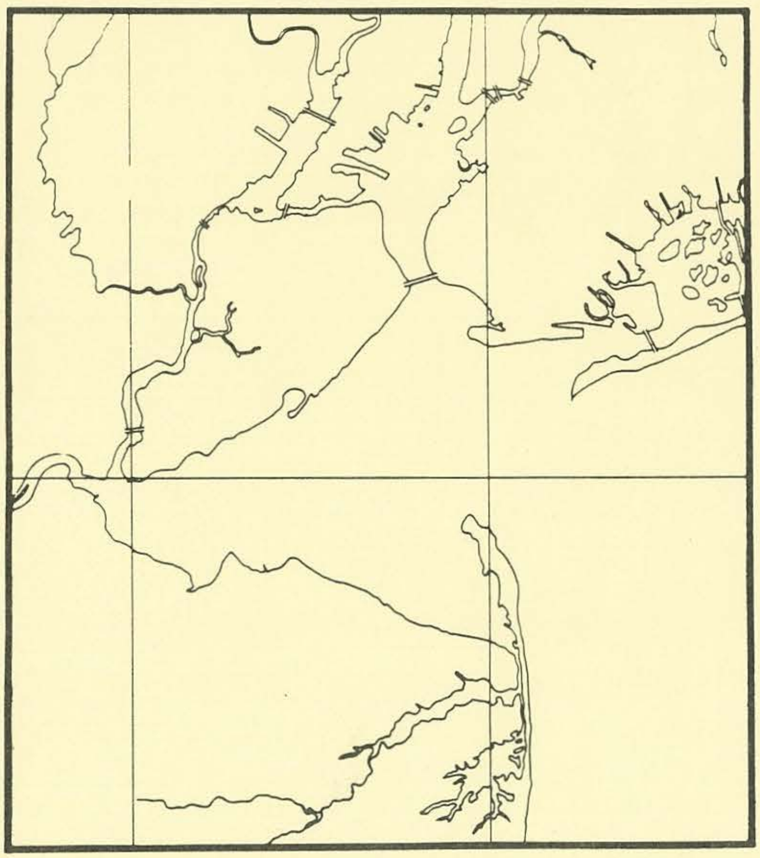
NOAA Estuary-of-the-Month

Seminar Series No. 9

Hudson/Raritan Estuary: Issues, Resources, Status, and Management

June 1988



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NOAA Estuarine Programs Office

NOAA Estuary-of-the-Month
Seminar Series No. 9

Hudson/Raritan Estuary: Issues, Resources, Status, and Management

Proceedings of a Seminar
Held February 17, 1987
Washington, D.C.

U.S. DEPARTMENT OF COMMERCE
C. William Verity, Secretary

National Oceanic and Atmospheric Administration
William E. Evans, Under Secretary

NOAA Estuarine Programs Office
Virginia K. Tippie, Director

The NOAA Estuarine Programs Office

presents

AN ESTUARY-OF-THE-MONTH-SEMINAR
<u>HUDSON/RARITAN ESTUARY</u>
ISSUES, RESOURCES, STATUS, AND MANAGEMENT

February 17, 1987

U.S. Department of Commerce
14th and Constitution Avenue, N.W.
Washington, D.C.

<u>TABLE OF CONTENTS</u>

PREFACE

These proceedings represent the presentations made at a seminar on the Hudson/Raritan Estuary held on February 17, 1987, at the Herbert C. Hoover Building of the U.S. Department of Commerce in Washington, D.C. It was one of a continuing series of "Estuary-of-the-Month" seminars sponsored by the NOAA Estuarine Programs Office (EPO), held with the objective of bringing to public attention the important research and management issues in our Nation's estuaries. To this end, the seminar first presented an overview of the Estuary including the geology, the biological resources, diseases, contaminants by senior scientific investigators, followed by an examination of management issues by leaders of planning and regulatory agencies involved in the Bay.

The Estuarine Programs Office wishes to thank Dr. J. B. Pearce, who coordinated this effort, and all those who gave their time to travel to the meeting, prepare their papers, and comment on the final edited versions.

