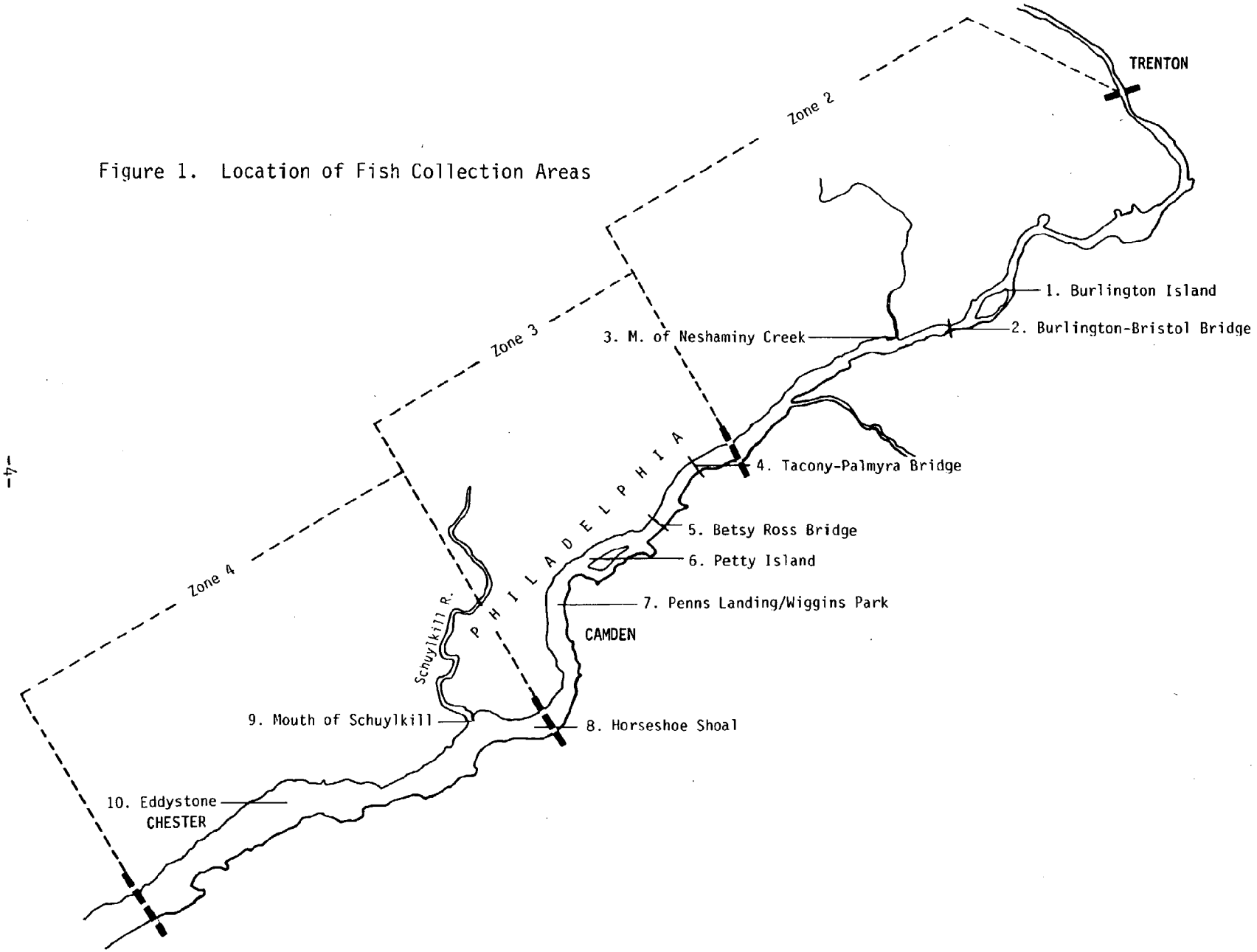
The Fish Health and Contamination Study was largely conducted with funds from the Pennsylvania Department of Environmental Resources Coastal Zone Management Program with a 20% match from the Commission. The study itself was developed through consultation with personnel from the Pennsylvania Department of Environmental Resources Division of Coastal Zone Management, the New Jersey Department of Environmental Protection (NJDEP) Division of Fish, Game and Wildlife, the NJDEP-Office of Science and Research, the Pennsylvania Fish Commission, the U.S. Fish and Wildlife Service, and the Philadelphia Academy of Natural Sciences. Three subcontractors were used to conduct the study: the NJDEP for fish pathology work, the Academy of Natural Sciences for fish tissue toxics analyses and Rutgers University for fish collection. Fish were also collected by U.S. Fish and Wildlife Service and NJDEP personnel. The study was supervised and administered by DRBC staff.

Study Area

The study area for the Fish Health and Contamination Study is a portion of the Delaware Estuary, a tidal freshwater river in its upper sections and an estuary in its lower reaches. It runs 85 miles from the head of tide at Trenton, New Jersey (River Mile 133.4) to Liston Point, Delaware (R.M. 48.2). For water quality management purposes the estuary is divided into four zones: Zone 2 from Trenton (R.M. 133.4) to Philadelphia (R.M. 108.4); Zone 3 from R.M. 108.4, past Philadelphia and Camden, to near the mouth of the Schuylkill River (R.M. 95.0); Zone 4 to the junction of the Delaware, New Jersey and Pennsylvania boundaries near Marcus Hook, Pennsylvania (R.M. 78.8); and Zone 5 to Liston Point, Delaware (R.M. 48.2). The Delaware Estuary is the world's largest freshwater port and one of its great concentrations of heavy industry. The population of the estuary region is greater than 80% of the 50 states.

The reach of the estuary selected for study ran from the upstream end of Burlington Island (R.M. 120) in Zone 2 to Eddystone, Pennsylvania (R.M. 84) in Zone 4. This reach of the river has been intensely studied by other DEL USA Project studies. Contained within the study reach are water supply intakes, various large industrial and municipal discharges and other point and

Figure 1. Location of Fish Collection Areas



non-point sources of pollution. Fishing and other recreational activities are increasing along this reach and the establishment of a viable, although marginal, year-round fish population has been documented in the study reach as a result of recent water quality improvements. Important migratory fish migrate to or through this reach including such important species as the American shad and striped bass, both the subject of the fisheries management efforts of the Delaware Basin Fish and Wildlife Cooperative. Short-nose sturgeon, an endangered fish species, is found in Zone 2 and elsewhere.

In recent years, new fishing access areas and other recreational facilities have been provided on both sides of the river in Zones 2, 3 and 4 by state fisheries agencies, coastal zone management programs and by local and state recreation programs. This trend is expected to continue. In addition, tiger muskellunge have been stocked by the Pennsylvania Fish Commission since 1984 for sport fishing. In more recent years, an ad-hoc, non-commercial blue crab fishery has arisen in Zone 4 as well. Trends indicate that recreational use of the estuary will likely increase dramatically in the future. The recreational potential of the Delaware Estuary is immense considering the number of people residing nearby.

Study Approach

The study approach involved a five part process: selection of target fish, selection of sampling sites, fish collection, fish health analyses, and fish tissue toxics analyses. The process was a sequential process with the exception that fish tissue toxics data were also reviewed by NJDEP personnel before the completion of the fish health report. The entire study was conducted in accordance with a DRBC-prepared Quality Assurance Project Plan which was approved by the U.S. Environmental Protection Agency.

Selection of Target Fish

Target fish for this study were selected on the basis of their presence and importance as resident estuary fish, and their importance as a recreational sport fish (i.e., the likelihood of being both caught and eaten). Ictalurids (channel catfish, white catfish and brown bullheads) and white perch were selected with channel catfish being the preferred Ictalurid wherever possible.

Catfish were considered good target fish for numerous reasons. Various studies have found the three catfish species throughout the Delaware Estuary. Fish population data from the Pennsylvania Fish Commission's 1984-86 surveys suggested that channel catfish might be more common than brown bullheads and white catfish but this generality is not applicable to any given site or season.

Catfish are indiscriminate feeders and eat any form of food from algae to small fish. Generally considered predominately a bottom feeder, catfish are opportunists that feed throughout the water column. There is also some belief that catfish are not wide-ranging, preferring to remain in a local area of the waterbody although with some seasonal movement. Catfish, by feeding at different levels in the food chain and throughout the water column and near bottom sediments, may thus be expected to reflect environmental contaminants in the estuary, where present. Summertime observations of emaciation suggest that adult channel catfish in the Delaware Estuary are less healthy than catfish found elsewhere. In the Delaware Estuary from the Schuylkill River downstream to Tinicum Island a fish advisory has been issued by Pennsylvania for channel catfish due to chlordane and PCB exceedence of FDA action levels.

White perch were selected as a target fish because of their abundance in the estuary and the possibility that they are the most commonly caught and eaten fish by fishermen. Pennsylvania Fish Commission surveys in the summers of 1984-86 found that white perch was the third most abundant fish species next to the blueback herring and bay anchovy. Compared to these two fish, however, white perch was more evenly distributed throughout the estuary and the only one of the three living within the Delaware River system for its entire life history.

White perch are generally bottom oriented in their feeding. As larvae and juvenile fish, white perch are primarily consumers of plankton. Young fish eat insect larvae and other macroinvertebrates with adult fish feeding primarily on small forage fish, crabs, eggs of other species, etc. Unlike catfish, white perch exhibit extensive seasonal movement within the tidal Delaware system. In the warmer months, spawning and post-spawning fish are located in the upper estuary and tributaries. However, as cold weather

approaches, white perch leave this area for the deeper waters of the lower Delaware Estuary and Delaware Bay. Because of their life history, it was believed at the start of the study that white perch would reflect environmental problems much less than catfish would.

Selection of Sampling Locations

Initially ten general sampling locations for the study were selected from the 29 sampling locations used by the DEL USA water and sediment toxics surveys. In general, the fish collection locations were selected to represent three toxic survey sites, i.e., locations where water and sediment were collected right side, left side and center channel. The initial distribution of the fish collection sites were one in Zone 2; six in Zone 3; and three in Zone 4.

Fish collection locations were shifted during the study to take advantage of the completion of the DEL USA report, Toxics Review of the Delaware Estuary. Based on the analyses of DEL USA and other toxics data, the report recommended priority attention be given to River Mile segments 93-105 and 114-120 due to the consistently elevated levels of toxicant contamination which were noted. As a result the final distribution of fish collection locations were three in Zone 2, four in Zone 3 and three in Zone 4.

Table 1 compares the initial and final fish collection locations and the fish collection locations are delineated on Figure 1. Part B contains tabulations and maps delineating precisely the fish collection sites within each general location.

Table 1: Comparison of Initial and Final Fish Collection Sites

Zone	Initial (planned)	Final (sampled)
2	-	Upper End of Burlington Island
2	Burlington-Bristol Bridge area	Burlington Bristol Bridge area
2	-	Mouth of Neshaminy Creek
3	Tacony-Palmyra Bridge area	Tacony-Palmyra Bridge area
3	Betsy Ross Bridge area	Betsy Ross Bridge area
3	Petty Island (lower end)	Petty Island (midway)
3	Penns Landing area	Penns Landing area
3	Between Penns Landing and Walt Whitman Bridge	-
3	Below Walt Whitman Bridge	-
4	Horseshoe Shoals area	Horseshoe Shoals area
4	Mouth of Schuylkill River	Mouth of Schuylkill River
4	Eddystone, PA area	Eddystone, PA area

Fish collection

The study design called for the collection of at least 900 fish at the ten fish collection locations including at least 150 target fish. A total of 1301 fish (23 fish species) were collected and enumerated by Rutgers University personnel. Table 2 summarizes the fish collected. The distribution of the fish by location and species is presented in Table 3, Part B. Due to the nature of the collection devices all fish were adult. An additional number of target fish were also collected by U.S. Fish and Wildlife Service and NJDEP personnel whose collection activities augmented the Rutgers collection. Non-target fish were not enumerated by these latter fish collection activities.

TABLE 2

SUMMARY OF TOTAL FISH CAPTURED (RUTGERS ONLY)

Location	No. of Fish Caught	No. of Fish Species	No. of Target Fish Caught
1	100	15	72
2	177	18	59
3	82	11	44
4	128	4	125
5	205	9	186
6	29	4	27
7	353	5	344
8	63	6	60
9	54	6	50
10	110	5	29
Total	1301	23	996

Target fish retained for subsequent analyses were Ictalurids (channel catfish, white catfish and brown bullheads) and white perch. These fish were delivered by the collector to NJDEP personnel either fresh or live, depending on the analyses to be performed. After enumeration and identification, non-target fish were returned to the estuary except for short-nose sturgeon which were retained as part of the Rutgers short-nose sturgeon research project.

Most fish were collected with 6-foot deep experimental gill nets with 2, 3, 4 and 5 inch stretch mesh panels. Some target fish were also collected with a 4 to 8 inch stretch mesh panel gill net, and trot-line. Water quality and other data collected at each sampling site is presented in Table 2 of Part B.

Fish Health Analyses

Target fish delivered to NJDEP personnel were subsequently analyzed by a fish pathologist and a wildlife toxicologist for:

- o general necropsy (all individual target fish),
- o screening for specific pathogens (subsample of total),
- o histological examination of any abnormal lesions (on all found),
- o general parasite examination (subsample of total),
- o biochemical testing of tissues for specific enzymatic compounds.

Table 3 indicates the number of necropsies which were performed on individual fish per species and location. Part C, the NJDEP fish health data report, presents the methodologies used in the fish health component of the study, study findings and other information.

TABLE 3

NECROPSIES PERFORMED BY SAMPLING LOCATION

SITE	1	2	3	4	5	6	7	8	9	10
White Perch	40	26	35	60	60	21	60	55	5	24
Channel Catfish	6	8	4	9	21	4	3	3	1	4
White Catfish	16	8	4	-	-	-	16	1	4	-
Brown Bullhead	10	6	1	-	27	-	2	1	1	1

Fish Tissue Analyses

Composites of target fish were prepared by NJDEP for subsequent shipment to the Philadelphia Academy of Natural Sciences. The goal of the study was to obtain three composites per sampling location as follows: one composite of catfish livers, one of catfish fillets and one of white perch fillets. Two composites of white perch were subsequently analyzed as well. The number of fish per composite ranged from 1 to 6 with the 5 being the target number. A total of 31 composites of fillets or livers were analyzed. Table 4 indicates the distribution of the composites by location, tissue and fish species. The exact distribution of the composites and the number of fish per composite were determined by the success of capturing target fish at each location.

TABLE 4

SUMMARY OF FISH COMPOSITES BY SPECIES AND LOCATION

Site	Filets		Livers		
1	WP	CC	CC		
2	WP	CC	CC	WC	BB
3	WP	CC	CC		
4	WP	CC	CC		
5	WP	CC	CC	BB	WP(2)
6	WP	CC	CC		
7	WP	WC		WC	
8	WP				
9	WP	CC	CC		
10	WP				

WP = White Perch

CC = Channel Catfish

WC = White Catfish

BB = Brown Bullhead

The fish composites were analyzed for various organic and inorganic toxic compounds. The parameters analyzed were various pesticides of interest (see Part D), polychlorinated biphenyls (PCBs), cyanide, antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, thallium, zinc, and various polynuclear aromatic hydrocarbons. Phenols, originally scheduled for analyses, were dropped from the parameter list when EPA determined the standard test methodology used for this parameter was no longer acceptable. Cyanide became an optional parameter, run only when sufficient fish tissue remained after the other analyses were completed. With minor exceptions, the parameters selected for the tissue analyses were parameters analyzed in the DEL USA water column and sediment surveys of May and June 1986.

SUMMARY OF RESULTS

The following describes, in non-scientific terms, the general findings of this study. More detailed information is presented in Parts C and D.

Fish Health

1. Bacterial pathogens. Two opportunistic bacterial pathogens were detected which can result in fish mortalities under conditions of environmental stress. One of these was positively correlated with higher water temperature. This pathogen caused eye protrusions in white perch from site 8 and subclinical kidney infections in white perch, white catfish and channel catfish.

2. Parasites. Sixteen species of parasites, three of them potential pathogens were recovered. One pathogen, the eye fluke, may cause visual problems for catfish. No environmental significance was attached to the parasites.

3. Liver tumors. Invasive bile duct tumors were found in 18% of the white perch with the prevalence increasing with fish length. This condition is not common and has only been reported once in the literature. Although the tumors were not statistically correlated with environmental contaminants, the livers of tumor-bearing perch had higher metal levels than did others. A recent study of Chesapeake Bay white perch suggested that abnormal copper storage in liver tissue might be associated (along with other possible factors) to the development of tumors. Very high copper levels were found in DEL USA white perch liver tissue composites and levels were higher in tumor bearing perch than those without grossly visible tumors.

4. Lip tumors and liver lesions. These were found in brown bullheads: lip tumors at site 10 and liver lesions at site 2, 5 and 10. The latter will likely develop into tumors. Frequency of occurrence in brown bullheads, while low, was highest at site 10. The condition may be indicative of toxics although the small sample sizes and prevalence precluded definitive conclusions.

5. Liver enzyme assays provided evidence of fish exposure to polynuclear aromatic hydrocarbons (PAHs or PNAs) at sites 7 and 10. The DEL USA toxic surveys identified PAHs in the sediment at site 7. Exposure of fish at site 10 provide a circumstantial link between PAHs and the brown bullhead

tumors discussed in 4 above. A relationship between tumors and PAHs has been theorized by others in the literature.

6. Gill pathology. A non-specific lesion or growth due to increased cell growth was evident in target fish. It was most severe in fish from sites 6 through 10 and particularly site 6. The lesions are possibly due to low dissolved oxygen conditions or environmental contaminants. It is of note that the bottom of the estuary dissolved oxygen sag is generally found in the reach of river between sites 6 and 10.

7. Miscellaneous. Various fish individuals showed emaciation (30% less than normal weight-length relationship), liver enlargement (channel catfish) and asciles (fluid buildup).

Fish Tissue Toxics

1. Organics. Organic pollutants found in fish tissue were PCBs and the metabolites of DDT: DDE and DDD. PAHs were not found. PCBs found were Aroclors 1254 and 1260. Aroclors refer to types of PCSs that were produced commercially. For example Aroclor 1254 contains 12% carbon and 54% chlorine.

   PCBs and the DDT metabolites were highest in channel catfish samples (fillet and liver) with six of the seven fillet composites exceeding the FDA Action Level. Two of these samples were 2 to 2.5 times greater than the FDA limit. One white perch liver sample was high in PCBs and, in fact, had the highest PCB value observed. The corresponding fillet sample, however, while higher in PCBs than brown bullhead, white catfish and other white perch composites, did not exceed the FDA Action limit. Chlordane was found in all samples having PCBs but it was not quantified. Based on past Delaware Estuary studies, it can be assumed that chlordane was present at problem levels.

2. Metals. All but three of the 12 metals examined were found in most fish composites. Arsenic was found only in channel catfish and white perch. These two species had similar metal levels in the fillet samples (except for selenium). White perch, however, had higher liver metal levels than

channel catfish for arsenic, cadmium, nickel and particularly copper; zinc and selenium. The data indicate that fish species accumulate toxics differently and that this distinction includes members within a family (e.g., the catfish species).