CHANGING PATTERNS OF BIOLOGICAL RESPONSES TO POLLUTION IN THE NEW YORK BIGHT

John B. Pearce

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Center
Woods Hole Facility
Woods Hole, MA 02543

1. Introduction

To manage habitat quality in an urbanized region such as metropolitan New York City, it is necessary to conduct research on biological effects. Temporal and spatial changes in habitat quality which have occurred in the New York Bight and contiguous estuarine and continental shelf waters over the past several decades must be understood through assessments using recent and historical data; such assessments are essential to management which is based on a multiple use concept.

Portions of the estuarine and marine coastal waters of the Northeast (NE) region of the United States, from the Canadian Border to Cape Hatteras, are among the most heavily polluted and physically degraded of any in the United States. Their status has been reviewed in a series of papers (Larson and Doggett, 1979; Lippson and Lippson, 1979; Maurer, 1979; McCarthy et al., 1979; Pearce, 1979, 1980; Phelps, 1979; and Reid, 1979) presented to the International Council for the Exploration of the Seas (ICES). Specific indicators of the degree of degradation of the Middle Atlantic Bight areas include: apparent increase in frequency and intensity of algal blooms; abnormal depletion of summer dissolved oxygen (DO) in the vicinity of dumpsites and along extensive stretches of coast line; increases in heavy metals in biota, including commercially important species such as the surf clams, as well as in sediments and water; closures of offshore surf clam/ocean quahog beds because of bacterial contamination; and closure of finfish fisheries because of PCB contamination in tissues of bluefish, striped bass, and other species. Differences in the incidence of certain fish and crustacean disease syndromes have been reported in polluted and unpolluted regions of the Bight.

Stimulation of phytoplankton productivity by nutrients carried from riverine systems such as the Hudson and the Delaware have been reported. Recent studies indicate that genetic mechanisms of marine fishes are being affected by surface water pollution and this may reduce the viability of eggs and larvae (Longwell, 1976).

Wherever such effects have been observed they seem to have resulted not from a single type or source of pollution but rather from a multiplicity of pollutants or insults, ranging from terrestrial runoff and atmospheric inputs to estuarine and coastal waters to massive ocean dumping and effluent discharges at specific points. Regions experiencing significant biological changes usually are located in close proximity to a densely populated or heavily industrialized urban area (Fig. 1). The case-by-case approach to studying pollution effects is being reconsidered with emphasis placed on cumulative impact assessment (Dickert and Tuttle, 1985).

The following situations have been noted in several areas of the middle Atlantic U.S. coastline and invariably these responses can be related to overwhelming levels of pollutants of several kinds:

1.1 Changes in biological productivity and fish distribution and consequent loss of living resources.

1.2 Degradation or loss of estuarine and offshore benthic habitats.

1.3 Diminished economic value of fish and shellfish because of:

1.3.1 contaminant burdens in flesh;

1.3.2 human pathogens in seafood, sediments and water; and

1.3.3 areas closed to fishing.

1.4 Diminished aesthetics associated with fishing and the coastal zone.

1.5 Unknown efficacy of regulatory actions and pollution abatement activities in terms of improving the health of the coastal environment.

1.6 Unknown extent and rate of impact on coastal and shelf habitats by seaward flow of polluted estuarine and riverine waters.

Many changes in habitat and resource quality are not recent. As is indicated in Figure 2, one of the first-documented changes involved tainting of seafood (oysters and shad) occurred in Newark Bay due to coal oil (kerosene), at about the time of the U.S. Civil War (Goode, 1887). By World War I estuarine waters of New York Harbor and lower Hudson River were so contaminated that fish could not be held in estuarine water pumped from an area off Battery Park to the New York Aquarium (Townend, 1917). At about the same time, Nelson (1916) reported that industrial wastes discharged into Raritan Bay resulted in declines in shellfish populations then found in the Bay. He predicted that these contaminants, in particular copper, would cause the collapse of the oyster fishery; this occurred within a few decades. In the early 1920's, shellfish biologists noted that the abundance and diversity of the molluscan fauna had declined. This was attributed to increased urbanization and contamination by gasoline and other wastes (Jacot, 1920).

Between the 1920's and early 50's, relatively few published studies of environmental quality and impacts of contaminants on estuarine and marine species were conducted in the Bight. Hence there is a sparse record to indicate precisely when major biological responses occurred in relation to ever increasing studies commenced in the New York Bight off the Hudson-Raritan Bay complex to document the effects of ocean dumping of contaminated dredged material, industrial wastes, and sewage sludge. Some of the first results from these studies (Pearce, 1972) indicated that ocean dumping had had an effect on habitat quality, benthic communities, and various populations of shellfish and finfish. These results were later confirmed in subsequent, more intensive investigations of the Bight (Swanson, 1977). The paragraphs following are drawn from studies which have been conducted during the past decade and, along with the brief foregoing historical resume, provide insight into how marine populations and communities have responded to pollution loading through time and space.

2. Raritan Bay and the New York Bight; the Physical/Chemical Environment

As noted in the papers by Pearce (1979, 1980) and others, the lower Hudson River and Newark and Raritan Bays constitute the most intensively developed and industrialized estuary on the U.S. east coast. The effects of pollution in the Bay have spread seaward into the Bight through nonpoint sources and runoff, terrigenous export, ocean dumping of dredged materials and sewage sludge, and disposal of industrial wastes. A massive oxygen depletion episode occurred in 1976 and this event plus subsequent mortalities of benthic and demersal organisms recently have been summarized and documented in Swanson and Sindermann (1979); earlier research indicated locally deteriorated conditions of the Bight in regard to reduced oxygen (Pearce, 1972).

2.1 The physical/chemical condition of Raritan Bay and the Bight

In a summary report published in 1967 (Federal Water Pollution Control Administration, 1967), it was noted that shellfish in Raritan Bay were so contaminated by phenols and mineral oils "as to render them unsuitable for market". Nevertheless, few quantitative studies of the degree of contamination of the biota and their habitats have subsequently been made. Recently shellfish, finfish, and elements of the physical environment have been analyzed to establish baselines for levels of certain organic compounds and toxic heavy metals. Moreover, it has been frequently suggested as important that the routes of transport of contaminants (sources and fates) and their residence times within various portions of the ecosystem be well understood.

2.1.1 Hydrography. Jefferies (1959, 1962) summarized the movements of water in Raritan Bay and into the Bight. It was recognized that there is an eddy off the south shore of Staten Island which effectively separates the flows of the Raritan and Hudson Rivers within major parts of the Bay. Thus, the principal sources of riverine waters are Raritan River in the western end of the Bay and the Hudson River inflow from the northeast (Fig. 3). Ayers et al. (1949) suggested a slow seaward drift which involved mixing of outflowing waters with incoming masses, and little opportunity for significant flushing with each tidal cycle. Jeffries (1962) estimated a flushing time of 32-42 tidal cycles, or 16-21 days. Such prolonged residence time of water masses tends to retard dilution with estuarine, riverine, and oceanic waters, thereby pollutants which enter the embayment.

2.1.2 Heavy metals. Greig and McGrath (1977) reported on six heavy metals in Raritan Bay sediments. They noted that high values for all metals were found at stations located in the central, organically enriched, portion of the Bay with lower, but still elevated values, in shallow waters to the northeast and south of the central east-west axis (Fig. 4).

Waldhauer et al. (1978) measured the amounts of copper and lead in waters of Raritan and Lower New York Bays. Their determinations indicated concentrations of Cu (65 ugl^{-1}) among the highest reported to date for estuarine waters; lead values of 13.9 ugl^{-1} were found.