Overall Summary

The many fish examined during this study were reasonably healthy although affected by physical stresses such as seasonal high water temperature, low dissolved oxygen, the onset of spawning and other environmental factors. A range of fish health problems were observed. This range, however, is analogous to the range of health problems that might be anticipated if a random sample of 996 individuals from any wild fish population were analyzed. Circumstantial evidence indicate that toxics may be affecting fish health in some cases. No conclusive evidence exists, however, that toxics are currently limiting fish populations or would prevent increases in fish populations if, for example, dissolved oxygen levels in the estuary were raised.

As would be expected, fish in the Delaware Estuary have accumulated various heavy metals, organics and other contaminants in their tissue. Table 5 compares heavy metal concentrations from several studies with the DEL USA ranges. The contaminants in fish tissue are generally the same as are found in estuary sediments and water. The data indicate that eating some fish caught in the estuary is probably unhealthy and that the consumption of channel catfish should be avoided.. PCBs indicated as a problem parameter in past fish testing, is indicative of an extremely persistent problem. A problem with chlordane, unquantified by the study, is indicated as well.

Table 6 tabulates (to the degree possible) the major study findings by sampling site. The tabulation is presented in order to determine whether or not the study findings are evenly distributed or, rather, whether fish from some sites have more "problems" than others. The items listed are not necessarily equally important nor related to each other. A tabulation of the number of times a site appeared in Table 6 is shown in Table 7. As would be expected, the number of citations is greater for Zone 3 and 4 locations than Zone 2 locations.

Table 5
Comparison of Heavy Metals in DEL USA Fish
With Several Past Sampling Efforts

	1977 PADER	1981 PADER	1978-80 NYDEC	1978 Tennessee	DEL USA Channel Catfish	DEL USA White Perch
Cd	N.D - 0.24	0.050 - 5.34	<0.01 - 0.05	0 - 1.70	<0.020 - 0.064	0.027 - 0.104
Cr	N.D - 13.93	0.400 - 1.42	0.03 - 0.14	0 - 0.35	1.120 - 6.920	0.970 - 3.020
Cu	0.09 - 9.76	0.670 - 14.97	0.48 - 0.88	0 - 10.50	2.310 - 7.660	2.260 - 10.600
Pb	N.D - 15.86	<0.005 - 12.43	-	0 - 0.90	0.137 - 1.110	0.187 - 0.385
Nl	N.D - 7.53	-	-	-	0.730 - 2.070	1.150 - 3.130
Zn	4.47 - 30.50	-	5.30 - 12.40	-	21.400 - 28.200	23.600 - 30.900
As	N.D - 0.30	-	<0.10 - 2.90	-	<0.600 - 1.120	<0.600 - 2.200
Se	N.D - 3.34	-	-	-	0.832 - 1.100	3.030 - 4.560

N.D = None detected

Non - DEL USA values for edible portion of fish as reported in Concentrations of Environmental Contaminants in Fish from Selected Waters in Pennsylvania (U.S. Fish and Wildlife Service, 1984). Ranges for PADER include data from Delaware Estuary fish. See Part D, Table 3 for a comparison of heavy metals found in fish tissue in specific U.S. rivers and fish species.

Table 6
Summary of various study study findings by site

CC = channel catfish BB = brown bullhead
WP = white perch WC = white catfish

Condition	Site
CC emaciation	6
WP emaciation	8
CC enlarged livers	5/6
BB lip tumors	10
Grade 2/3 Gill hyperplasia - WC	6
Grade 2/3 Gill hyperplasia - WP	6
Grade 2/3 Gill hyperplasia - BB	7 thru 10
high frequency Aeromonas hydrophila	5
highest frequency WP liver tumors	9
significantly higher CC hepatic AHH Activity	10
significantly higher WC hepatic AHH Activity	7
WP - grossly visible liver tumors	5, 10
highest Cd - CC muscle	5
highest Cd - WP muscle	5
highest Cr - CC muscle	10
highest Cr - WP muscle	3
highest Pb - CC muscle	9
highest Pb - WP muscle	9
highest Ni - CC muscle	5
highest Ni - WP muscle	9
highest Zn - CC muscle	4
highest Zn - WP muscle	7
highest As - CC muscle	1
highest As - WP muscle	9
highest Se - CC muscle	9
highest Cd - CC liver	2
highest Cr - CC liver	9
highest Cu - CC liver	2
highest Pb - CC liver	3
highest Ni - CC liver	3
highest Zn - CC liver	9
highest As - CC liver	2
highest Se - CC liver	1
highest CC PCBs muscle	5
highest WP PCBs muscle	7
highest CC DDE muscle	5
highest WP DDE muscle	7
highest CC DDD muscle	5
highest WP DDD muscle	7
highest CC PCBs liver	9
highest CC DDE liver	5
highest CC DDD liver	5

Table 7
Summary of Table 6 citations by site

Site	Zone	Number of times cited in Table 6
1	2	2
2	2	4
3	2	3
4	3	1
5	3	10
6	3	4
7	3	4*
8	3/4	2*
9	4	10
10	4	6*

* No channel catfish tissue examined at these sites

An issue germane to the DEL USA project is the relationship of fish edibility concerns (i.e., human health concerns) to the federal fishable water quality goal which only addresses fish health concerns. Is the fishable water quality goal "attainable" if some fish cannot be eaten after a viable fishery is restored? The results of this study certainly indicate the need for increased toxics management and control programs plus more extensive fish tissue monitoring - fish consumption advisory networks in the estuary. However, edibility problems should not be used to justify water quality that does not adequately protect aquatic life. Higher dissolved oxygen standards, for example, benefit the entire estuary ecosystem including 30 to 40 species of fish. These benefits should not be subordinate to edibility concerns in a few fish species.

This study, like other DEL USA toxics studies, was designed to be a reconnaissance study - a first look at possible fish health, fish tissue toxics and estuary contamination relationships. The study findings indicate that these relationships do exist. Future estuary studies, including those recommended below, will build on this data base. Some of this new information may lead to more definitive interpretations of the data and findings of this study.

The data presented herein add to the body of knowledge about fish tissue contamination in the estuary. Unfortunately, this body of knowledge resides in various forms with many state and federal agencies that collect this type of information. Due to the lack of resources, the compilation and analysis of these past fish tissue data was not possible and, thus, not included as part of this report. Based on the findings of this report a comprehensive evaluation of the available fish tissue data appears warranted.

Recommendations

1. The most immediate concern raised by this study is the apparent high PCB (and possibly chlordane) levels found in channel catfish. Based on the widespread locations where PCB concentrations were found, an estuary-wide fish advisory for channel catfish should be considered in order to protect human health.

2. Regardless whether or not an advisory is issued as in 1 above, a systematic approach for monitoring fish contamination is needed. This need will increase as the fishing potential of the estuary is discovered by the fishing public. The systematic approach should consist of the following steps:

   a. the collection, compilation and evaluation of all available fish tissue toxics data for historical trends, spatial extent of toxics, levels of parameters of concern, species, and so forth, plus an evaluation of existing fish tissue monitoring programs for their extent of coverage, frequency, strengths and weaknesses,

   b. the conduct of creel surveys to assess fishing activity, species caught and species kept for consumption,

   c. the development of a coordinated, unified multi-agency fish tissue monitoring plan covering all estuary zones with delegated responsibilities, uniform reporting procedures, and, if applicable, joint fish advisory procedures,

   d. implementation of c. above on a trial basis with adjustments made thereafter.

   Logically, development of the systematic approach should be extended to include both the non-tidal Delaware River and Delaware Bay. The interstate nature of the problem indicates plan development (primary responsibility) should be delegated to the Delaware River Basin Commission, the Delaware Bay Fish and Wildlife Cooperative, the U.S. Fish and Wildlife Service, or a special committee established specifically for the task. Agencies implementing the program would be delegated by the plan.

3. The concern for toxic contamination should extend throughout the estuary food chain from first level carnivores through waterfowl and other wildlife. In other words, while fish and human health considerations are primary concerns, ecosystem considerations should not be ignored.

4. Fish contamination is only one part of an overall toxics problem. Efforts to initiate an interstate toxics control strategy for the estuary and basic research into the fate and transport of toxics in the estuary (such as the ongoing Academy of Natural Sciences study) should be accelerated.

5. Two fish health conditions observed during this study warrant followup studies. These are (1) the liver tumors in white perch which may be related to environmental contaminants, and (2) the tumors in brown bullheads that might be associated with PAHs. Specific recommendations concerning these followup studies are presented in Part C.

6. Additional fish pathology and toxicology (i.e., fish health) studies should be conducted in the estuary by the fish management agencies. Such studies should address additional fish species and seasons preferably as part of a year-round or multi-year study.

7. The inter-relationships between fish health, water temperature and dissolved oxygen concentrations suggest the need to address, on a comprehensive basis, the possible cumulative impact of heated discharges on estuary ambient water temperatures and the possible additional environmental stress imposed on aquatic life (as indicated herein). Logically, such studies should include impingement/entrainment issues as well.

PART B - DATA FROM FISH COLLECTION ACTIVITIES

RUTGERS, THE STATE UNIVERSITY

Table 1. Sampling locations and fishes collected for the DRBC Delaware Estuary Fish Health and Contamination Study, October, 1986 - July, 1987.

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1. Upper end - Burlington Island. Sampled July 9, 1987.

A. 20 m below Buoy 52 and 10 m into the channel from the New Jersey side. [SN-1198] *
Cyprinus carpio (1)

B. 20 m below Buoy 53 and 10 m into the channel from the Pennsylvania side. [SN-1199]
No fish taken.

C. New Jersey shallows abreast Buoy 52. [SN-1200]
Brevoortia tyrannus (2)
Dorosoma cepedianum (2)
Cyprinus carpio (1)
Notemigonus crysoleucas (1)
Catostomus commersoni (3)
Ictalurus catus (4)
Ictalurus nebulosus (4)
Ictalurus punctatus (1)
Morone americana (23)
Lepomis gibbosus (1)
Perca flavescens (1)

D. New Jersey shallows 150 m below Buoy 52. [SN-1201]
Alosa pseudoharengus (1)
Brevoortia tyrannus (1)
Dorosoma cepedianum (4)
Notropis hudsonius (1)
Catostomus commersoni (6)
Ictalurus catus (12)
Ictalurus nebulosus (6)
Ictalurus punctatus (5)
Morone americana (17)
Morone saxatilis (1)
Lepomis gibbosus (1)
Stizostedion vitreum vitreum (1)

2. Burlington-Bristol Bridge area. Sampled October 28, 1986.

A. Mid-channel abreast rangefinder dolphin across from Burlington Generating Station. [SN-1090]
No fish taken.

B. 40 m above rangefinder dolphin across from Burlington Generating Station. [SN-1091]
Morone americana (2)

C. Mid-channel immediately below Burlington-Bristol Bridge. [SN-1093]
Acipenser brevirostrum (3)
Ictalurus catus (2)
Ictalurus punctataus (2)
Morone americana (5)

Burlington-Bristol Bridge area. Sampled July 6, 1987.

A. Directly between Burlington-Bristol Bridge and upstream end of bulkhead at Burlington-Generating Station, along channel edge from New Jersey side. [SN-1194]
Acipenser brevirostrum (2)
Ictalurus punctatus (2)

B. Abreast rangefinder dolphin across from Burlington Generating Station, along channel edge from Pennsylvania side. [SN-1195]
Ictalurus punctatus (2)

C. Pennsylvania shallows abreast rangefinder dolphin across from Burlington Generating Station. [SN-1196]
Anguilla rostrata (1)
Brevoortia tyrannus (44)
Dorosoma cepedianum (1)
Notemigonus crysoleucas (7)
Catostomus commersoni (1)
Ictalurus catus (1)
Ictalurus nebulosus (1)
Morone americana (10)
Lepomis gibbosus (3)
Micropterus salmoides (1)

(Table 1 continued)
(2. Burlington-Bristol Bridge area. Sampled July 6, 1987 continued)

D. Pennsylvania shallows immediately abreast Burlington Generating Station. [SN-1197]

Alosa pseudoharengus (4)
Brevoortia tyrannus (32)
Dorosoma cepedianum (6)
Esox lucius X E. masquinongy (1)
Cyprinus carpio (2)
Notemigonus crysoleucas (3)
Catostomus commersoni (1)
Ictalurus catus (4)
Ictalurus nebulosus (5)
Ictalurus punctatus (4)
Morone americana (16)
Morone saxatilis (4)
Ambloplites rupestris (1)
Pomoxis nigromaculatus (1)

3. At or above the Mouth of Neshaminy Creek. Sampled June 29, 1987.

A. 100 m below Buoy 36, along channel edge from New Jersey side.
No fish taken. [SN-1190]

B. Pennsylvania shallows 100 m below riverfront boat ramp at Neshaminy Creek Marina.
[SN-1191]

Brevoortia tyrannus (13)
Dorosoma cepedianum (5)
Cyprinus carpio (1)
Notemigonus crysoleucas (2)
Ictalurus nebulosus (1)
Morone americana (13)
Micropterus salmoides (1)

C. New Jersey shallows 100 m above Buoy 36.
[SN-1192]

Alosa pseudoharengus (2)
Brevoortia tyrannus (6)
Dorosoma cepedianum (3)
Cyprinus carpio (1)
Ictalurus catus (4)
Ictalurus punctatus (4)
Morone americana (22)
Lepomis gibbosus (2)

D. 100 m below riverfront boat ramp at Neshaminy Creek Marina along channel edge from Pennsylvania side.
Cyprinus carpio (2) [SN-1193]

4. Tacony-Palmyra Bridge area. Sampled June 11, 1987.

A. 100 m below Buoy 8 and 10 m into the channel from the New Jersey side.
No fish taken. [SN-1182]

B. 100 m below Buoy 10 along channel edge from New Jersey side.
No fish taken. [SN-1183]

C. New Jersey shallows 100 m below Buoy 8.
[SN-1184]

Dorosoma cepedianum (1)
Ictalurus punctatus (4)
Morone americana (3)
Morone saxatilis (1)

D. Pennsylvania shallows immediately above Buoy 6.
[SN-1185]

Ictalurus punctatus (5)
Morone americana (113)
Morone saxatilis (1)

5. Betsy Ross Bridge area. Sampled June 18, 1987.

A. 150 m below Conrail Bridge along channel edge from Pennsylvania side.
No fish taken. [SN-1186]

B. 100 m below Buoy 2 along channel edge from New Jersey side.
[SN-1187]

Ictalurus punctatus (3)
Morone americana (1)

(Table 1 continued)
(5. Betsy Ross Bridge area. Sampled June 18, 1987 continued)

C. Pennsylvania shallows between Betsy Ross Bridge and Frankford Creek.
Dorosoma cepedianum (1) [SN-1188]
Cyprinus carpio (5)
Ictalurus nebulosus (27)
Ictalurus punctatus (14)
Morone americana (82)
Morone saxatilis (2)

D. New Jersey shallows immediately below Betsy Ross Bridge.
Carassius auratus (5) [SN-1189]
Cyprinus carpio (2)
Catostomus commersoni (1)
Ictalurus punctatus (3)
Morone americana (55)
Lepomis gibbosus (3)

6. Midway along Petty Island. Sampled May 28, 1987.

A. 200 m above Pier 11, Port Richmond, along channel edge from Pennsylvania side.
No fish taken. [SN-1173]

B. 200 m below Mooring Buoy A along channel edge from New Jersey side.
Acipenser brevirostrum (1) [SN-1174]
Ictalurus punctatus (1)

C. New Jersey shallows abreast Mooring Buoy A.
Ictalurus punctatus (3) [SN-1175]
Morone americana (4)

D. New Jersey shallows immediately below Mooring Buoy B.
Morone americana (6) [SN-1176]

E. Pennsylvania shallows 200 m above Pier 11, Port Richmond, within interpier area.
Alosa pseudoharengus (1) [SN-1177]
Morone americana (13)

7. Penns Landing/Wiggins Park area. Sampled May 18,1987.

A. Abreast Wiggins Park close to, but not inside, Anchorage Area 13 from the New Jersey side.
No fish taken. [SN-1168]

B. Abreast restaurant ship 'Moshulu' along upstream half of Penns Landing along channel edge from Pennsylvania side.
No fish taken. [SN-1169]

C. 50 m below Benjamin Franklin Bridge in line with pier faces along New Jersey side.
Morone americana (7) [SN-1170]

D. 30 m below face of pier to RCA, Camden.
Alosa aestivalis (6) [SN-1171]
Ictalurus catus (14)
Ictalurus punctatus (3)
Morone americana (262)

E. New Jersey shallows 50 m below Benjamin Franklin Bridge within interpier area.
Alosa aestivalis (3) [SN-1172]
Ictalurus catus (2)
Ictalurus nebulosus (2)
Morone americana (54)

(Table 1 continued)

8. Horseshoe Shoals area. Sampled May 11, 1987.

A. 40 m below Buoy 37 along channel edge from Pennsylvania side.
No fish taken. [SN-1164]

B. 100 m above Buoy 46A along channel edge from New Jersey side.
No fish taken. [SN-1165]

C. Immediately below Buoy 37 and 100 m out of the channel from the Pennsylvania side.
Alosa aestivalis (1) [SN-1166]
Ictalurus catus (1)
Ictalurus punctatus (1)
Morone americana (15)

D. Pennsylvania shallows immediately below Buoy 37.
Acipenser brevirostrum (1) [SN-1167]
Alosa aestivalis (1) Morone americana (40)
Ictalurus nebulosus (1)
Ictalurus punctatus (2)

9. Mouth of Schuylkill River. Sampled May 1, 1987.

A. Immediately above Buoy 44 along channel edge from New Jersey side.
No fish taken. [SN-1152]

B. Immediately below Buoy 1 along channel edge from Pennsylvania side.
Ictalurus catus (2) [SN-1153]

C. Abreast Buoy 1 and 30 m out of the Schuylkill River mouth channel from the Mud Island, Pennsylvania side.
Alosa aestivalis (1) [SN-1154]
Dorosoma cepedianum (2)
Ictalurus catus (3)
Ictalurus nebulosus (1)

D. Immediately above Buoy 44 and 50 m out of the channel from the New Jersey side.
Alosa aestivalis (1) [SN-1155]
Ictalurus punctatus (1)
Morone americana (43)

10. Eddystone. Sampled June 4, 1987.

A. 100 m above Buoy 4T and 10 m out of the channel from the New Jersey side.
Ictalurus punctatus (1) [SN-1178]

B. New Jersey shallows immediately below Buoy 2T.
Alosa aestivalis (1) [SN-1179]
Brevoortia tyrannnus (49)
Ictalurus punctatus (3)
Morone americana (15)

C. Pennsylvania shallows 250 m below downstream end of Little Tinicum Island.
Brevoortia tyrannus (31) [SN-1180]
Ictalurus nebulosus (1)
Morone americana (9)

D. 150 m below Buot 3T and 20 m into the channel from the Pennsylvania side.
No fish taken. [SN-1181]

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* This is a Shortnose Sturgeon Project collection number.

Table 2. Water quality data taken at sites of fish sampling for the DRBC Delaware Estuary Fish Health and Contamination Study, October, 1986 - July, 1987.