High values of metals in such embayments not only are of local significance but, obviously, water moving seaward can carry entrained dissolved and suspended substances to other habitats. Moreover, contaminated sediments are regularly removed from ship channels (Pearce, 1979a) to maintain their depth; such wastes are then deposited offshore. Elevated metal values have been measured regularly at the sewage sludge and dredged material disposal sites in the New York Bight apex (Carmody et al., 1973) (Fig. 5). Their research indicates that elevated levels of metals are to be found up to 60 kilometers southeast of the dumpsites; it is suggested that the metals are carried seaward in the Hudson Shelf Valley.

2.1.3 Extractable organics and hydrocarbons. Stainken et al. (1983) and Koons and Thomas (1979) have reported on petroleum hydrocarbons (HC) in sediments from Raritan Bay and adjucent waterways. As with metals, greatly elevated values of extractable HC tended to be associated with the highly organic sediments in the central portions of the Bay, although elevated values were found at other stations sampled. Stainken (1979) suggested a movement or transport of sediments and associated HC to the central area of the Bay.

Koons and Thomas (1979) found the highest HC values for sediment samples collected in riverine habitats or where rivers emptied into the Bay (Fig. 6). As with metals the dredging material disposal area in the Bight contained large amounts of HC. This, again, indicates that contaminants accumulating in estuarine sediments can affect offshore habitats when dredging occurs and dredged materials are dumped offshore or suspended materials are carried entrained in currents to be deposited offshore in settling areas such as the Christiaensen Basin.

Searl, et al. (1977) measured the amounts of HC in New York Harbors waters, including Raritan Bay (Fig. 7). They found the average concentration of extractable nonvolatile HC, measured over a 6-month period in New York Harbor, to be 39 ug/1. This concentration was about the same found in Boston Harbor, the same as Tokyo Harbor, and greater than at the entrance to San Francisco Harbor. An extended study of the entire New York Harbor showed gradients of decreasing concentration progressing from Newtown Creek, to the East River, the Narrows, and to the entrance of the harbor. Gradients also exist between Kill Van Kull and the Upper Bay, and Arthur Kill and the Lower Bay. These were among the first measurements in New York Harbor and the authors noted that they will be useful as baseline data of interest to those testing the effects of HC on marine life.

3. The Response of Biota to Pollution

Several recent papers have discussed the various biological components of the New York Bight and Raritan Bay ecosystems. These have ranged from descriptions of microbial community structure and function through discussions of primary productivity and benthic community structure. In many instances, the papers have emphasized the effects of pollutants and the responses of organisms to contaminant loading.

3.1 Microorganisms.

Until recently, there were few studies of microbial communities and populations in sediments of these waters. In the early 1960s, public health biologists reported finding elevated numbers of indicator bacteria in the Bight where sludge was being dumped (Bigelow, 1968). Subsequently, Babinchak et al. (1977) investigated various bacteria isolated from marine sediments collected from the Bight. Koditschek and Guyre (1974) studied the resistance of coliform bacteria collected from dumping grounds in the Bight to antibiotics and heavy metals. They noted that while the levels of metals in sediments from the dredged material disposal areas would normally preclude microorganisms, selective pressures favored the survival of resistant bacteria. This was of concern because of the possible development of strains resistant to antimicrobial substances and the eventual transport of such organisms to marine organisms used for human consumption.

Timoney and Port (1979) continued this line of research in the Bight apex and suggested that an increase in the gene pool for antibiotic resistance would have importance in genera such as *Escherichia*, *Pseudomonas*, and *Vibrio*. These bacteria can function as pathogens and their presence in seafoods, especially if they are resistant, could have effects on humans who might consume improperly collected or prepared foodstuffs. Timoney and Port (1979) also suggested that bacteria resistant to certain metals, including mercury, could play an important role in "promoting the mobilization and loss of elemental mercury from sediments into the water colum where it would be diluted and dispersed".

Atlas and Bartha (1973) intensively investigated oil degrading microorganisms in Raritan Bay and reported that their distribution showed a marked relationship to influx of oil from Arthur Kill. Studies on benthic microflora (Litchfield et al. 1976) indicate wide spatial differences in the bacterial flora sediments from the Bay.

Subsequently, personnel of the Oxford Laboratory (Maryland), National Marine Fisheries Service, investigated the distribution and abundance of potentially pathogenic protozoans in relation to pollution gradients in New York Bight dumping grounds as well as heavily contaminated estuaries such as the inner reaches of Narragansett Bay (Sawyer, 1974; 1976; Saywer et al., 1977). Their more recent research conducted in 1980 indicated a close association between the presence of indicator coliform bacteria and potentially pathogenic protozoans, including the pathogen, Acanthamoeba hatchetti (Sawyer, personal communication).

3.2 Phytoplankton and primary productivity.

Patten (1962) described the species diversity of net phytoplankton in Raritan Bay, noting that "diversity increased downbay in association with diminishing pollution". He further stated that diatoms dominated during coldwater periods, while the nannoplankton (<64 u) were dominant during warmer seasons. His statements and discussions were based upon research conducted in 1957-58.

Two decades later O'Reilly, Thomas, and Evans (1976) conducted studies of the annual primary production cycle in Lower New York and Raritan Bays. The authors found that annual primary production in this highly polluted estuary was 817 $gC/m^2/yr$ (the greatest value recorded to date in the world), with 67% of the annual production due to synthetic activities by nannoplankton and only 18% by netplankton or diatoms. Over 15% of total photoassimilated carbon was released as dissolved organic matter (DOM). The consequences of such shifts from predominantly netplankton dominated populations to the smaller cells of nannoplankton populations are only now becoming appreciated. Ninivaggi (1979), in a very preliminary report, notes that work ongoing at the State University of New York, Stony Brook, indicated that certain species of copepods cannot feed effectively on nannoplankton; their filtering appendages do not allow adequate collection or retention of smaller phytoplankton cells. He speculated that, "in addition to potentially reducing food resources (copepods) for finfish, the reduced consumption of small algae by copepods may partially account for reduced amounts of DO (a basic measure of water quality) in Long Island Sound waters, as a result of the decay of uneaten phytoplankton". The same may hold true for Raritan Bay.

Moreover, the release of DOM will exacerbate further the situation since these materials are not readily available to zooplankton and most of the benthos, except through direct uptake as postulated by Stephens (1964); DOM is largely available only for reduction by bacteria and other microorganisms, further reducing levels of DO available to metazoans. Kawamura (1962), in his earlier report on the phytoplankton populations of Sandy Hook Bay, noted the reduced levels of DO in bottom waters, even in June.

Another major problem reported to occur in the southern portion of the Bight is the clogging of fishing gear, apparently as a result of extensive blooms of the diatom, <u>Cosinodiscus</u> <u>wailesii</u> (Mahoney and Steimle, 1980). The efficiency of fishing nets was reduced and lines and nets were difficult to handle because of the slime, thus further affecting fisheries.

3.3 Zooplankton distribution and abundance.

Yamazi (1962) and Jeffries (1964) reported on the zooplankton of Sandy Hook and Raritan Bays. The former paper describes the distribution of zooplankton in relation to the hydrographic conditions in Sandy Hook Bay in May and June of 1962. Yamazi noted the dominant mero- and holoplankton and observed that minor constituents of the plankton were immigrants from the open sea. This latter phenomenon was elaborated upon further by Jeffries (1962) in his work on indicator species.

Jeffries (1964) considered the zooplankton in a study to determine the effects of local pollution abatement in Raritan Bay which resulted when a regional trunk sewer began discharging treated sewage; previously this material had been discharged into the head of the Bay with little or no treatment. The holoplankton of the Bay was dominated by Acartia clausi in the winter and spring and by A. tonsa in the summer and fall. Eurytemora spp. was dominant in waters of reduced salinity (5-15%), in winter and spring.

The meroplankton of Raritan Bay was characterized by largè numbers of larval Polydora spp. (Yamazi, 1962; Jeffries, 1964), a polychaete worm favoring organically enriched environments as result of pollution. Jeffries (1964) noted a paucity of decapod crustacean larvae and attributed the sparseness of lamellibranch larvae to high concentrations of organic debris in the water column. He suggested further that the relative proportions of major groups of zooplankton, especially larvae of benthic invertebrates, indicated "artificial complications" due to pollution.