Locale*	Coll. #**	Date	Time (EST)	Depth (m)	Temperature °C		Dissolved O_2 (ppm)		Secchi (m)	Tide	Current	
					Bott.	Surf.	Bott.	Surf.			Velocity (m/s)	Direction
1.	SN-1198	07/09/87	1027	15.5	26.2	26.3	3.94	4.30	0.55	flood	42.8	upstream
	SN-1199	07/09/87	1044	11.3	26.2	26.5	3.99	4.70	0.80	flood	11.7	upstream
	SN-1200	07/09/87	1001	2.4	26.7	26.7	5.06	5.01	0.75	flood	40.4	downstream
	SN-1201	07/09/87	0929	2.4	26.5	26.6	5.29	5.72	0.70	flood	24.3	downstream
2.	SN-1090	10/28/86	0935	11.9	13.2	13.4	8.68	8.81	1.60	flood	19.6	upstream
	Sn-1091	10/28/86	(See SN-1090)									
	SN-1093	10/28/86	1230	18.0	13.3	13.4	8.62	8.74	1.55	ebb	70.9	downstream
	SN-1194	07/06/87	0931	14.3	25.2	25.5	4.58	5.20	0.45	flood	5.4	upstream
	SN-1195	07/06/87	0912	13.1	25.3	25.4	4.54	5.10	0.50	flood	19.6	upstream
	SN-1196	07/06/87	0855	2.4	25.1	25.2	4.90	5.23	0.45	flood	+	downstream
	SN-1197	07/06/87	0837	2.4	25.2	25.3	4.76	5.08	0.50	flood	+	downstream
3.	SN-1190	06/29/87	1040	8.2	25.1	25.2	4.90	6.19	1.20	ebb	32.1	downstream
	SN-1191	06/29/87	1023	1.2	25.7	25.6	6.21	6.19	0.60	ebb	+	upstream
	SN-1192	06/29/87	1103	2.4	25.1	25.7	5.70	6.45	1.00	ebb	+	downstream
	SN-1193	06/29/87	0939	9.8	25.1	25.2	5.25	5.49	1.15	ebb	37.2	downstream
4.	SN-1182	06/11/87	1007	14.6	22.8	22.9	4.20	4.45	1.60	flood	109.0	upstream
	SN-1183	06/11/87	0938	13.8	22.8	22.8	4.70	4.83	2.00	flood	67.5	upstream
	SN-1184	06/29/87	0921	3.0	22.4	22.4	4.99	5.03	1.40	flood	66.7	upstream
	SN-1185	06/29/87	0903	2.7	22.8	22.9	4.00	4.26	1.50	flood	28.0	upstream
5.	SN-1186	06/18/87	0944	12.2	23.8	23.8	3.98	4.00	1.50	ebb	60.4	downstream
	SN-1187	06/18/87	1022	12.2	23.9	24.0	5.22	5.34	1.65	ebb	83.4	downstream
	SN-1188	06/18/87	1048	1.2	24.1	24.2	3.95	4.00	1.40	ebb	38.3	downstream
	SN-1189	06/18/87	1145	1.2	24.5	24.5	7.34	7.34	0.80	ebb	0.0	none
6.	SN-1173	05/28/87	0811	10.7	18.6	18.7	4.81	5.17	2.00	ebb	32.6	downstream
	SN-1174	05/28/87	1055	13.8	18.6	18.6	5.20	5.30	1.60	flood	91.0	upstream
	SN-1175	05/28/87	1032	5.5	18.6	18.7	5.60	5.67	1.35	flood	62.3	upstream
	SN-1176	05/28/87	1009	3.4	18.5	18.6	5.43	5.61	1.50	flood	31.8	upstream
	SN-1177	05/28/87	1515	3.0	(See SN-1173)							

(Table 2 continued)

Locale	Coll. #	Date	Time (EST)	Depth (m)	Temperature °C		Dissolved O_2 (ppm)		Secchi (m)	Tide	Current	
					Bott.	Surf.	Bott.	Surf.			Velocity (m/s)	Direction
7.	SN-1168	05/18/87	0807	11.3	17.1	17.2	8.30	8.56	1.20	ebb	46.3	downstream
	SN-1169	05/18/87	1023	12.2	17.2	17.2	7.99	8.10	1.25	ebb	58.7	downstream
	SN-1170	05/18/87	1003	7.6	17.3	17.5	8.78	9.72	1.20	ebb	59.6	downstream
	SN-1171	05/18/87	0935	12.5	17.2	17.3	8.58	9.18	1.10	ebb	0.0	none
	SN-1172	05/18/87	(See SN-1170)									
8.	SN-1164	05/11/87	1004	13.7	15.0	15.0	7.38	7.50	1.10	flood	75.2	upstream
	SN-1165	05/11/87	1037	14.9	15.0	15.3	7.18	7.50	1.60	flood	33.6	upstream
	SN-1166	05/11/87	0939	6.7	15.0	15.0	7.01	7.12	0.95	flood	70.1	upstream
	SN-1167	05/11/87	0912	7.3	15.0	15.0	6.90	7.01	1.10	flood	68.9	upstream
9.	SN-1152	05/01/87	0804	15.5	13.3	13.3	7.92	8.09	1.30	ebb	90.4	downstream
	SN-1153	05/01/87	0845	9.8	13.7	13.5	7.18	7.68	1.30	ebb	44.6	downstream
	SN-1154	05/01/87	0927	5.8	13.7	13.4	7.19	7.62	1.40	ebb	34.9	downstream
	SN-1155	05/01/87	1005	12.2	13.3	13.3	7.82	7.98	1.40	ebb	67.1	downstream
10.	SN-1178	06/04/87	1110	10.4	21.7	21.7	3.18	3.27	1.40	ebb	79.4	downstream
	SN-1179	06/04/87	1028	2.1	21.7	21.4	3.60	3.76	1.15	ebb	58.3	downstream
	SN-1180	06/04/87	1009	3.4	21.2	21.5	3.85	3.78	1.10	ebb	24.9	downstream
	SN-1181	06/04/87	0938	14.3	21.6	21.7	3.20	3.32	1.15	ebb	87.4	downstream

* 1. - Upper end - Burlington Island.
2. - Burlington-Bristol Bridge area.
3. - At or above the Mouth of Neshaminy Creek.
4. - Tacony-Palmyra Bridge area.
5. - Betsy Ross Bridge area.
6. - Midway along Petty Island.
7. - Penns Landing/Wiggins Park area.
8. - Horseshoe Shoals area.
9. - Mouth of Schuylkill River.
10. - Eddystone.

** These are Shortnose Sturgeon Project collection numbers.

Table 3. Total species list and abundance of fishes captured for the DRBC Delaware Estuary Fish Health and Contamination Study, October, 1986 - July, 1987.

Species	Numbers captured at each sampling locale*										
LOCALE:	1	2	3	4	5	6	7	8	9	10	Total
Shortnose sturgeon *Acipenser brevirostrum*	0	5	0	0	0	1	0	1	0	0	7
American eel *Anguilla rostrata*	0	1	0	0	0	0	0	0	0	0	1
Blueback herring *Alosa aestivalis*	0	0	0	0	0	0	9	2	2	1	14
Alewife *Alosa pseudoharengus*	1	4	2	0	0	1	0	0	0	0	8
Menhaden *Brevoortia tyrannus*	3	76	19	0	0	0	0	0	0	80	178
Gizzard shad *Dorosoma cepedianum*	6	7	8	1	1	0	0	0	2	0	25
Tiger muskellunge *Esox lucius* X *E. masquinongy*	0	1	0	0	0	0	0	0	0	0	1
Goldfish *Carassius auratus*	0	0	0	0	5	0	0	0	0	0	5
Common carp *Cyprinus carpio*	2	2	4	0	7	0	0	0	0	0	15
Golden shiner *Notemigonus crysoleucas*	1	10	2	0	0	0	0	0	0	0	13
Spottail shiner *Notropis hudsonius*	1	0	0	0	0	0	0	0	0	0	1
White sucker *Catostomus commersoni*	9	2	0	0	1	0	0	0	0	0	12

(Table 3 continued)

Species	Numbers captured at each sampling locale										
	1	2	3	4	5	6	7	8	9	10	Total
White catfish *Ictalurus catus*	16	10**	4	0	0	0	16	1	5	0	52
Brown bullhead *Ictalurus nebulosus*	10	6	1	0	27	0	2	1	1	1	49
Channel catfish *Ictalurus punctatus*	6	10	4	9	21***	4	3	3	1	4	65
White perch *Morone americana*	40	33	35	116	138	23	323	55	43	24	830
Striped bass *Morone saxatilis*	1	4	0	2	2	0	0	0	0	0	9
Rock bass *Ambloplites rupestris*	0	1	0	0	0	0	0	0	0	0	1
Pumpkinseed *Lepomis gibbosus*	2	3	2	0	3	0	0	0	0	0	10
Largemouth bass *Micropterus salmoides*	0	1	1	0	0	0	0	0	0	0	2
Black crappie *Pomoxis nigromaculatus*	0	1	0	0	0	0	0	0	0	0	1
Yellow perch *Perca flavescens*	1	0	0	0	0	0	0	0	0	0	1
Walleye *Stizostedion vitreum vitreum*	1	0	0	0	0	0	0	0	0	0	1
Total:	100	177	82	128	205	29	353	63	54	110	1301

(Table 3 continued)

* 1. - Upper end - Burlington Island.
2. - Burlington-Bristol Bridge area.
3. - At or above the Mouth of Neshaminy Creek.
4. - Tacony-Palmyra Bridge area.
5. - Betsy Ross Bridge area.
6. - Midway along Petty Island.
7. - Penns Landing/Wiggins Park area.
8. - Horseshoe Shoals area.
9. - Mouth of Schuylkill River.
10. - Eddystone.

** Three taken by angling.

*** One taken by angling.

PART C - FISH HEALTH DATA REPORT

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

INTRODUCTION

This study was conducted to provide data on fish health in the Delaware River Estuary, to investigate potential relationships between fish health and toxic substances in the environment, and to provide an assessment of the general health of fish from various locations in the estuary. The study was designed using a variety of examinations and diagnostic procedures to obtain the data necessary to accomplish those objectives. Adult catfish and white perch were selected as target species.

Catfish were chosen for the study because 1) they are bottom-dwelling species that live and feed in close proximity to sediments which are a potential source of contaminants, 2) although reported to make random or seasonal movements (Calhoun 1966), they were considered more location-specific than other species of fish common in the Delaware Estuary, and 3) channel catfish were thought to comprise a significant portion of the sport fish catch in the study area and therefore would be important from an edible standards perspective. White perch were added as target species because they are relatively abundant in the estuary and, because they also comprise a significant portion of the sport catch in the study area.

Procedures comprising the study were necropsy, bacteriological screening, parasitological examination, histological examination, liver enzyme assay, and tissue analysis. All procedures except the tissue analysis were performed by personnel of the New Jersey Division of Fish, Game, and Wildlife and are the subject of this report.

Necropsies were conducted to detect any gross changes in tissues that might be significant to the health of the fish. Coincidentally, information necessary for the calculation of organosomatic indices and condition factors was obtained. Condition factor or coefficient of condition is a measure of the relative robustness of the fish (Lagler 1971). Liver somatic index is a more sensitive measure of the nutritional status of fish (Heidinger and Crawford 1977). Other studies have used similar measures of relative liver weight in studies on the effects of water pollution and on tumor incidence in fish (Slooff et al. 1983; Fabacher and Baumann 1985). In this study, the condition factor and liver somatic index are used to measure differences in condition of fish between sampling locations, and differences in condition of fish with and without various pathological conditions.

Aeromonas hydrophila and Flexibacter columnaris are ubiquitous bacteria which may cause disease in fish which have been stressed (Post 1983). Aeromonas hydrophila is common in the gut flora of healthy fish in fresh waters (Trust et al. 1974; MacFarlane et al. 1986 b). When fish are

stressed, some strains of A. hydrophila may become pathogenic and cause systemic infections of motile aeromonad septicemia (Cipriano et al. 1984). The disease has been reported in catfish following episodes of sublethal hypoxia (Rock and Nelson 1965; Plumb et al. 1976), and in suckers after exposure to high levels of copper and zinc (Pippy and Hare 1969). Outbreaks often occur in the spring (Snieszko 1983); and are probably induced by stress associated with increasing water temperature and spawning of warmwater fish. Disease due to Flexibacter columnaris is also related to stress. Susceptibility of fish is influenced by water temperature (Becker and Fujihara 1978) and exposure to metals (MacFarlane et al. 1986a). The prevalence of these organisms among the gill and gut flora of fish was determined to evaluate the potential for epizootics if fish were subjected to environmental stress. Gross sings of disease, culture from kidneys, and histopathologic examinations were used to detect clinical infections.

Parasites are often overlooked in fish health surveys because they usually occur in a symbiotic relationship with fish and have little effect on their hosts. However, there is evidence that some parasites are pathogenic among wild fish populations and may cause direct mortality or make fish more susceptible to environmental stressors (Sindermann 1986). A parasite survey was included in the present study to assess the contribution of parasites to the pathology observed, and to determine whether any parasites were present that might adversely affect the aesthetic appearance of the fish to anglers.

Histological examinations were performed on gills and livers of fish in this study. Gills are the interface between the fish's circulatory system and the outside environment. Due to their intimate contact with the water they display pathologic changes caused by environmental irritants. The liver functions as a detoxifying organ, and as such may display the effects of toxins produced by pathogenic organisms or from exposure to toxins in the environment.

A number of fish species have been shown to possess a group of enzymes known as mixed function oxidases (MFOs) that are involved in the metabolism of various lipophilic organic compounds (see Chambers and Yarbrough, 1976). Increased activity of one type of MFO, aryl hydrocarbon hydroxylase (AHH), is induced when fish are exposed to petroleum contamination (Payne and Penrose, 1975). Measurements of AHH activity have been used successfully in field studies to indicate the exposure of fish to elevated levels of petroleum compounds (Stegeman, 1978; Davies and Bell, 1984; Luxon et al. 1987). In addition to being useful indicators of exposure, MFOs are also important toxicologically because of their role in the oxidation of polycyclic aromatic

hydrocarbons (PAHs). These reactions act primarily to increase the water solubility of the compounds, thus enhancing the ability of the organism to excrete them. However, many PAHs are converted to carcinogenic intermediates in this process (Neff, 1979). Exposure to high concentrations of PAHs is a suspected cause of elevated tumor frequencies in some fish populations (Baumann et al. 1982; Baumann et al. 1987). In this study the hepatic AHH activities of fish from different areas of the Delaware River are compared in an attempt to identify areas where fish are exposed to elevated levels of aryl hydrocarbon contaminants. The data were examined to look for relationships between AHH activity and tumor incidence in fish from different areas of the river.

Results of all examinations and assays performed are presented in this report. The results were evaluated to compare fish health among locations within the Delaware River Estuary, and to provide an overall assessment of fish health.

MATERIALS AND METHODS

The study area consisted of ten sampling sites on the Delaware River Estuary between river miles 84 and 120. The sites and their approximate river miles were as follows:

1) Burlington Island (river mile 120)
2) Burlington-Bristol Bridge (river mile 118)
3) mouth of Neshaminy Creek (river mile 116)
4) Tacony-Palmyra Bridge (river mile 107)
5) Betsy Ross Bridge (river mile 104)
6) Petty Island (river mile 102)
7) Penns Landing (river mile 99)
8) Horseshoe Shoals (river mile 95)
9) mouth of Schuylkill River (river mile 92)
10) Paulsboro-Eddystone area (river mile 84.5)

Fish were collected from all sites by John O'Herron of Rutgers University between October 28, 1986 and July 9, 1987. Sampling was done primarily by gill netting. Details of the sampling can be found in part B of this report. Additional samples were collected with gill nets from site 10 by the U.S. Fish and Wildlife Service on November 8, 1986, and with set trot lines from site 9 by the N.J. Division of Fish, Game, and Wildlife on September 25, 1987.

White perch were transported on ice to the Pequest Hatchery laboratory where pathological examinations were conducted. When possible, catfish were transported live to the laboratory, and killed by a blow to the head immediately prior to necropsy. That method of killing was employed in place of anesthesia to avoid chemical contamination of samples used for enzyme assays and tissue analyses. Necropsies were performed on a maximum of 60 fish of each species from each site. Necropsy procedures recommended by the American Fisheries Society Fish Health Section (Amos 1985) were followed. The presence of abnormal growths, lesions, or other gross changes was recorded. Liver, gonad, and total body weights and total length were obtained for the calculation of organosomatic indices and condition factors. Liver somatic index (LSI) as defined by Heidinger and Crawford (1977) was calculated as follows:

$$LSI = \text{liver weight} \times 100 / (\text{total weight} - \text{gonad weight})$$

Gonadal somatic index (GSI) was calculated as follows:

$$GSI = \text{gonad weight} \times 100 / \text{total weight}$$

Condition factor (CF) was calculated as follows:

$$CF = \text{total weight} \times 100 / (\text{total length})^3$$

For purposes of calculation, all weights were expressed in grams and length was expressed in centimeters.

The term prevalence as used in this report is defined as the proportion or percentage of individuals affected by a certain agent or condition, i.e. the frequency of occurrence of a condition or agent. When expressed as a proportion prevalence will take the form:

number of fish affected / total number examined.

Bacteriology

A subsample of 20 white perch and 20 ictalurids from each site were screened for the presence of Aeromonas hydrophila and Flexibacter columnaris. Using a 10 µl sterile plastic loop, inocula were taken from the lower intestine and kidney of each fish and streaked onto RS agar (Shotts and Rimler 1973) and Trypticase Soy Agar (TSA) for the detection and isolation of A. hydrophila. Identification was confirmed biochemically using Roche Oxi-Ferm tubes. Inocula from the gills of the fish were taken using 10 µl. sterile plastic loops and streaked onto Cytophaga agar. Colonies having the characteristics of Flexibacter columnaris were identified with an indirect fluorescent antibody technique using a rabbit anti-F. columnaris serum (NFRL) and a goat anti-rabbit FITC conjugate (Gibco).

Parasitology

From each site, up to 10 individuals of each species of fish were examined for parasites. Parasites were collected, fixed, and preserved following the methods of Pritchard and Kruse (1982). Trematodes, cestodes, and acanthocephalans were fixed and preserved in Alcohol-Formalin-Acetic acid (AFA), and were stained with Semichon's acetocarmine. Monogeneans were fixed and preserved in 10% formalin and mounted unstained in glycerin jelly. Nematodes were fixed and preserved in hot 70% alcohol and mounted unstained in glycerin jelly. Copepods were fixed and preserved in 10% formalin and were identified from wet mounts of whole organisms.

Histopathology

Gill and liver tissues from a subsample of 10 white perch from each site were examined histologically. All other white perch livers which had gross lesions were also examined. Gill tissues from 10 ictalurids from each site, and livers from all ictalurids collected were examined. Any gross lesions detected during necropsy were also processed for histological examination.

Tissues were fixed in 10% formalin, processed for paraffin embedding, sectioned at 5 micrometers, and stained with hematoxylin and eosin. Histologic procedures followed were those of the Armed Forces Institute of Pathology (Luna 1968).

Tissue sections containing suspect neoplasms were submitted to the Registry of Tumors in Lower Animals (RTLA) in Washington, D.C. for diagnostic evaluation and classification. Gill pathology (hyperplasia) was graded using the system of Post (1983). Numerical grades were assigned as follows:

0 = no hyperplasia;
1 = hyperplasia of some lamellae, no fusion of lamellae;
2 = fusing of some lamellae, primarily at distal ends of gill filaments;
3 = most lamellae fused, no gill filaments fused;
4 = lamellae and most gill filaments fused.

Liver Enzyme Assay

Liver samples were collected from channel catfish, white catfish and brown bullheads for AHH assay. Fish were transported live to the laboratory, killed by a blow to the head, and the livers were removed. Those livers that were not assayed immediately were stored at -20 $^{\circ}$ C for no longer than one week prior to processing. A portion of liver tissue weighing between 0.5 and 2.0 grams was homogenized in cold Tris-sucrose buffer (pH 7.5) and the homogenate was centrifuged for 10 minutes at 10,000 x g (Payne and Penrose, 1975).

The aryl hydrocarbon hydroxylase (AHH) activity in the 10,000 x g supernatant was measured using the method of Nebert and Gelboin (1968). 2,5-diphenyloxazole (PPO) was substituted for benzo[a]pyrene in the assay. PPO has been shown to be a suitable substrate for the determination of AHH activity in fish (Ahokas, 1976) and is safer to use than benzo[a]pyrene, a known carcinogen (Walton et al. 1978). All assays were performed in duplicate. A 20 µL aliquot of the 10,000 x g supernatant was added to a screw top centrifuge

tube containing 1.0 mL of the reaction mixture (0.36 µmoles NADPH and 3 µmoles MgCl in 0.05 M Tris buffer at pH 7.5). The tube was equilibrated in a 30 ° C water bath and the enzymatic reaction was initiated by adding 10 µg PPO (in 20 µL of methanol) to the mixture. The reaction was stopped after 25 minutes by adding 1.0 mL of acetone.

The mixture was vortex-mixed for 30 seconds with 3.25 mL of hexane and the phases were allowed to separate. A 2.0 mL aliquot of the organic phase was vortex-mixed for 30 seconds with 5.0 mL of 1 N NaOH. The fluorescence of the hydroxylated PPO metabolite was measured in the alkaline phase against a quinine sulfate standard by excitation at 345 nm and emission at 510 nm. Blank fluorescence was determined using a duplicate set of tubes to which acetone was added prior to the addition of PPO.

The protein content of the 10,000 x g supernatant was determined in duplicate by the method of Lowry et al. (1951) using bovine serum albumin as a standard. Enzyme activity is expressed as quinine sulfate fluorescence units per milligram of protein per 25 minutes (FU/mg protein/25 min.)

Preparation of Tissues for Toxics Analysis

Fish from the following size ranges were selected for toxics analysis:

channel catfish between 380 and 440 mm total length,
brown bullheads between 280 and 340 mm total length,
white catfish between 280 and 340 mm total length, and
white perch between 170 and 200 mm total length.

An attempt was made to randomly select individuals from among those collected; however, the limited availability of fish from some sites dictated which individuals would be used, and sometimes fish outside the desired ranges were included in analyses. When possible five fish composites were used. However, insufficient numbers of channel catfish from sites 3 and 6 necessitated the use of four fish composites from those sites.

Fish used for toxics analysis were skinned and filleted using stainless steel utensils. The fillets were cut into cubes and homogenized into a paste in a glass container Waring blender. Homogenized tissue was wrapped in aluminum foil and frozen prior to submission to the analytical laboratory. Livers were wrapped in aluminum foil directly upon removal without homogenization. All utensils, vessels, work surfaces, and aluminum foil were rinsed with pesticide grade hexanes prior to their use in sample preparation.

Toxics analyses were performed by Dr. Steve Friant of the Philadelphia Academy of Natural Sciences. Details on analytical methods are presented in part D of this report.

Statistical Analysis

The statistical tests used to analyze data in this report were single factor analysis of variance (ANOVA), correlation, chi-square analysis, and Student's t-test. A 5% significance level was set for all tests. Results of significant tests are reported giving value of the applicable test statistic (F for ANOVA, r for regression, χ^2 for chi-square), degrees of freedom (df), and greatest level of significance (either 5% or 1%, $P<.05$ or $P<.01$).

RESULTS

Gross Pathology

Gross lesions were visible on many of the fish examined. Most were external lesions that resulted from capture by gill nets; however, some lesions were due to other factors.

Eye pathology was a common occurrence. Individuals of all species from all collection sites had some degree of cloudy or opaque lenses. Since all white perch were transported to the laboratory on ice and examined several hours after death, it is not known whether the lens opacity was a post-mortem change in that species. Most catfish, however, were kept alive until examination, and cloudy lenses were observed in some live individuals. The condition was found to be associated with the presence of trematode metacercariae, Diplostomum, in the lens. The trematodes were observed in both squash preparations and stained histologic sections of the lenses. Prevalence of Diplostomum was high in all species.

Another type of eye pathology noted was exophthalmus. This was observed in 3 of 55 white perch from the Horseshoe Shoals area (site 8). It appeared to be due to an accumulation of fluid behind the eye. A bacterium, Aeromonas hydrophila, was isolated from the fluid of two of the fish with exophthalmus.

Internally, the most common observation was the presence of white spots or nodules in livers of white perch. Fish from all sites were affected. The liver nodules were examined histologically and were diagnosed as tumors of duct cell origin (cholangiomas). The pathology is described in more detail with the results of the histopathologic examinations.

Less commonly observed abnormalities were emaciation, ascites, lip tumors, and enlarged livers. Infectious agents were not found associated with any of those conditions.

Emaciation occurred in a channel catfish from the Petty Island area (site 6) and in a white perch from the Horseshoe Shoals area (site 8). In both cases the fish had condition factors more than 30% lower than the site mean for fish of the same species. Digestive tracts were devoid of food indicating anorexia. Histologically, hepatocytes were less vacuolated than normal and liver somatic indices were 40% lower than the mean values for that parameter.

A white perch from the Horseshoe Shoals area had a distended abdomen filled with an ascitic fluid. No bacteria could be cultured from the fluid on TSA.

Brown bullheads from the Paulsboro area (site 10) had lip tumors (figure 1) diagnosed as epidermal papillomas. Histologically, epidermal pegs from the tumors were well

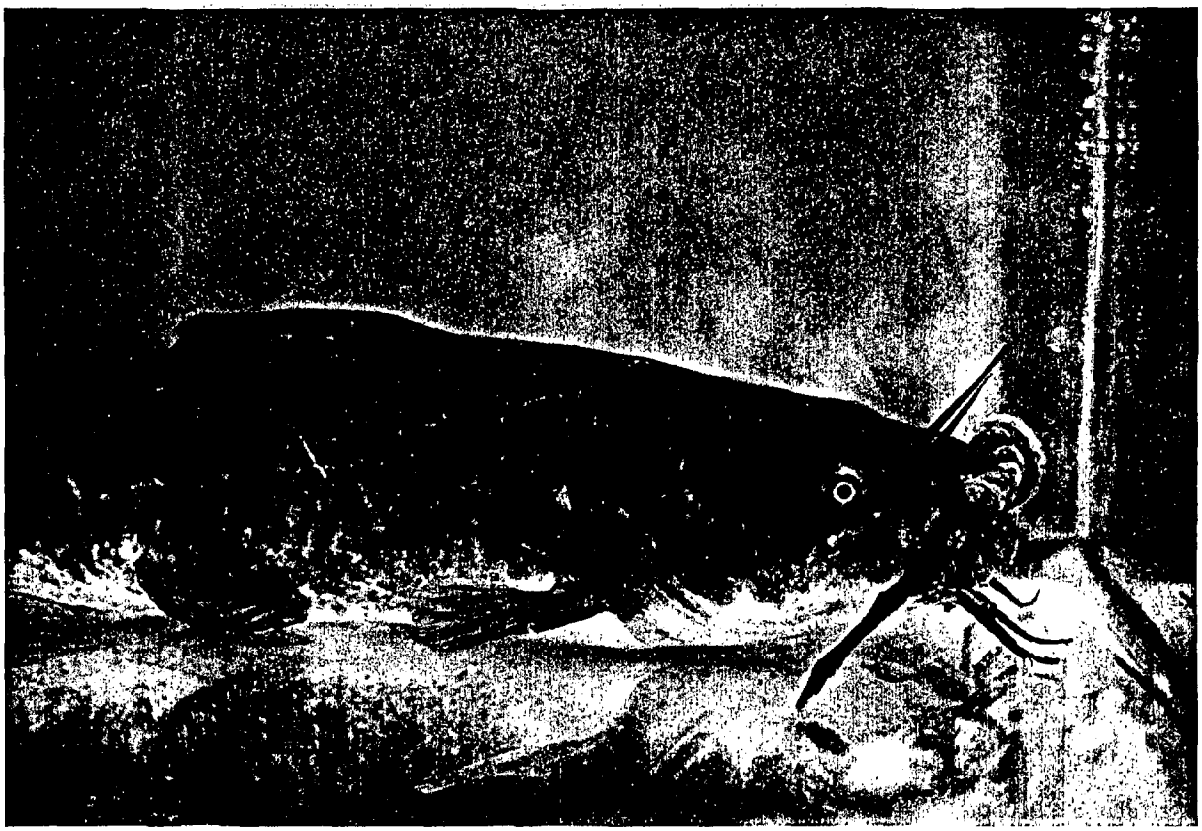

Figure 1. Brown bullhead, Ictalurus nebulosus, with epidermal papilloma.

circumscribed by a basement membrane and did not appear to invade underlying tissues.

Several channel catfish from the Betsy Ross Bridge area and the Petty Island area (sites 5 & 6) had enlarged, friable livers. In those two areas, 3 of 25 (12%) of the channel catfish were affected. The condition was not observed in fish from any other site.

Organosomatic Indices

Liver somatic indices, gonadal somatic indices, and condition factors for the four species studied are presented in tables 1-4. The gonadal somatic indices shown in the tables were calculated from female fish only.

The liver somatic index (LSI) varied significantly between collection sites in three of the four species; white perch ($F=91.3$, $P<.01$), white catfish ($F=29.6$, $P<.01$), and brown bullhead ($F=3.5$, $P<.05$). In the same three species, mean LSI was found to be inversely correlated with water temperatures in the period of May through July when temperatures exhibited a rapid increase (water temperature data taken from part B--Rutgers University Fish Collection Data Report). The correlations were significant for all three species; white perch ($r=-.96$, $df=8$, $P<.01$), white catfish ($r=-.97$, $df=4$, $P<.01$), brown bullhead ($r=-.85$, $df=6$, $P<.01$). For the same species LSI was also correlated with dissolved oxygen levels measured at the time of sampling (see section B). The test statistics were as follows: white perch ($r=.80$, $df=8$, $P<.01$), white catfish ($r=.94$, $df=4$, $P<.01$), and brown bullhead ($r=.83$, $df=6$, $P<.05$). The correlation between LSI and dissolved oxygen may have been a reflection of the LSI-temperature relationship, since temperature and dissolved oxygen were themselves correlated in our data ($r=-.69$, $df=8$, $P<.05$).

The LSI of channel catfish did not exhibit any significant variations.

Gonadal somatic index (GSI) and observations on the condition of the ovaries of female fish indicated when spawning took place relative to the sampling period. White perch spawning occurred between May 18 and June 18 as reflected in the GSI which decreased from 6.02 to 1.23 during that period. White catfish spawning appeared to have taken place prior to May 18, as all females examined from May through July were spent. GSI of female white catfish remained low through the study period. Spawning of brown bullheads did not begin until early July. Both gravid and spent females were found in the July 9 sample from site 1. Only gravid females were collected from the other sites, which were sampled prior to July 9. The time of channel

TABLE 1. LIVER SOMATIC INDEX (LSI), GONADAL SOMATIC INDEX (GSI), AND CONDITION FACTOR (CF) OF WHITE PERCH FROM THE DELAWARE RIVER ESTUARY

SITE #	DATE	# EXAMINED	LSI	GSI	CF
2	10-28-86	7	1.47	1.15	1.38
10	11-6-86	33	2.12	1.32	1.51
9	5-1-87	5	3.18	8.93	1.70
8	5-11-87	55	3.16	6.69	1.56
7	5-18-87	60	2.96	6.02	1.57
6	5-28-87	21	2.52	3.93	1.52
10	6-4-87	24	1.71	3.40	1.45
4	6-11-87	10	1.53	3.10	1.40
5	6-18-87	60	1.97	1.23	1.45
3	6-29-87	34	1.33	0.74	1.35
2	7-6-87	26	1.29	0.82	1.28
1	7-9-87	36	1.38	0.61	1.35

TABLE 2. LIVER SOMATIC INDEX (LSI), GONADAL SOMATIC INDEX (GSI), AND CONDITION FACTOR (CF) OF CHANNEL CATFISH FROM THE DELAWARE RIVER ESTUARY

SITE #	DATE	# EXAMINED	LSI	GSI	CF
2	10-28-86	2	2.35	0.10	0.68
9	5-1-87	1	2.20	----	0.80
8	5-11-87	3	2.23	1.00	0.85
7	5-18-87	3	2.87	1.05	0.92
6	5-28-87	4	3.50	0.40	0.90
10	6-4-87	4	2.18	0.80	0.82
4	6-11-87	9	2.03	0.80	0.84
5	6-18-87	21	2.59	1.41	0.96
3	6-29-87	3	2.03	18.75	0.93
2	7-6-87	7	2.06	5.70	0.92
1	7-9-87	6	1.77	7.75	0.95
9	9-25-87	5	2.24	0.52	0.83

TABLE 3. LIVER SOMATIC INDEX (LSI), GONADAL SOMATIC INDEX (GSI), AND CONDITION FACTOR (CF) OF WHITE CATFISH FROM THE DELAWARE RIVER ESTUARY

SITE #	DATE	# EXAMINED	LSI	GSI	CF
2	10-28-86	2	2.10	1.06	0.97
9	5-1-87	4	3.58	----	1.20
8	5-11-87	1	3.60	----	1.08
7	5-18-87	15	3.56	1.25	1.19
3	6-29-87	4	2.10	2.37	1.24
2	7-6-87	7	1.77	1.00	1.23
1	7-9-87	16	1.92	2.94	1.27
9	9-25-87	2	2.55	0.90	1.12

TABLE 4. LIVER SOMATIC INDEX (LSI), GONADAL SOMATIC INDEX (GSI), AND CONDITION FACTOR (CF) OF BROWN BULLHEADS FROM THE DELAWARE RIVER ESTUARY

SITE #	DATE	# EXAMINED	LSI	GSI	CF
10	11-6-86	4	3.72	0.60	1.25
9	5-1-87	1	3.10	----	1.33
8	5-11-87	1	3.60	9.40	1.37
7	5-18-87	2	3.35	9.90	1.50
10	6-4-87	1	2.50	15.90	1.76
5	6-18-87	27	2.67	8.65	1.55
3	6-29-87	1	2.40	15.30	1.51
2	7-6-87	6	2.48	10.93	1.51
1	7-9-87	10	2.63	3.32	1.46

catfish spawning was not well defined. Both gravid and spent females were found throughout the main sampling period (May-July).

Condition factors (CF) of white perch exhibited significant variation among collection sites ($F=26.3$, $P<.01$). Since gonad weight was expected to have influenced the CF, a possible correlation between CF and GSI was tested, and the effect was found to be significant ($r=.94$, $df=8$, $P<.01$). No variations in CF between collection sites were found for any of the three species of catfish.

Bacteriology

Results of bacteriological screening for Aeromonas hydrophila and Flexibacter columnaris are presented in tables 5 and 6.

Aeromonas hydrophila occurred in the intestines of fish with an overall frequency of 72.8%. Prevalence in brown bullheads was significantly higher than in the other species. Prevalence was found to vary significantly among sampling sites ($\chi^2=24.98$, $df=9$, $P<.01$). A high frequency of occurrence (95%) in all species collected from site 5 (Betsy Ross Bridge area), and low frequencies at sites 6, 8 and 9 (Petty Island, Horseshoe Shoals, and mouth of Schuylkill River) were responsible for the variation. Prevalence was significantly correlated ($r=.76$, $df=8$, $P<.05$) with water temperature, but not with dissolved oxygen levels.

Aeromonas hydrophila was isolated from kidneys of fish at much lower levels. An overall prevalence of 5.0% varied significantly among species ($\chi^2=18.7$, $df=3$, $P<.01$). White catfish were most frequently infected (17.8%), followed by channel catfish (3.8%), white perch (2.2%), and brown bullheads (0%). No significant differences between collection sites were found.

Flexibacter columnaris was isolated from gills of 17% of the fish examined. Frequency of occurrence was higher in catfish (28%) than in white perch (10.8%). No significant differences among collection sites were found for Flexibacter columnaris in white perch or channel catfish. Sample sizes of white catfish and brown bullheads were insufficient for valid statistical analysis.

Parasitology

Results of the parasite examinations are presented in table 7. Parasites from seven major taxonomic groups were found. Parasites were distributed throughout the study area.

TABLE 5. PREVALENCE OF AEROMONAS HYDROPHILA FROM INTESTINES OF FISH IN THE DELAWARE RIVER ESTUARY

SITE #	DATE	WHITE PERCH	WHITE CATFISH	BROWN BULLHEAD	CHANNEL CATFISH
1	7-9-87	13/20	7/11	3/3	5/6
2	7-6-87	16/20	6/10	6/6	6/9
3	6-29-87	18/20	3/4	1/1	1/4
4	6-11-87	17/20			6/9
5	6-18-87	18/20		10/10	10/10
6	5-28-87	12/20			1/4
7	5-18-87	10/20	15/16	2/2	2/3
8	5-11-87	10/20		0/1	2/3
9	5-1-87	3/5	1/4	1/1	
10	6-4-87	29/40		1/1	3/4
TOTALS (%)		146/205 (71.2)	32/45 (71.1)	24/25 (96.0)	36/52 (69.2)

TABLE 6. PREVALENCE OF FLEXIBACTER COLUMNARIS FROM GILLS OF FISH IN THE DELAWARE RIVER ESTUARY

SITE #	DATE	WHITE PERCH	WHITE CATFISH	BROWN BULLHEAD	CHANNEL CATFISH
1	7-9-87	2/20	5/11		2/6
2	7-6-87	1/20	0/7	1/9	1/7
3	6-29-87	4/20	3/4	0/1	0/4
4	6-11-87	4/20			4/9
5	6-18-87	2/20		3/10	4/10
6	5-28-87	2/20			3/4
7	5-18-87	1/20	1/14	0/2	1/3
8	5-11-87	2/20	0/1	0/1	0/3
9	5-1-87	1/5	0/4		
10	6-4-87	2/20		1/1	2/4
TOTALS (%)		20/185 (10.8)	9/41 (22.0)	5/24 (20.8)	17/50 (34.0)

TABLE 7. PREVALENCE OF PARASITES OF FISHES FROM THE DELAWARE RIVER ESTUARY

PARASITE	WHITE PERCH	WHITE CATFISH	BROWN BULLHEAD	CHANNEL CATFISH
NUMBER EXAMINED	95	27	29	42
PROTOZOA				
Henneguya sp.		7	2	8
Ichthyophthirius sp.				1
Trichodina sp.		1	2	12
MONOGENEA				
Ligictaluridus mirabilis				11
Ligictaluridus pricei		9	3	
Pterocleidus nactus	91			
TREMATODES				
Allocreadium ictaluri				1
Alloglossidium geminum				1
Diplostomum sp.	86	26	28	40
CESTODES				
Corallobothrium fimbriatum		17		
Megathylacoides giganteum				20
Proteocephalus sp.			2	
NEMATODES				
Camallanus oxycephalus	6			
Eustrongylides sp.		1		2
ACANTHOCEPHALA				
Leptorhynchoides thecatus	5			2
COPEPODS				
Ergasilus sp.	1			1

For the most common species of parasites, no significant differences in prevalence between sites were observed. Statistical analysis was not possible on parasites found at low prevalence; however, no obvious site differences were evident in the data. The most frequently encountered parasite was the eye fluke, Diplostomum, which was found in the lenses of over 90% of all fish examined. Individuals of all four species of fish from all collection sites were infected. As stated previously, eye flukes were associated with lens opacity in catfish and possibly white perch.