3.4 Distribution and abundance of benthic invertebrates.

In addition to the terrigenous export of pollutants via Hudson River outflow (1 $\times 10^9$ gal/day), each year millions of tons of solid and semisolid wastes are barged offshore and dumped at designated sites in the New York Bight. During recent years, approximately 5 million cubic yards of sewage sludge and 6-11 million cubic yards of dredged material have been dumped each year. Several other categories of wastes have been disposed of in large amounts in the Bight. As noted in section 1.2 these disposal operations have had a noticeable effect on benthic-dwelling invertebrates and the physical/chemical nature of the sediments; the extensive beds of sewage sludge and dredged material that have formed as a result of ocean dumping are characterized by elevated levels of heavy metals, organic substances, bacteria, and other indicators of contamination.

The point to be made in this section is that ocean dumping, and settling of materials suspended in the seaward moving Hudson plume, have had a significant effect upon bottom-dwelling invertebrates. Bottom grab samples collected at stations inside the sludge and spoils beds are frequently devoid of normal benthic fauna that one might expect to find in these waters; when benthic organisms are found in samples collected from the waste disposal areas, the diversity of the species is often greatly reduced (Pearce, 1980a).

Observed reductions in numbers of individuals and diversity of species in grab samples collected from the disposal areas are undoubtedly the result of several factors. These include: the presence of petrochemicals, heavy metals, and other toxins in contaminated sediments; reducing conditions and accompanying reduced DO; and direct burial of the invertebrate fauna.

The first major published paper on benthic populations of Raritan Bay was done by Dean and Haskin (1964). This paper was concerned principally with the repopulation of benthic habitats of the riverine portion of the Bay following a point source pollution abatement project in the 1950s. Subsequently, Dean (1975) published on the macrobenthos of the remainder of Raritan Bay; his samples were collected during the summers of 1957-60. Dean (1975) provided a comprehensive list of species collected at 193 stations. His papers also contained information on benthic sediment types, levels of DO, temperature, and salinity.

In 1973, personnel at the Sandy Hook Laboratory, National Marine Fisheries Service, began a comprehensive census of the benthic populations in the Bay. Eighty-six stations were selected for study, with 78 of these based on stations established by the U.S. Environmental Protection Agency (USEPA) in an earlier water quality monitoring program. Replicate grab samples were collected with a Smith-McIntyre grab using accepted standard methods for handling and processing the samples (Swartz, 1978).

The results of the first phase of this program were reported by McGrath (1974). He noted that: "The most striking characteristic of the benthic fauna of Raritan Bay is its impoverishment [of benthic fauna]". He compared the benthic fauna density of the Bay to those of other, similar, temperate estuaries. In all cases, Raritan Bay had reduced densities and species divesity. It was noted that very low summer DO values (0.4 mg/1) were found in the western portions of the Bay which receive waters from the Raritan and Arthur Kill.

Perhaps the most important observation was the complete absence of certain Amphipoda from samples collected in the western one-third of the Bay. Earlier work by Blumer et al. (1970) reported ampeliscid amphipods to be sensitive to low concentrations of petroleum HC. Since Raritan Bay sediments contain large amounts of such substances it is probable that amphipods have been precluded. The findings of McGrath are even more interesting when his data are compared with those of Dean (1975). The latter counted up to 13,000 Ampelisca per m^2 at station in the central Bay; especially large numbers were found in summer of 1957, 1959, and 1960. McGrath (1974) did not find a single ampeliscid amphipod in his 1972 survey.