The most common parasite of white perch was a monogenean, Pterocleidus nactus. It was found on the gills of 96% of the white perch examined, but not on any of the other three species of fish.

All of the protozoans, monogeneans, and copepods were parasitic on the gills of their hosts. A larval nematode, Eustrongylides sp., and a cestode plerocercoid, Proteocephalus sp., were recovered from the livers of catfish. Diplostomum sp. infected the lens of the eye in all four species of fish. All of the remaining parasites were parasitic in the digestive tract of their hosts.

Histopathology

Gill pathology was evaluated on 172 fish. The most consistent finding among all four species of fish was hyperplasia of the lamellar epithelium. A summary of the grading of gill hyperplasia using Post's (1983) system is presented in table 8. Slight hyperplasia (grade 1) was characterized by a thickening of the lamellar epithelium. Moderate hyperplasia (grade 2) involved fusion of some adjacent lamellae usually at the distal end of the filament (figure 2). In fish with severe hyperplasia (grade 3) most lamellae were fused together (figure 3). Gill hyperplasia was least severe in channel catfish. Grade 1 hyperplasia was observed only in fish from sites 6, 7, 8 and 9; no hyperplasia was observed in channel catfish from other sites. Among the other three species of fish, grade 1 hyperplasia was observed in fish from all sites. More extensive hyperplasia (grades 2 & 3) was most common in brown bullhead from sites 7, 8, 9 and 10; in white catfish from site 6; and in white perch from site 6. There was no apparent relationship with dissolved oxygen levels at the time of collection. Sites where gill hyperplasia was more common had dissolved oxygen levels that ranged from the lowest (3.5 mg/l O_2 at site 10) to the highest (8.65 mg/l O_2) levels measured during sample collection.

Another type of gill pathology observed was a dilation of capillaries in the gill lamellae known as lamellar telangiectiasis (figure 4). This was observed in all four species. Prevalence of telangiectiasis did not appear to

TABLE 8. PREVALENCE OF GILL HYPERPLASIA AMONG FOUR SPECIES OF FISH FROM THE DELAWARE RIVER ESTUARY

	WHITE PERCH	WHITE CATFISH	BROWN BULLHEAD	CHANNEL CATFISH
GRADE 0 -- NO HYPERPLASIA	5/89	9/21	10/24	30/38
GRADE 1 -- SLIGHT HYPERPLASIA	63/89	4/21	8/24	8/38
GRADE 2 -- MODERATE HYPERPLASIA	19/89	4/21	4/24	0/38
GRADE 3 -- SEVERE HYPERPLASIA	2/89	4/21	2/24	0/38

TABLE 9. PREVALENCE OF LIVER TUMORS IN WHITE PERCH FROM THE DELAWARE RIVER ESTUARY

SITE	PREVALENCE
1	5/40 (12.5%)
2	6/33 (18.2%)
3	7/35 (20.0%)
4	12/60 (20.0%)
5	15/60 (25.0%)
6	3/21 (14.3%)
7	9/60 (15.0%)
8	9/55 (16.4%)
9	2/5 (40.0%)
10	8/57 (14.0%)

TABLE 10. PREVALENCE OF LIVER TUMORS BY LENGTH CLASS AND SEX OF WHITE PERCH FROM THE DELAWARE RIVER ESTUARY

LENGTH (mm.)	PREVALENCE MALES	FEMALES	COMBINED
140-149	0/4 (0%)	0/11 (0%)	0/15 (0%)
150-159	1/23 (4%)	3/47 (6%)	4/70 (6%)
160-169	10/40 (25%)	10/91 (11%)	20/131 (15%)
170-179	5/17 (29%)	9/60 (15%)	14/77 (18%)
180-189	2/12 (17%)	11/42 (26%)	13/54 (24%)
190-199	2/9 (29%)	10/29 (34%)	12/38 (32%)
200+	2/4 (50%)	11/30 (37%)	13/34 (38%)
TOTAL	22/109 (20%)	54/310 (17%)	76/419 (18%)

Figure 2. Gills of brown bullhead with grade 2 hyperplasia, H & E, X 100.

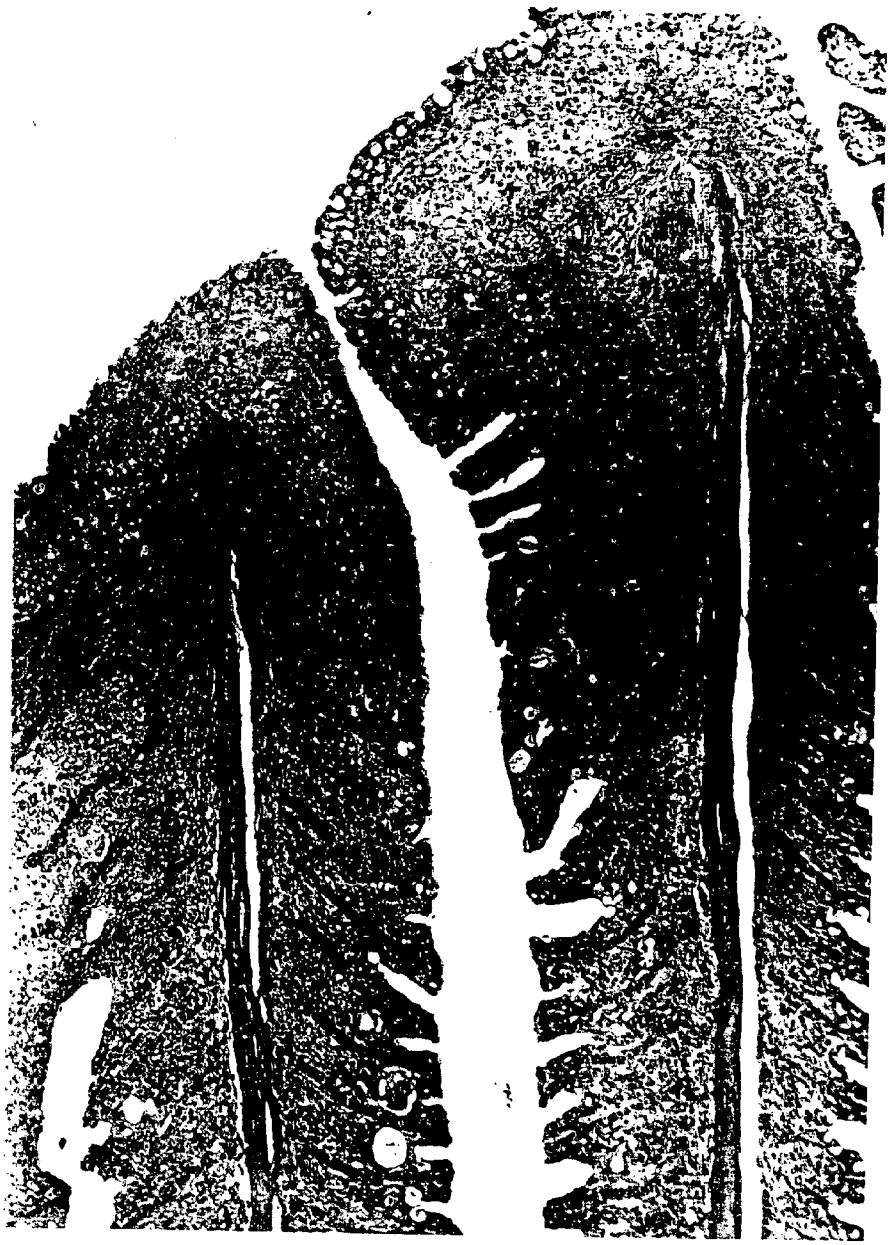

Figure 3. Gills of brown bullhead with grade 3 hyperplasia, H & E, X 100.

Figure 4. Gills of channel catfish with lamellar telangiectiasis H & E, X 100.

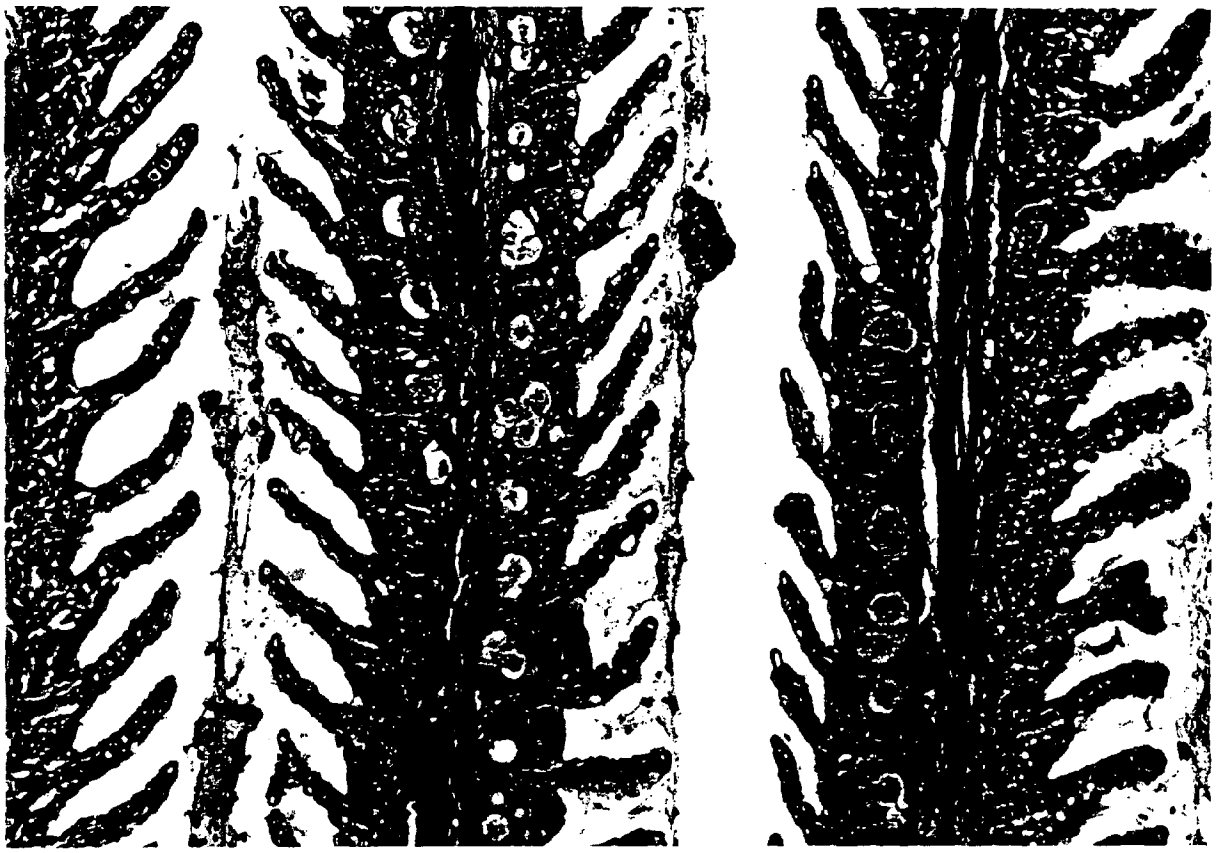

Figure 5. Cysts of Henneguya sp. between lamellae of gills of channel catfish, H & E, X 450.

Figure 6. Ligictaluridus mirabilis on gills of channel catfish, H & E, X 450.

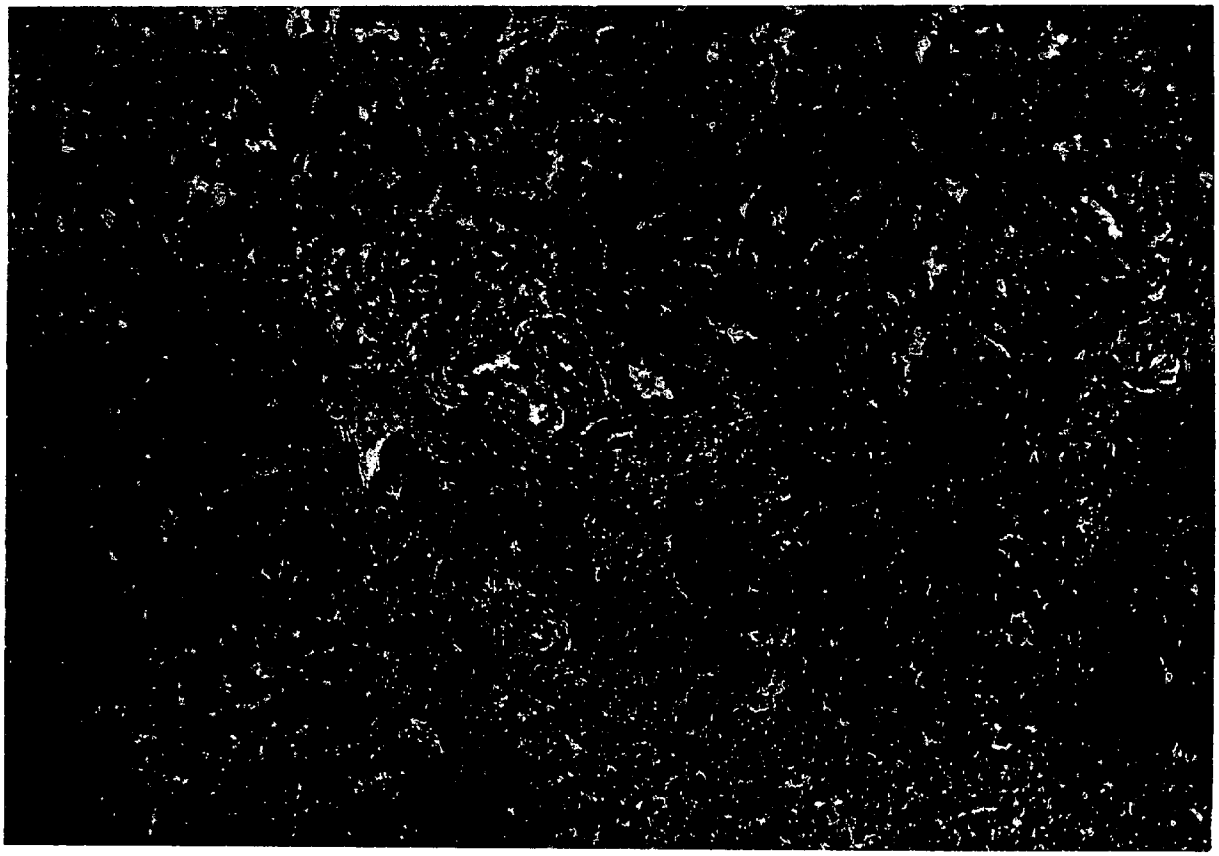

Figure 7. Cholangiocarcinoma (top of photo) in liver of white perch, normal hepatocytes at bottom, H & E, X 100.

vary between sites.

Gill pathology due to parasites was minor. Henneguya cysts in catfish gills elicited a more pronounced host response than monogenean parasites on catfish or white perch. Henneguya cysts occurred between gill lamellae at their bases (figure 5), resulting in a partial obstruction of the respiratory surface. Monogeneans (Pterocleidus nactus and Ligictaluridus spp.) attached to the lamellae by means of sclerotized hooks (figure 6); little or no gill damage was observed.

Liver pathology was common in white perch. Grossly visible nodules were observed during necropsy. Histologically, they were determined to be of duct cell origin (figure 7). Nodules up to 5 mm. in diameter were observed. Specimens submitted to the RTLA were diagnosed as cholangiomas and cholangiocarcinomas (RTLA accession #'s 3883-3886). Ducts comprising the nodules were poorly to moderately well-differentiated, mitotic figures were readily apparent, and in some areas the tumor cells interdigitated or invaded the surrounding normal liver tissue. Prevalence of the liver tumors in white perch is shown in tables 9 and 10. No significant differences were found in prevalence among collection sites or between sexes of white perch. However, prevalence did vary significantly with length of fish (χ^2 =26.3, df=6, P<.01). Prevalence increased progressively with size.

Liver pathology was also observed in brown bullheads. Sections submitted to the RTLA (RTLA accession #'s 3975, 3978, 3980) were diagnosed as foci of hepatocellular alteration of the type believed to be incipient neoplasms. The foci were 1.0-1.2 mm in diameter. Hepatocellular alteration was observed in livers of 3 of 53 bullheads examined. One fish from each of sites 2, 5, and 10 were affected.

The only other significant liver pathology observed was in channel catfish with grossly enlarged livers. Hepatocytes of those fish were extensively vacuolated and in areas appeared necrotic, suggesting fatty liver degeneration.

Liver Enzyme Assay

Hepatic AHH activity data were analyzed by single factor analysis of variance (ANOVA) to test for differences related to sampling location. Data from males and females were pooled for channel catfish and white catfish. Data from male and female brown bullheads were treated separately due to significant sex-related differences in AHH activity (F=7.2, P<.01). Significant differences in hepatic AHH activity were observed among channel catfish from seven of the sampling

sites ($F=2.7$, $P<.05$, Table 11). No statistically significant differences related to sampling location were observed in either white catfish or brown bullhead males or females. Results for the latter two species are listed in Table 12.

Channel catfish were also obtained from the Charles O. Hayford Fish Hatchery at Hackettstown, NJ for comparison. Only channel catfish from Site 10 had hepatic AHH activities that were significantly higher (Student's t Test; $P<.05$) than the hatchery fish (AHH activity = 12.1 FU/mg protein/25 min).

Some caution must be exercised in the interpretation of the AHH activity data. Equipment problems prevented the collection of fish samples in the fall of 1986. Therefore, sampling was conducted during the spring and early summer of the following year, which coincides with the spawning seasons of the three Ictalurids. Several studies have documented changes in hepatic AHH activities during the spawning season (Luxon et al. 1987; Walton et al. 1978), probably related to the role of MFO enzymes in hormone metabolism (see Koivusaari et al. 1981). Also, Walton et al. (1978) found the hepatic MFO system of the cunner to be less responsive to induction by petroleum hydrocarbons during spawning.

It is not clear why AHH was higher in female brown bullheads than in males. In other studies, AHH was found to be lower in females than in males in pre-spawning cunner (Walton et al. 1978), spawning lake trout (Luxon et al. 1987), and two species of sanddab (Spies et al. 1982).

Besides spawning, other factors that have been found to affect AHH activity are body size (Stegeman, 1978), starvation (Walton et al. 1978) and water temperature (Stegeman, 1979). To determine whether these factors influenced comparisons of AHH activity made in the present study, correlations between AHH activity and the following factors were tested: body weight, water temperature, liver somatic index (an indicator of nutritional status) and gonadal somatic index (an indicator of the degree of sexual maturity in females). The degree of sexual maturity appeared to be a significant factor in the level of AHH activity in brown bullheads (Table 13). The hepatic AHH activity increased with increasing gonadal-somatic index ($y = 0.300x + 9.238$). In channel catfish, a significant correlation was found between water temperature and AHH activity ($y = 0.533x + 1.632$). Body weight was correlated with AHH activity in the white catfish ($y=0.011x + 9.923$).

AHH activity data were adjusted for temperature (channel catfish) and body weight (white catfish) and retested for differences among sampling sites. For channel catfish, site-related differences in AHH activity were no longer statistically significant, although fish from site 10 still exhibited the highest enzyme activity (Table 14). White catfish AHH activity data, when adjusted for body weight,

TABLE 11. HEPATIC AHH ACTIVITIES IN CHANNEL CATFISH FROM THE DELAWARE RIVER ESTUARY

Site	River Mile	n	AHH Activity (FU/mg Protein/25 minutes) Mean	(SD)	
10	84.5	4	20.2	(5.5)	A *
2	118	8	16.7	(5.0)	A B
1	120	5	13.2	(1.2)	A B
5	104	6	12.8	(5.4)	B
4	107	6	12.3	(4.1)	B
6	102	4	10.7	(5.4)	B
8	95	3	9.9	(2.7)	B
3	116	2**	14.4		
7	99	1**	11.4		
9	92	1**	2.4		

* Means with the same letter are not statistically different (two-tailed Student's t Test; alpha = 0.05)

** Samples with n < 3 were not statistically analyzed.

TABLE 12. HEPATIC AHH ACTIVITIES IN WHITE CATFISH AND BROWN BULLHEADS FROM THE DELAWARE RIVER ESTUARY

Site	River Mile	n	AHH Activity (FU/mg Protein/25 minutes) Mean	(SD)
		White Catfish		
1	120	12	15.9	(6.5)
2	118	8	16.2	(7.2)
3	116	3	13.3	(3.9)
7	99	9	11.6	(4.5)
		Brown Bullhead (Males)		
1	120	3	8.6	(3.9)
2	118	3	8.9	(2.8)
5	104	4	6.3	(1.5)
		Brown Bullhead (Females)		
1	120	4	9.7	(1.1)
2	118	3	13.1	(4.5)
5	104	11	11.2	(1.8)

TABLE 13. CORRELATION OF HEPATIC AHH ACTIVITY TO BODY WEIGHT, WATER TEMPERATURE, LIVER SOMATIC INDEX (LSI), AND GONADAL SOMATIC INDEX (GSI)

	Correlation Coefficients (r)			
Species	Water Temp.	Body Wt.	LSI	GSI
Channel Catfish	0.368 *	0.150	0.275	0.305
White Catfish	0.305	0.536*	0.289	0.305
Brown Bullhead (Males)	0.519	0.178	0.311	ND **
Brown Bullhead (Females)	0.240	0.227	0.173	0.451 *

* Correlation coefficient statistically significant ($P < 0.05$)

** ND - Not determined

TABLE 14. HEPATIC AHH ACTIVITIES (TEMPERATURE CORRECTED) IN CHANNEL CATFISH FROM THE DELAWARE RIVER ESTUARY

Site	River Mile	n	AHH Activity (FU/mg Protein/25 minutes/ °C) Mean	(SD)
10	84.5	4	0.934	(0.257)
2	118	8	0.662	(0.200)
8	95	3	0.660	(0.178)
6	102	4	0.574	(0.288)
4	107	6	0.542	(0.181)
5	104	6	0.530	(0.223)
1	120	5	0.497	(0.046)
3	116	2**	0.570	
7	99	1**	0.663	
9	92	1**	0.179	

** Samples with n < 3 were not statistically analyzed.

TABLE 15. HEPATIC AHH ACTIVITIES

(CORRECTED FOR BODY WEIGHT)

IN WHITE CATFISH FROM THE DELAWARE RIVER ESTUARY

Site	River Mile	n	AHH Activity (FU/mg Protein/25 minutes/ gram body weight) Mean	(SD)	
7	99	8	0.073	(0.039)	A*
3	116	3	0.039	(0.008)	A B
1	120	12	0.036	(0.015)	B
2	118	7	0.033	(0.024)	B

* Means with the same letter are not statistically significant (two-tailed Student's t Test; alpha = 0.05)

exhibited significant site-related differences ($F=4.3$, $P<.05$, table 15).

The finding of elevated AHH activities in white catfish from Site 7 is consistent with a previous toxics study performed in this area of the river. The sediments at Site 7 (river mile 99) were found to be contaminated with several PAH compounds (DRBC, 1987).

No tumors were found in channel catfish in the present study. However, tumors were found in two brown bullheads collected at site 10, where the highest AHH activities were measured in channel catfish (brown bullhead liver samples from this site were not available for measurement of hepatic AHH activity). These observations are suggestive of exposure to elevated levels of organic contaminants in this area. More intensive sampling would be necessary to test this hypothesis.

Tissue Toxics Analyses

A total of 31 tissue composites (18 muscle and 13 liver) were submitted to the Philadelphia Academy of Natural Sciences for toxics analyses. The results of those analyses are presented in tables 16-19. Discussion of the results as they relate to recommended action levels is included in the Academy's section of this report (section D). This section will deal only with possible relationships to observed fish pathology.

Channel catfish with enlarged, vacuolated livers were included in composites of liver tissue used for toxics analysis from sites 5 and 6. Both samples had trace metal concentrations below or only slightly above mean values for the seven sites from which channel catfish livers were analyzed. For levels of PCB's, DDE, and DDD, the sample from site 6 was well below the mean values, while the sample from site 5 had among the highest concentrations detected. No inference could be made concerning a possible relationship between tissue toxicants and the observed pathology.

White perch with liver tumors were included in nine of the ten composites of muscle tissues used for toxics analysis as follows:

sites 5 and 10 (3 of 5 fish had grossly visible tumors),
sites 2, 3, 8, and 9 (2 of 5 fish had visible tumors),
sites 1, 4, and 6 (1 of 5 fish had visible tumors), and
site 7 (no fish had visible liver tumors).

Statistical analysis of the tissue toxics data revealed no apparent relationship between prevalence of tumors in the samples and toxicant levels in the muscle. Similarly, analysis of composites of liver tissue from tumor-bearing and grossly normal white perch provided no insight into a

possible relationship. Livers of the tumor-bearing fish had higher levels of most metals than those of normal fish, while the normal fish had higher levels of PCB, DDE, and DDD.

TABLE 16. TRACE METAL CONCENTRATIONS (mg/kg dry weight) IN MUSCLE TISSUE

SITE	Cd	Cr	Cu	Pb	Ni	Zn	As	Se
				Channel Catfish				
1	0.025	1.12	5.12	0.279	0.73	27.6	1.12	0.931
2	0.028	2.13	2.50	0.176	1.50	27.0	1.11	0.832
3	0.025	1.18	2.35	0.137	1.13	21.4	<0.60	1.08
4	0.035	1.79	4.06	0.689	2.01	28.2	<0.60	0.849
5	0.064	2.18	6.65	0.357	2.07	24.8	<0.60	0.893
6	0.033	1.54	2.31	0.154	1.36	22.0	<0.60	0.865
9	<0.02	6.92	7.66	1.11	1.54	23.8	<0.60	1.10
				White Catfish				
7	0.150	2.61	61.6	3.70	3.39	53.3	<0.60	0.840

TABLE 16. CONTINUED

SITE	Cd	Cr	Cu	Pb	Ni	Zn	As	Se
				White Perch				
1	0.054	2.56	7.60	0.300	1.15	30.1	0.820	4.06
2	0.030	1.49	2.78	0.188	2.14	29.4	<0.60	4.56
3	0.028	3.02	5.56	0.712	2.03	30.5	0.780	3.12
4	0.038	1.00	2.80	0.310	1.45	31.6	0.800	3.80
5	0.042	1.80	7.58	0.313	2.70	31.1	0.600	3.03
6	0.027	2.19	3.05	0.238	1.67	25.5	1.14	3.24
7	0.039	1.61	4.84	0.275	1.69	30.9	1.14	3.23
8	0.035	0.97	2.71	0.242	1.49	23.6	0.969	3.39
9	0.048	1.10	10.6	0.385	3.13	23.7	2.20	3.65
10	0.104	1.38	2.26	0.187	1.19	27.4	1.18	3.88

TABLE 17. TRACE METAL CONCENTRATIONS (mg/kg dry weight) IN LIVER TISSUE

SITE	Cd	Cr	Cu	Pb	Ni	Zn	As	Se
				Channel Catfish				
1	0.612	1.50	12.0	1.28	0.70	104	0.600	10.8
2	1.58	0.90	12.4	2.52	2.22	97.5	0.800	5.98
3	0.626	1.50	8.77	3.35	2.55	85.2	0.600	5.31
4	1.20	1.50	9.97	3.31	2.24	99.9	<0.60	10.4
5	0.684	0.70	6.80	2.68	0.77	65.6	<0.60	4.54
6	0.200	0.45	5.19	1.04	1.53	55.7	<0.60	5.15
9	0.496	1.63	11.5	2.69	0.30	111	<0.60	10.5
				White Catfish				
2	1.11	1.62	14.9	0.992	2.27	112	<0.60	13.9
7	0.594	1.28	20.9	0.787	1.98	108	<0.60	12.2

TABLE 17. CONTINUED

SITE	Cd	Cr	Cu	Pb	Ni	Zn	As	Se
				Brown Bullheads				
2	0.607	1.79	34.6	2.19	1.45	103	<0.60	11.6
5	0.735	1.91	36.8	1.97	2.09	110	<0.60	12.3
				White Perch				
5	3.65	0.53	3,089	1.35	3.96	172	1.42	119
5*	8.63	1.36	5,711	1.55	4.60	254	1.35	158

* Composite sample of livers with tumors

TABLE 18. CONCENTRATIONS (mg/kg) OF PCBs, DDE, & DDD IN MUSCLE TISSUE

SITE	AROCLOR 1254	AROCLOR 1260	TOTAL PCBs	DDE	DDD
			Channel Catfish		
1	3.022	1.176	4.198	1.557	0.468
2	1.336	0.217	1.553	0.464	0.258
3	2.575	1.026	3.601	0.905	0.360
4	1.718	0.626	2.344	1.454	0.440
5	2.490	0.754	3.244	2.215	0.856
5*	3.158	1.275	4.433	2.151	1.118
6	2.004	0.540	2.544	0.965	0.355
6*	2.355	0.500	2.855	0.678	0.270
9	2.522	1.022	3.544	0.940	0.372
9*	1.354	0.684	2.038	0.692	0.358

TABLE 18. CONTINUED

SITE	AROCLOR 1254	AROCLOR 1260	TOTAL PCBs	DDE	DDD
			White Catfish		
7	0.600	0.161	0.761	0.545	0.162
			White Perch		
1	0.315	0.094	0.409	0.144	0.045
2	<0.100	<0.100	<0.100	0.035	<0.005
3	0.285	<0.100	0.285	0.208	0.060
4	0.794	0.326	1.120	0.476	0.301
5	0.563	0.176	0.739	0.464	0.153
6	0.588	0.401	0.989	0.400	0.113

TABLE 18. CONTINUED

SITE	AROCLOR 1254	AROCLOR 1260	TOTAL PCBs	DDE	DDD
		White Perch - Continued			
7	1.336	0.393	1.729	0.834	0.308
8	0.986	0.209	1.195	0.595	0.242
9	0.934	0.251	1.185	0.688	0.200
10	1.035	0.371	1.406	0.606	0.234

* Replicate extractions

TABLE 19. CONCENTRATIONS (mg/kg) OF PCBs, DDE & DDD IN LIVER TISSUE

SITE	AROCLOR 1254	AROCLOR 1260	TOTAL PCBs	DDE	DDD
			Channel Catfish		
1	0.335	<0.100	0.335	0.067	0.011
2	1.316	0.250	1.566	0.406	0.164
3	<0.100	<0.100	<0.100	0.263	0.071
4	0.538	0.226	0.764	0.280	0.087
5	1.320	0.371	1.691	0.736	0.250
5*	1.420	0.422	1.842	0.664	0.213
6	<0.100	<0.100	<0.100	0.059	0.016
9	1.427	0.938	2.365	0.152	0.076

TABLE 19. CONTINUED

SITE	AROCLOR 1254	AROCLOR 1260	TOTAL PCBs	DDE	DDD
			White Catfish		
2	<0.100	<0.100	<0.100	0.118	<0.005
7	0.353	<0.100	0.353	0.200	0.062
			Brown Bullheads		
2	<0.100	<0.100	<0.100	<0.005	<0.005
5	0.558	0.108	0.766	0.278	0.111
			White Perch		
5	3.085	2.515	5.600	2.060	0.725
5**	1.516	0.569	2.085	1.527	0.438

* Replicate extractions

** Composite sample of livers with tumors

DISCUSSION

General Condition

Significant differences among collection sites were detected in the measures of general condition of fish, liver somatic index (LSI) and condition factor (CF). The differences appear to be largely due to physiological changes in the fish rather than to differences in environmental quality between collection sites.

Variations in LSI among collection sites were found to be correlated with water temperature which increased from 13.4 to 26.5 degrees Centigrade over the May-July sampling period. Since sites were sampled at approximate one week intervals throughout that period, water temperature differences between sites increased up to 3 degrees C in successive sample collections. The effect of water temperature on LSI may have obscured any effect that might have resulted from other differences in environmental quality among sites. The negative correlation between LSI and water temperature observed in this study is consistent with previous findings of Heidinger and Crawford (1971) in largemouth bass.

Condition factor (CF) exhibited a significant variation among sites in white perch only. Since CF is calculated using total body weight and total length of fish, the relationship with gonad weight (GSI) was expected. It is apparent in table 1 that mean CF of fish that had not yet spawned (sites 7-9) were greater than CF of fish that were spent (sites 1-3). Lagler (1971) indicated that all sampling should be conducted within a single season to avoid such variations. The lack of significant differences in the catfish was probably due to the fact that none of those species had a well-defined spawning period during this study.

Bacteriology

Aeromonas hydrophila occurred with a frequency of 72.8% in Delaware River fishes, and was detected in fish from all collection sites. The high prevalence suggests that a substantial reservoir of infection is present and the potential for an epizootic exists if fish become stressed. Site differences in prevalence of Aeromonas hydrophila may have been due in part to variations in water temperature, since a positive correlation between temperature and prevalence was found.

A clinical case of the disease was detected from site 8.

Aeromonas hydrophila was isolated from fluid from the eyes of white perch exhibiting exophthalmus, which is considered a significant clinical sign of the disease (Cipriano et al. 1984). Isolations were also made from kidneys of other fish during the study; however, clinical signs were lacking.

Flexibacter columnaris was less prevalent than A. hydrophila among fish in the Delaware River Estuary. Isolation rates of F. columnaris from the gills of fish in this study were consistent with those reported by Becker and Fujihara (1978) from Columbia River fish collected during the same months, and would be expected to increase as water temperatures increased. No lesions indicative of clinical infections were observed on gills of fish during this study.

Parasitology

Of the sixteen parasites found during this study, only three species may be of significant consequence to the health of the fish stocks. Henneguya and Ichthyophthirius are protozoan parasites which have been reported as pathogens of channel catfish (Plumb 1985). Although most reports involve cultured catfish, Ichthyophthirius has been reported from several cases of mortality in feral fish populations (Allison and Kelly 1963; Dechtiar 1972). Pathology resulting from Henneguya infections in this study was not considered serious. Diplostomum has been reported as a cause of stunted growth, abnormal feeding behavior, and reduced visual acuity in fish (Palmeri et al. 1977), and in this study was associated with visible cloudiness of lenses in catfish. The effect of Diplostomum on the vision of fish has been reported to reduce their susceptibility to angling (Moody and Gaten 1981). This effect; however, would be expected to be less severe in catfish than in species which depend more on vision in locating prey. No parasites that would adversely affect appearance were found in the skin or flesh of the fish.

Idiopathic Lesions

A number of conditions observed were not associated with any known pathogens. The most common of these were cholangiocellular tumors in white perch. Cholangiocellular tumors have been reported recently from white perch from the Chesapeake Bay by May, et al. (1987). Similar tumors have also been reported from other species of fish (Dawe et al. 1964; Harshbarger et al. 1984) and may be associated with high levels of polycyclic aromatic hydrocarbons (PAH) in

sediments (Baumann et al. 1987). However, the cases on which the association is based involve bottom-feeding rather than pelagic fish, and are from areas with sediment PAH concentrations considerably higher than those reported for areas within the Delaware Estuary by the Delaware River Basin Commission (DRBC, 1987). PAH concentrations in white perch tissues analyzed during the present study did not exceed detection limits, although this is may be due to rapid metabolism which has been reported to occur in fish (Eisler 1987). Other organics sampled were present in lower concentrations in livers of tumor-bearing white perch (sample # 4505) than in perch without tumors (sample # 4105). There is no solid evidence linking the cholangiocellular tumors of white perch in the present study with environmental contaminants, although toxicants cannot be ruled out as a possible cause. Burton and Baksi (1988) reported that the condition of abnormal hepatic copper storage in white perch may have contributed to the development of cholangioma in Chesapeake Bay white perch. Using a specific stain, they demonstrated liver changes associated with copper storage, although tumor cells stained negatively for copper. High levels of copper in white perch liver composites were found in Delaware River perch and, as was the case with most of the metals analyzed, copper levels were higher in tumor-bearing perch than in fish without grossly visible tumors. Environmental pollution, peribiliary fibrosis, and parasites were other factors which Burton and Baski (1988) believed may have contributed to the development of tumors in Chesapeake Bay white perch.

Lip tumors (epidermal papillomas) and liver lesions (hepatocellular alteration) were found in brown bullheads from the Delaware Estuary. The overall prevalence of both conditions was somewhat low; 3.8% and 5.7% respectively. Lip tumors were found only from site 10, while bullheads from sites 2, 5, and 10 had liver lesions. Although neither lesion occurred frequently enough to permit statistical analysis, bullheads from site 10 had the highest combined prevalence of neoplastic and preneoplastic lesions. Hepatocellular alterations are considered preneoplastic lesions which may progress into full-blown hepatocellular tumors (Harshbarger, pers. comm. 1987). Circumstantial evidence exists for an association between hepatic tumors in bullheads and PAH in sediments (Baumann et al. 1987). Statements made previously concerning sediment toxics in the Delaware Estuary are also applicable here. As with white perch, detectable levels of PAH in bullhead livers were not found in this study. The liver enzyme assays provided the only evidence indicating a possible relationship with exposure to environmental contaminants. Brown bullheads from site 10 were not available for measurement of hepatic AHH activity; however, the highest AHH activity measured in

channel catfish was in fish from site 10. This observation is suggestive of exposure to elevated levels of organic contaminants in that area. Additional evidence of a fish response to elevated levels of PAH was observed in white catfish. Elevated levels of AHH activity were observed in fish from a site (Penns Landing area, site 7), where sediments are contaminated with several PAH compounds (DRBC, 1987). Additional sampling of bullhead populations within the Delaware Estuary might reveal more advanced hepatic neoplasms and test the hypothetical relationship with PAH's.

Gill pathology constituted another common idiopathic condition observed in fish from the Delaware Estuary. Epithelial hyperplasia was most severe in fish from sites at or below river mile 102 (sites 6-10). Lamellar telangiectiasis showed no apparent differences in prevalence or severity among sampling sites. Both epithelial hyperplasia and lamellar telangiectiasis have been reported as effects of sublethal hypoxia in channel catfish (Scott and Rogers 1980), although they are by no means pathognomonic for hypoxia. There was no apparent relationship between gill pathology and low dissolved oxygen levels during the present study. Similar gill lesions may also result from external bacterial infections (Post 1983), chemical agents (Eller 1975), and physical trauma (Herman and Meade 1985). Lamellar telangiectiasis, in particular, may have resulted from killing fish by a blow to the head as was the practice with catfish in this study. The observed lack of site variations in prevalence of lamellar telangiectiasis would be consistent with physical trauma from sampling methods as its cause.

Emaciation, ascites, and liver enlargement were other conditions without identifiable cause. Fish with enlarged livers were included in several of the samples submitted for toxicological analysis, but were not associated with elevated levels of any of the parameters tested. Bacterial infections, hypoxia, and environmental contaminants are among the possible causes.

A general lack of site differences in most parameters tested may have been due to movements of fish. Movements of fish associated with spawning activities as well as random movements cited in the introduction may have obscured any real differences in parameters tested. The effect of fish movements would be expected to be greater on chronic lesions such as tumors than on more acute lesions such as gill hyperplasia which, in fact, was the case.

With the exception of a relatively high prevalence of liver tumors in white perch, the findings of this study were not entirely unexpected. Much of the pathology observed might have resulted from physical stresses associated with seasonal increases in water temperature, decreases in oxygen levels, and the onset of spawning. Some circumstantial evidence presented indicates that environmental contaminants

may affect the health of fish; however, there is no conclusive evidence to indicate that toxics are having a pronounced impact on fish populations in the Delaware Estuary.

SUMMARY

1) Two opportunistic bacterial pathogens, Aeromonas hydrophila and Flexibacter columnaris, were detected as part of the normal intestinal and gill flora of fish from the Delaware River Estuary, indicating the potential for mortalities under conditions of environmental stress. Prevalence of Aeromonas hydrophila was positively correlated with water temperature and was highest at site 5. Clinical infections of motile aeromonad septicemia were found among white perch from site 8. Affected fish exhibited exophthalmus. Subclinical kidney infections were detected in white perch, white catfish, and channel catfish.

2) Sixteen species of parasites from seven major taxonomic groups were recovered. Three parasites were considered potential pathogens; Henneguya, Ichthyophthirius, and Diplostomum. The eye fluke, Diplostomum, was associated with lens opacity in catfish, and may affect visual acuity.

3) Liver tumors diagnosed as cholangiomas and cholangiocarcinomas occurred in white perch at an overall frequency of 18%. Prevalence increased with fish length, but did not vary significantly among collection sites. Similar tumors have been previously reported from bottom-feeding fish, but only once previously in white perch, a pelagic species. No association with environmental contaminants was detected, although livers of tumor-bearing perch had higher levels of most metals than did those of grossly normal fish.

4) Lip tumors (epidermal papillomas) and liver lesions (hepatocellular alteration) were found at low frequencies of occurrence in brown bullheads. Liver lesions were found in bullheads from sites 2, 5, and 10; lip tumors were found only in bullheads from site 10. Combined prevalence for both conditions was highest at site 10, although small sample sizes and low prevalence precluded valid statistical analysis.

5) Elevated hepatic AHH activities in fish from sites 7 and 10 suggest exposure to organic (aryl hydrocarbon) contaminants in those areas. PAH contaminated sediments were reported in the vicinity of site 7 in a previous DRBC report. Elevated AHH activities in fish from site 10, also the site of highest tumor prevalence, suggests a possible link between chemical contaminants and the occurrence of neoplasia. However, sample sizes were too small to draw any firm conclusions.

6) Gill pathology (epithelial hyperplasia) was evident in all four species of fish. The pathology was more severe in fish from sites 6 through 10; and particularly in site 6. The lesions are not characteristic of any one disease, and may have resulted from exposure to stress in the form of hypoxia or environmental contaminants.

7) Miscellaneous idiopathic conditions observed were emaciation, ascites, and liver enlargement. No information was found to support a relationship with infectious, physical, or chemical agents.

RECOMMENDATIONS

Two of the conditions observed warrant further study: (1) idiopathic liver tumors in white perch, and (2) tumors in brown bullheads and their possible association with increased AHH activity.

The occurrence of liver tumors in the white perch population follows a pattern that suggests environmental contaminants as a possible cause. Prevalence of tumors increased with size (age), the tumors occurred in an organ which functions in detoxification, and previous studies had detected environmental contaminants in the estuary. Further studies could test that theorized relationship by investigating other potential causes. Electron microscopic and cell culture studies would serve to detect viral involvement. Cytogenic studies could be conducted as suggested by Dawe (1987) to determine whether a visible chromosome anomaly is present suggesting a genetic cause. Efforts directed toward identification of an environmental cause would be difficult because of the mobility of the white perch. Future studies should investigate the tumor rates and hepatic copper levels of other populations of white perch in coastal rivers including some "cleaner" environments, and perhaps look at food preferences of the fish as a potential source of environmental carcinogens.

Further studies on brown bullhead tumors should be directed toward an intensification of sampling for that species at sites 7 and 10 to obtain larger sample sizes. The addition of an upstream control site is recommended. Necropsies, histological examinations and enzyme assays should be conducted on the fish concurrently with analysis of sediments for PAH's. Sampling should be conducted in the fall to eliminate the effects of spawning on AHH activity.

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PART D - DATA REPORT OF ANALYSES OF

DELAWARE RIVER FISH TISSUE FOR TOXIC SUBSTANCES

ACADEMY OF NATURAL SCIENCES

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U.S. Environmental Protection Agency method for the analysis of fish for cyanide.	

Introduction

At the request of the Delaware River Basin Commission (DRBC) the Academy of Natural Sciences participated in the Fish Health, Contamination and Suitability Study of the Delaware River Estuary. The Academy's role in this project was to analyze fish tissue for various contaminants including trace metals, cyanide, PCBs, selected chlorinated pesticides and polyaromatic hydrocarbons. Phenols were originally part of the list, but because no good analytical method for the analyses of phenols in fish tissue exists, this parameter was dropped.

This report summarizes the results of these analyses.

Methods

Metals

Each fish tissue sample for metal analysis was prepared by drying a 1-g piece of tissue at 60°C overnight. The dried tissue was ground, weighed and placed in a 100-ml beaker. The tissue in the beaker was digested by adding 30 ml of concentrated nitric acid, covering the beaker with a watch glass and heating the sample on a hot plate at 95°C for 2 h. The watch glass was then removed and the acid evaporated to 3-5 ml. The sample was washed from the beaker with distilled/deionized water into a 100-ml volumetric flask and diluted with distilled/deionized water to volume. Analysis was completed by flame or flameless techniques on a Perkin Elmer Zeeman 5000 Atomic Absorption Spectrophotometer. Acid and glassware blanks were carried through the complete process. The concentrations of metals found in the blanks were subtracted from the sample values. Results are reported as mg/kg dry weight unless otherwise noted.

Fish tissue for mercury determination was prepared by digesting 0.5 g wet weight of tissue with concentrated sulfuric

acid overnight in a waterbath at 95°C. The digested tissue was analyzed by the cold trap method as modified by Perkin Elmer (1982).

Fish tissue for cyanide was prepared for analysis by the EPA Method in the Appendix. Cyanide quantitation was completed by an ion selective electrode. Because of limited sample size in some cases, it was impossible to analyze all samples for cyanide.

Organics

To facilitate sample processing within time constraints, and to accommodate small sample size in some cases, a modification of an EPA method was used (conversation with Larry Holland, EPA Duluth Lab). This method permits concurrent extraction of the sample for pesticides and polynuclear aromatics (PNAs). The method uses Soxhlet extraction of 20 g of tissue dried with anhydrous sodium sulfate. Each tissue sample was extracted with 350 ml of 1:1 hexane:acetone for 16 h. The extract was concentrated to 5 ml in a Kuderna-Danish evaporator/concentrator with a 3-ball Snyder column. The concentrated extract was placed on the head of a Florisil column and eluted with 50% hexane/ether. The extract was concentrated to 2 ml for pesticide and PCB analyses and to 0.5 ml for polyaromatic hydrocarbons.

Analyses were completed on Hewlett Packard 5890 GC. For pesticides and PCBs a 30-m J&W 608 Megabore capillary column 608 was used. The column was operated in program temperature mode with on-column injection, from an initial temperature of 100°C to 275°C at 8°C/min, with an initial hold of 2 min. Injector port temperature was 225°C. Carrier gas was helium at 10 ml/min. The detector was an electrolytic conductivity detector operated in the halogen mode.

For the analysis of PNAs a 30-m J&W DB-1 capillary column was used. The GC was operated in the splitless injection mode and programmed from an initial temperature of 65°C to 275°C at 10°/min with an initial hold of 2 min. The inlet temperature was

275°C. The detector was a HNU Systems Inc. photo-ionization detector. Confirmation of PNAs was completed by GC/MS.

Results

The results of fish tissue analysis for trace metals are shown in Tables 1 and 2 (all tables appear at the end of the report). Concentrations are reported as mg/kg unless otherwise noted. For comparison, fish metal concentrations from other Academy studies are summarized in Table 3. The mean muscle metal concentrations are summarized in Table 4. Mean liver metal concentrations by species are given in Table 5. A mean was calculated only for those metals where it was reasonable to calculate, i.e., when most of the values were above the detection limit. In those cases where one or two of the numbers were below detection, a value of one-half the detection limit was used in the calculation of the mean.

A summary of tissue concentrations for organics is given in Table 6. Pollutants detected were PCBs, DDE and DDD. No PNAs were detected in the tissue samples. For PCBs the major Aroclors detected were 1254 and 1260. Channel catfish had the highest muscle tissue concentrations (Table 6). Six of the seven channel catfish analyzed exceeded the FDA Action Level of 2.0 ppm for total PCB concentration. No other fish muscle tissue sample exceeded this level. One catfish liver sample exceeded the FDA level (1109). For white perch two liver samples (4105, 4505) exceeded the action level, although the corresponding tissue samples did not. A breakdown of average muscle tissue concentration by fish species is shown in Table 7. Means were calculated by using a value of one-half the detection limit. The average tissue concentration of channel catfish as a population exceeded the action level while white catfish and white perch did not. The pesticide metabolites DDE and DDD were considerably

higher in channel catfish than in the other two species. No detectable PCBs were found in brown bullhead liver tissue (Table 6). The highest concentrations were found in the livers of white perch along with higher pesticide concentrations. It should be pointed out that in addition to PCBs, chlordane was present in the majority of fish samples, but because of co-eluting peaks for both compounds, it was impossible to accurately quantify the chlordane.

The detection limits for other pesticides scanned, but not found in fish tissue, are given in Table 9.

Polynuclear aromatics were not detectable in fish tissue. Specific detection limits for the PNAs studied are given in Table 10.

Cyanide analysis was completed on fish samples for which a sufficient amount of sample existed for analysis. These results are given in Table 6.

Summary

Of the metals analyzed, only antimony, thallium and beryllium were, for the most part, below detection limits in Delaware River fishes. Arsenic was only found in channel catfish and white perch livers. Metal concentrations in muscle tissue were generally comparable between channel catfish and white perch, with the exception of selenium, which was higher in white perch. Generally, liver concentrations of metals were highest in white perch for arsenic, cadmium and nickel, and particularly for copper, zinc and selenium.

For organics the highest muscle concentrations of PCBs were found in channel catfish. Of the seven samples analyzed six exceeded the FDA Action Level. Similarly, the pesticides DDE and DDD were highest in the muscle tissue of channel catfish. Channel catfish liver tissue had the highest concentrations of

PCBs and pesticides. No PNAs were found in tissue samples, possibly as a result of their rapid metabolism in the water column by bacteria and fish.

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Table 1. Results of Delaware River fish muscle tissue analysis for trace metals. The first digit of the serial number indicates the fish species as follows: 1 = channel catfish, 2 = white catfish, 3 = brown bullhead and 4 = white perch.

	Dry Weight (mg/kg)											Wet Weight (mg/kg)
Serial #	Cd	Cr	Cu	Pb	Ni	Zn	As	Se	Sb	Tl	Be	Hg
NJD 1001	0.025	1.12	5.12	0.279	0.731	27.6	1.12	0.931	<0.5	<0.1	<0.01	0.0147
NJD 1002	0.028	2.13	2.50	0.176	1.50	27.0	1.11	0.832	<0.5	<0.1	<0.01	0.0077
NJD 1003	0.025	1.18	2.35	0.137	1.13	21.4	<0.6	1.08	<0.5	<0.1	<0.01	0.0077
NJD 1004	0.035	1.79	4.06	0.689	2.01	28.2	<0.6	0.849	<0.5	<0.1	<0.01	0.0133
NJD 1005	0.064	2.18	6.65	0.357	2.07	24.8	<0.6	0.893	<0.5	<0.1	<0.01	0.0093
NJD 1006	0.033	1.54	2.31	0.154	1.36	22.0	<0.6	0.865	<0.5	<0.1	<0.01	0.0025
NJD 1009	<0.02	6.92	7.66	1.11	1.54	23.8	<0.6	1.10	<0.5	<0.1	<0.01	0.0053
NJD 2007	0.150	2.61	61.6	3.70	3.39	53.3	<0.6	0.840	<0.5	<0.1	<0.01	0.0146
NJD 4001	0.054	2.56	7.60	0.300	1.15	30.1	0.820	4.06	<0.5	<0.1	<0.01	0.0452
NJD 4002	0.030	1.49	2.78	0.188	2.14	29.4	<0.6	4.56	<0.5	<0.1	<0.01	0.0474
NJD 4003	0.028	3.02	5.56	0.712	2.03	30.5	0.780	3.12	<0.5	<0.1	<0.01	0.0526
NJD 4004	0.038	1.00	2.80	0.310	1.45	31.6	0.800	3.80	<0.5	<0.1	<0.01	0.0195
NJD 4005	0.042	1.80	7.58	0.313	2.70	31.1	0.600	3.03	<0.5	<0.1	<0.01	0.0729
NJD 4006	0.027	2.19	3.05	0.238	1.67	25.5	1.14	3.24	<0.5	<0.1	<0.01	0.0254
NJD 4007	0.039	1.61	4.84	0.275	1.69	30.9	1.14	3.23	<0.5	<0.1	<0.01	0.0390
NJD 4008	0.035	0.97	2.71	0.242	1.49	23.6	0.969	3.39	<0.5	<0.1	<0.01	0.0306
NJD 4009	0.048	1.10	10.6	0.385	3.13	23.7	2.20	3.65	<0.5	<0.1	<0.01	0.0425
NJD 4010	0.104	1.38	2.26	0.187	1.19	27.4	1.18	3.88	<0.5	<0.1	<0.01	0.0415

Table 2. Results of Delaware River fish liver analysis for trace metals. The first digit of the serial number indicates the fish species as follows: 1 = channel catfish, 2 = white catfish, 3 = brown bullhead and 4 = white perch.

	Dry Weight (mg/kg)											Wet Weight (mg/kg)
Serial #	Cd	Cr	Cu	Pb	Ni	Zn	As	Se	Sb	Tl	Be	Hg
NJD 1101	0.612	1.50	12.0	1.28	0.70	104	0.600	10.8	<0.5	<0.1	<0.01	0.0459
NJD 1102	1.58	0.90	12.4	2.52	2.22	97.5	0.800	5.98	<0.5	<0.1	0.010	0.0223
NJD 1103	0.626	1.50	8.77	3.35	2.55	85.2	0.600	5.31	<0.5	<0.1	0.010	NS
NJD 1104	1.20	1.50	9.97	3.31	2.24	99.9	<0.6	10.4	<0.5	<0.1	0.010	0.0398
NJD 1105	0.684	0.70	6.80	2.68	0.77	65.6	<0.6	4.54	<0.5	<0.1	0.010	0.0284
NJD 1106	0.200	0.45	5.19	1.04	1.53	55.7	<0.6	5.15	<0.5	<0.1	<0.01	0.0171
NJD 1109	0.496	1.63	11.5	2.69	0.30	111	<0.6	10.5	<0.5	<0.1	<0.01	0.0321
NJD 2102	1.11	1.62	14.9	0.992	2.27	112	<0.6	13.9	<0.5	<0.1	<0.01	0.0688
NJD 2107	0.594	1.28	20.9	0.787	1.98	108	<0.6	12.2	<0.5	<0.1	<0.01	NS
NJD 3102	0.607	1.79	34.6	2.19	1.45	103	<0.6	11.6	<0.5	<0.1	<0.01	NS
NJD 3105	0.735	1.91	36.8	1.97	2.09	110	<0.6	12.3	<0.5	<0.1	<0.01	0.0177
NJD 4105	3.65	0.53	3089	1.35	3.96	172	1.42	119	<0.5	<0.1	0.018	NS
NJD 4505	8.63	1.36	5711	1.55	4.60	254	1.35	158	<0.5	<0.1	<0.01	NS

NS = No sample remaining

Table 3. Concentration (mg/kg dry weight) of heavy metals in tissues of fish collected in the 1980 Savannah River survey and in other rivers of the United States by The Academy of Natural Sciences of Philadelphia.

Waterbody	Common Name	No. Fish	Cadmium		Chromium		Copper		Nickel		Lead		Zinc		Reference
			Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	
Kennebec River (Maine)	Pumpkinseed	6	-	-	<0.01	-	-	<0.01-6.0	-	-	-	0.04-1.0	-	5-49	Friant, 1979
	Smallmouth bass	3	-	-	-	0.15-1.67	-	1.5-6.8	-	-	-	0.3-0.5	-	30-39	Friant, 1979
	Other (2)	6	-	-	-	<0.01-0.22	-	<0.01-6.1	-	-	-	0.04-1.3	-	16-75	Friant, 1979
Sabine River ** (Texas)	Blue catfish	8	<0.05*	<0.05	0.45*	<0.20-1.6	1.78	0.99-4.60	0.69	0.4-1.5	<0.4*	<0.4	27.4	15.5-48.1	ANSP, 1984a
	Channel catfish	6	<0.06*	<0.05-0.20	0.38*	<0.20-1.20	1.45	1.12-1.94	0.6	0.3-0.9	2.5*	<0.4-14	41.2	26.7-72.2	ANSP, 1984a
	Other (1)	15	0.052*	<0.050-0.10	0.295*	<0.20-0.60	1.746	0.84-3.80	0.668	0.3-1.9	2.675*	<0.4-20.0	23.85	14.9-35.3	ANSP, 1984a
Savannah River (Georgia)	Channel catfish	10	-	-	1.7*	<0.05-8.50	0.4*	<0.1-0.9	0.44*	<0.05-1.85	<0.05*	<0.05	13.1	1-21	ANSP, 1981
	Other (2)	21	0.028	0.02-0.375	1.0	0.95-1.05	3.72	3.31-4.13	0.933	0.883-0.983	6.64	3.98-9.3	-	-	ANSP, 1994b
	Other (2)	4	-	-	0.365*	<0.05-0.68	0.255	0.23-0.28	0.15*	<0.05-0.25	<0.05*	<0.05	6.0	5.0-7.0	ANSP, 1981
Susquehanna River (Pennsylvania)	Yellow bullhead	10	-	-	-	-	-	-	-	-	-	-	-	-	ANSP, 1984c
	Brown bullhead	5	-	-	1.39	-	12.7	-	8.5	-	3.61	-	-	-	ANSP, 1984c
	Channel catfish	5	-	-	0.92	-	8.7	-	1.5	-	36.2	-	-	-	ANSP, 1984c
	Rock bass	10	-	-	-	-	-	-	-	-	-	-	-	-	ANSP, 1984c
	Redbreast sunfish	5	-	-	1.46	-	21.0	-	5.5	-	1.5	-	5	-	ANSP, 1984c
	Pumpkinseed	5	-	-	1.26	-	14.0	-	2.9	-	0.2	-	-	-	ANSP, 1984c
	Smallmouth bass	20	-	-	0.28	0.63-4.78	16.7	7.7-38.5	21.9	2.1-75.2	0.27	0.2-0.46	-	-	ANSP, 1984c
	Smallmouth bass	90	-	-	0.23	0.09-0.738	1.041	0.144-1.880	0.86*	<0.015-9.064	0.07*	<0.015-0.671	-	-	ANSP, 1982
	Largemouth bass	5	-	-	5.73	-	28.4	-	3.9	-	31.3	-	-	-	ANSP, 1984c
	White crappie	5	-	-	1.14	-	9.0	-	8.9	-	2.9	-	-	-	ANSP, 1984c
	Black crappie	5	-	-	0.65	-	37.1	-	8.5	-	17.4	-	-	-	ANSP, 1984c
	Other (2)	90	-	-	0.352	0.343-0.362	1.158	1.153-1.164	0.888	0.738-1.038	0.0391	0.0276-0.051	-	-	ANSP, 1982
	Other (8)	40	-	-	1.89	0.98-2.64	12.46	6.8-22.7	20.65	2.3-71.1	4.275	0.2-19.0	-	-	ANSP, 1984c

* = Includes at least one value below detection limit.

** = Study area included effluent of organic chemical plant.

Table 4. Mean concentrations (mg/kg dry wt, except for Hg, which is mg/kg wet wt) of metals in Delaware River fish muscle tissue, by species.

Species	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Channel Cat.	0.53	0.03	2.41	4.38	0.0086	1.48	0.41	0.94	25
White Perch	0.99	0.04	1.71	4.98	0.0417	1.86	0.32	3.60	28

Table 5. Mean concentrations (mg/kg dry wt, except for Hg, which is mg/kg wet wt) of metals in Delaware River fish livers, by species.

Species	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Br. Bullhead	0.30	0.67	1.85	35.7	0.0177	1.77	2.08	11.95	106
Channel Cat.	0.46	0.77	1.17	9.5	0.0309	1.47	2.41	7.53	88
White Catfish	0.30	0.85	1.45	17.9	0.0688	2.13	0.90	13.05	110
White Perch	1.39	6.14	0.95	4400	NS	4.28	1.45	139	213

NS = no sample.

Table 6. Summary of tissue concentrations (mg/kg) of organics in Delaware River fish.

Serial Number	Aroclor 1254	Aroclor 1260	Total PCB[a]	DDE[b]	DDD[b]	CN
1001	3.022	1.176	4.198	1.557	0.468	1[c]
1002	1.336	0.217	1.553	0.464	0.258	1.0
1003	2.575	1.026	3.601	0.905	0.360	1[c]
1004	1.718	0.626	2.344	1.454	0.440	1[c]
1005.1[d]	2.490	0.754	3.244	2.215	0.856	1[c]
1005.2[d]	3.158	1.275	4.433	2.151	1.118	
1006.1[d]	2.004	0.540	2.544	0.965	0.355	1[c]
1006.2[d]	2.355	0.500	2.855	0.678	0.270	
1009.1[d]	2.522	1.022	3.544	0.940	0.372	1[c]
1009.2[d]	1.354	0.684	2.038	0.692	0.358	
1101	0.335	0.100	0.335	0.067	0.011	
1102	1.316	0.250	1.566	0.406	0.164	
1103	0.100	0.100	0.100	0.263	0.071	
1104	0.538	0.226	0.764	0.280	0.087	
1105.1[d]	1.320	0.371	1.691	0.736	0.250	
1105.2[d]	1.420	0.422	1.842	0.664	0.213	
1106	0.100	0.100	0.100	0.059	0.016	
1109	1.427	0.938	2.365	0.152	0.076	
2007	0.600	0.161	0.761	0.545	0.162	1.3
2102	0.100	0.100	0.100	0.118	0.005	
2107	0.353	0.100	0.353	0.200	0.062	
3102	0.100	0.100	0.100	0.005	0.005	
3105	0.558	0.108	0.766	0.278	0.111	
4001	0.315	0.094	0.409	0.144	0.045	1[c]
4002	0.100	0.100	0.100	0.035	0.005	1[c]
4003	0.285	0.100	0.285	0.208	0.060	1[c]
4004	0.794	0.326	1.120	0.476	0.301	1[c]
4005	0.563	0.176	0.739	0.464	0.153	1.0
4006	0.588	0.401	0.989	0.400	0.113	1[c]
4007	1.336	0.393	1.729	0.834	0.308	1[c]
4008	0.986	0.209	1.195	0.595	0.242	1.0
4009	0.934	0.251	1.185	0.688	0.200	1[c]
4010	1.035	0.371	1.406	0.606	0.234	1.2
4105	3.085	2.515	5.600	2.060	0.725	
4505	1.516	0.569	2.085	1.527	0.438	

[a] Detection limit for PCBs = 0.100 mg/kg.
[b] Detection limit for DDE and DDD = 0.005 mg/kg.
[c] Below detection of 1 mg/kg.
d Serial numbers with decimals are replicate extractions.

Table 7. Mean concentrations (mg/kg) of organics in Delaware River fish muscle tissue, by species.

Species	Aroclor 1254	Aroclor 1260	Total PCB	DDD	DDE
Channel Catfish	2.253	0.782	3.035	0.486	1.202
White Catfish	0.600	0.161	0.761	0.162	0.545
White Perch	0.689	0.232	0.911	0.166	0.445

Table 8. Mean concentrations (mg/kg) of organics in Delaware River fish livers, by species.

Species	Aroclor 1254	Aroclor 1260	Total PCB	DDD	DDE
Brown Bullhead	0.304	0.079	0.408	0.057	0.140
Channel Catfish	0.807	0.295	1.083	0.111	0.328
White Catfish	0.202	<0.10	0.202	0.032	0.159
White Perch	2.301	1.542	3.843	0.582	1.794

Table 9. Detection limits for chlorinated pesticides in fish tissue.

Compound	Detection Limit ug/kg
Lindanes	5
Heptachlor	5
Aldrin	5
Heptachlor epoxide	5
Endosulfan I	5
DDE	10
Dieldrin	10
Endrin	10
DDD	10
Endosulfan II	10
DDT	20
Endrin aldehyde	20
Endosulfan sulfate	20

Table 10. Detection limits for PNAs in fish tissue.

Compound	Detection Limit ug/kg
Napthalene	62.5
Acenaphthylene	62.5
Acenaphthene	62.5
Fluorene	62.5
Phenanthrene	62.5
Anthracene	62.5
Fluoranthene	125
Pyrene	125
Benzo(a)anthracene	125
Chrysene	125
Benzo(b)fluoranthene	250
Benzo(k)fluoranthene	250
Benzo(a)pyrene	250
Indeno(123)pyrene	250
Dibenzo(ah)anthracene	250
Benzo(h)perylene	250

APPENDIX

U.S. Environmental Protection Agency method for the analysis of fish for cyanide.

APPENDIX

Analysis of Fish for Cyanide

1. Scope and Application

   1.1 This method is used for the determination of cyanide in fish. All samples must be distilled prior to the analytical determination. For cyanide levels exceeding 0.2 mg/200 ml of absorbing liquid, the silver nitrate titrimetric method is used. For cyanide levels below this value, the colorimetric procedure is used.

2. Sample Preparation

   2.1 A 5g portion of the frozen, ground fish (see "Sample Handling") is used for the analysis. The sample should be thawed before the analysis begins.

3. Preparation of Calibration Curve

   3.1 The calibration curve is prepared from values for portions of spiked fish tissue distilled in the manner used for the tissue sample being analyzed. For preparation of the calibration standards, choose and weigh a 50g portion of fish and blend in a Waring blender (or equivalent) with 10 ml of 10% NaOH and sufficient deionized, distilled water to bring the volume of the mixture to 500 ml.

   3.2 Using a volumetric pipet which has had the tip removed, withdraw eight 50 ml portions and place in a series of 1 liter boiling flasks. Seven of the flasks should be spiked with progressively larger volumes of the cyanide standard as given in 8.7 (Method 335.2), Reference 7. Adjust the final volume of each flask to 500 ml with deionized, distilled water.

3.3 Add 50 ml of 5% NaOH solution to the absorbing tube and dilute, if necessary, with deionized distilled water to obtain an adequate depth of liquid in the absorber. Connect the boiling flask, condenser, absorber, and trap in the train as shown in Figure 1 (Method 335.2), Reference 7.

3.4 Continue with step 8.2 through 8.6 (Method 335.2), Reference 7.

3.5 The calibration curve is prepared by plotting the absorbance versus the cyanide concentration. The blank absorbance value must be subtracted from each value before plotting the curve.

4. Sample Procedure

4.1 Place a weighed portion of the ground fish (approximately 5g) in a blender with 100 ml of deionzized, distilled water and 1 ml of 5% NaOH solution.

4.2 Blend until a homogeneous mixture is obtained and transfer to a 1-liter boiling flask. Rinse the blender with several portions of deionized, distilled water totaling 400 ml and add to the boiling flask.

4.3 Add 50 ml of 5% NaOH solutuion to the absorbing tube and dilute if necessary with deionized, distilled water to obtain an adequate depth of liquid in the absorber. Connect the boiling flask, condenser, absorber, and trap in the distillation train as shown in Figure 1 (Method 335.2) and continue with step 8.2 through 8.6, Reference 7.

4.4 Read the absorbance and determine the cyanide concentration from the calibration curve.

5. Quality Assurance

5.1 Initially, demonstrate quantitative recovery with each distillation digestion apparatus by comparing distilled aqueous standards to non-distilled aqueous standards. Each day, distill at least one standard to confirm distillation efficiency and purity of reagents.

5.2 At least 15% of the cyanide analyses should consist of duplicate and spiked samples. Quality control limits should be established and confirmed as described in Chapter 6 of the "Analytical Quality Control Handbook," Reference 4.

6. Reporting of Data

6.1 Report cyanide concentrations as follows: less than 1.0 mg/kg, to the nearest 0.01 mg; 1.0 mg/kg and above, to two significant figures.

6.2 Report all quality control data with the analytical results for the samples.

APPENDIX

TABLE I

Priority Pollutants Analyzed by Soxhlet Extraction

Pesticides

Aldrin	DDD	Endosulfan sulfate
a-BHC	DDE	Endrin
b-BHC	DDT	Endrin aldehyde
d-BHC	Dieldrin	Heptachlor
g-BHC	Endosulfan - I	Heptachlor epoxide
Chlordane	Endosulfan -II	Toxaphene

PCBs

Arocler 1016	Arocler 1242	Arocler 1254
Arocler 1221	Arocler 1248	Arocler 1260
Arocler 1232		

Non-polar Neutrals

Acenaphthylene	1,3-dichlorobenzene	Bis (2-ethylhexyl) phthalate
Acenaphthene	1,4-dichlorobenzene	Benzo (a) anthracene
Isophorone	Hexachloroethane	Benzo (b) fluoranthene
Fluorene	1,2-dichlorobenzene	Benzo (k) fluoranthene
Phenanthrene	Hexachlorobutadiene	Benzo (a) pyrene
Anthracene	1,2,4-trichlorobenzene	Indeno (1,2,3-cd) pyrene
Dimethylphthalate	2,6-dinitrotoluene	Dibenzo (a,h) anthracene
Diethylphthalate	Hexachlorobenzene	Benzo (ghi) perylene
Fluoranthene	4-bromophenyl phenyl ether	4-chlorophenyl phenyl ether
Pyrene	Bis (2-chloroethoxy) methane	2,3,7,8-tetrachlorodibenzo-p-dioxin
Naphthalene	2-chloronaphthalene	Di-n-butylphthalate
Chrysene		Butyl benzylphthalate

Table II Base-neutral Extractables

Compound Name	RRT[1] (hexachloro-benzene)	Limit of Detection (ng)	Characteristic EI ions (Rel. Int.)	CI ions (Methane)
1,3-dichlorobenzene	0.35	40	146(100), 148(64), 113(12)	146, 148, 150
1,4-dichlorobenzene	0.36	40	146(100), 148(64), 113(11)	146, 148, 150
hexachloroethane	0.38	40	117(100), 199(61), 201(99)	199, 201, 203
1,2-dichlorobenzene	0.39	40	146(100), 148(64), 113(11)	146, 148, 150
bis(2-chloroisopropyl) ether	0.47	40	45(100), 77(19), 79(12)	77, 135, 137
hexachlorobutadiene	0.55	40	225(100, 223(63), 227(65)	223, 225, 227
1,2,4-trichlorobenzene	0.55	40	74(100), 109(80), 145(52)	181, 183, 209
naphthalene	0.57	40	128(100), 127(10), 129(11)	129, 157, 169
bis(2-chloroethyl)ether	0.61	40	93(100), 63(99), 95(31)	63, 107, 109
hexachlorocyclopentadiene	0.64	40	237(100), 235(63), 272(12)	235, 237, 239
nitrobenzene	0.64	40	77(100), 123(50), 65(15)	124, 152, 164
bis(2-chloroethoxy)methane	0.68	40	93(100), 95(32), 123(21)	65, 107, 137
2-chloronaphthalene	0.76	40	162(100), 164(32), 127(31)	163, 191, 203
acenaphthylene	0.83	40	152(100), 153(16), 151(17)	152, 153, 181
acenaphthene	0.86	40	154(100), 153(95), 152(53)	154, 155, 183
isophorone	0.87	40	82(100), 95(14), 138(18)	139, 167, 178
fluorene	0.91	40	166(100), 165(80), 167(14)	166, 167, 195
2,6-dinitrotoluene	0.93	40	165(100), 63(72), 121(23)	183, 211, 223
1,2-diphenylhydrazine	0.96	40*	77(100), 93(58), 105(28)	185, 213, 225
2,4-dinitrotoluene	0.98	40	165(100), 63(72), 121(23)	183, 211, 223
N-nitrosodiphenylamine	0.99	40*	169(100), 168(71), 167(50)	169, 170, 198
hexachlorobenzene	1.00	40	284(100), 142(30), 249(24)	284, 286, 288
4-bromophenyl phenyl ether	1.01	40	248(100), 250(99), 141(45)	249, 251, 277
phenanthrene	1.09	40	178(100), 179(16), 176(15)	178, 179, 207
anthracene	1.09	40	178(100), 179(16), 176(15)	178, 179, 207
dimethylphthalate	1.10	40	163(100), 164(10), 194(11)	151, 163, 164
diethylphthalate	1.15	40	149(100), 178(25), 150(10)	177, 223, 251
fluoranthene	1.23	40	202(100), 101(23), 100(14)	203, 231, 243
pyrene	1.30	40	202(100), 101(26), 100(17)	203, 231, 243
di-n-butylphthalate	1.31	40	149(100), 150(27), 104(10)	149, 205, 279
benzidine	1.38	40*	184(100),92(24), 185(13)	185, 213, 225
butyl benzylphthalate	1.46	40	149(100), 91)50)	149, 299, 327

Table II Base-neutral Extractables (Cont'd.)

Compound Name	RRT[1] (hexachloro-benzene)	Limit of Detection (ng)	Characteristic EI ions (Rel. Int.)	CI ions (Methane)
chrysene	1.46	40	228(100), 229(19), 226(23)	228, 229, 257
bis(2-ethylhexyl)phthalate	1.50	40	149(100), 167(31), 279(26)	149
benzo(a)anthracene	1.54	40	228(100), 229(19), 226(19)	228, 229, 257
benzo(b)fluoranthene	1.66	40	252(100), 253(23), 125(15)	252, 253, 281
benzo(k)fluoranthene	1.66	40	252(100), 253(23), 125(16)	252, 253, 281
benzo(a)pyrene	1.73	40	252(100), 253(23), 125(21)	252, 253, 281
indeno(1,2,3-cd)pyrene	2.07	100	276(100), 138(28), 277(27)	276, 277, 305
dibenzo(a,h)anthracene	2.12	100	278(100), 139(24), 279(24)	278, 279, 307
benzo(g h i)perylene	2.18	100	276(100), 138(37), 277(25)	276, 277, 305
N-nitrosodimethylamine			42(100), 74(88), 44(21)	
N-nitrosodi-n-propylamine			130(22), 42(64), 101(12)	
4-chloro-phenyl phenyl ether			204(100), 206(34), 141(29)	
endrin aldehyde				
3,3'-dichlorobenzidine			252(100), 254(66), 126(16)	
2,3,7,8-tetrachlorodibenzo-p-dioxin			322(100), 320(90), 59(95)	
bis(chloromethyl)ether			45(100), 49(14), 51(5)	
deuterated anthracene (d10)	1.09	40	188(100), 94(19), 80(18)	189, 217

[1] 1% SP-2250 on 100/120 mesh Supelcoport in a 6' x 2 mm id glass column; He @ 30 ml/min; Program: 50° for 4 min, then 8°/min to 260° and hold for 15 min.

* Conditioning of column with base is required.

Table III Acid Extractables

Compound Name	RRT[1] (2-nitrophenol)	Limit of Detection (ng)	Characteristic EI ions (Rel. Int.)	CI ions (Methane)
2-chlorophenol	0.63	100	128(100), 64(54), 130(31)	129, 131, 157
phenol	0.66	100	94(100), 65(17), 66(19)	95, 123, 135
2,4-dichlorophenol	0.96	100	162(100), 164(58), 98(61)	163, 165, 167
2-nitrophenol	1.00	100	139(100), 65(35), 109(8)	140, 168, 122
p-chloro-m-cresol	1.05	100	142(100), 107(80), 144(32)	143, 171, 183
2,4,6-trichlorophenol	1.14	100	196(100), 198(92), 200(26)	197, 199, 201
2,4-dimethylphenol	1.32	100	122(100), 107(90), 121(55)	123, 151, 163
2,4-dinitrophenol	1.34	2 µg	184(100), 63(59), 154(53)	185, 213, 225
4,6-dinitro-o-cresol	1.42	2 µg	198(100), 182(35), 77(28)	199, 227, 239
4-nitrophenol	1.43	100	65(100), 139(45), 109(72)	140, 168, 122
pentachlorophenol	1.64	100	266(100), 264(62), 268(63)	267, 265, 269
deuterated anthracene (d10)	1.68	40	188(100), 94(19), 80(18)	189, 217

[1] Column: 6' glass, 2 mm i.d.
Tenax GC - 60/80 mesh
180^{0} - 300^{0} @ 8^{0}/min.
He @ 30 ml/min

APPENDIX

Metals in Fish

Fish fillets are dried in a 60C oven. One gram of dried muscle tissue is placed in a 100ml beaker with 30ml of Instra-analyzed grade nitric acid, covered with a watch glass, heated on a hot plate at 95C and refluxed for 2hrs. The digestion solutions are evaporated until 3-5mls of acid remain, transferred to a 100ml volumetric flask and taken to volume with 0.5% HNO_3. Metal concentrations are determined with a Perkin Elmer Model Zeeman 5000 Atomic Absorption Spectrophotometer (Perkin Elmer, 1982).

BLANKS

Incorporation of blank samples (distilled water or solvent) into the general sample pool is necessary to assess contamination levels. Blanks for each sample container type and sample handling procedure are introduced into the sample pool as early as possible and analyzed at a frequency of 5% of the total number of samples.

PRECISION, ACCURACY, CALIBRATION

For routine chemical analysis conducted in the Academy's field or main laboratories the following QC checks apply:

1. minimum of 10% replicate samples;
2. minimum of 5% spiked samples;
3. measurement of known reference solutions that are within the range of values expected for the real samples;
4. calibration curves must have at least one blank;
5. there must be at least three (organic) or five (inorganic) standards;
6. reference sample results must be within the acceptable range.

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