In June 1979, scientists from the New Jersey Marine Sciences Consortium (NJMSC), in conjunction with the Ocean Pulse habitat assessment and monitoring program (Pearce, 1977), began a new census of benthic populations and their habitats in Raritan Bay. Multer (personal communication) reports that based upon preliminary visual scans, the benthic populations remain depressed at most of the 80 stations which he resampled in Raritan Bay. A more recent study being conducted jointly by the NJMSC and NMFS Ocean Pulse Program has to do with the uptake of contaminants by caged mussels (Mytilus edulis) suspended in dumpsite and polluted estuarine areas, as contrasted with mussels held in a similar manner at control sites thought to be relatively unpolluted. In part, such studies have been spurned by recent findings of Wenzloff et al (1978) who reported that heavy metals in two bivalve molluscs, the surf clam and ocean quahog, collected from offshore waters of the Middle Atlantic coast of the United States, had an interesting pattern of heavy metal distribution. Clams taken from the southern portions of their range had relatively low levels of heavy metals; in the northern ranges the amount of heavy metals increased (Fig. 8). Both of these clam species are found offshore and would normally be regarded as forms not likely to be impinged upon by heavy metals having their origin in polluted estuaries. It is significant that there is a linear relationship between increasing heavy metals and latitude. It has been suggested that the clams taken from the more northern portions of their ranges may be exposed to heavy metals which are eminating from the Hudson River estuary and Raritan Bay complex. Further research will be required to document this relationship. Nevertheless, this is one of the few instances where sedentary species collected synoptically over a wide range of latitude show increases in heavy metals when they are found in waters which have been shown to be contaminated with heavy metals.

In regard to petroleum HC body burdens in coastal and shelf species, recent studies (Boehm et al., 1979) have indicated that fish, not thought to have been immediately exposed to chronic levels of oil, or to acute levels resulting from oil spills (i.e., the Argo Merchant tanker sinking), had levels of mixed petroleum HC greater than would be expected. Moreover, in a recent attempt to collect "clean" mussels for use in caging experiments to measure uptake of petroleum HC, investigators found that mussels collected from supposedly unpolluted habitats in estuaries along the central New Jersey coast had up to 90 ug/g of unidentified HC.

These and other data indicate that benthic invertebrates and demersal finfish habituating the New York Bight have body burdens of organic substances such as petroleum HC and PCBs (Pearce, 1979) which may affect the well being of these organisms.

3.4.1 Disease and symbionts of shellfish and fish. Mahoney et al. (1973) reported extensive fin erosion in 22 species of fish from the area, with the primary center of the epizootic being Raritan, Lower New York, and Sandy Hook Bays. Of 1,152 bluefish examined in July-August 1967, 70% were diseased. Winter flounder, *P. americanus*, and summer flounder, *P. dentatus*, were also heavily diseased. Subsequently, Ziskowski and Murchelano (1975) conducted a comparative study of the Raritan Bay system and the less polluted Great Bay in central New Jersey. Considering only winter flounder, these authors found in March-May 1973 a 15.0% prevalence of fin erosion in 451 fish from Rartian Bay as contrasted with 2.2% in 480 fish from Great Bay. Similar figures were reported for the same period of 1974. In more recent years, the prevalence of disease has been reduced relative to the late 1960s although an increased incidence of disease has been found in Boston Harbor.

It should be recognized that invertebrate organisms also suffer from disease in the New York Bight system. Samples of benthic crustaceans collected from the New York Bight in 1968-69 showed overt signs of exoskeleton disease (Pearce, 1972). Later, Young and and Pearce (1975) reported in more detail on shell or exoskeleton disease in crabs, *Cancer* spp., and lobsters, *Homarus americanus*, found in the New York Bight and adjunct embayments. The disease syndrome could be duplicated in the laboratory if decapod crustaceans were held on sediments contaminated with sewage sludge or dredged material. Gopalan and Young (1975) found a similar syndrome in the shrimp, *Crangon septemspinosa*, abundant throughout the Bight apex and Raritan Bay. Upwards of 80% of the shrimp from these areas were diseased whereas only a small percentage of shrimp from pristine or relatively uncontaminated areas were affected.

Young (personal communication) has found that similar syndromes can be induced by experimental exposure of shrimp to copper, a metal which is greatly elevated in the waters (Waldhauer et al., 1978) and sediments (Carmody et al., 1973) of the Raritan Bay-New York Bight systems.

In addition to possibly causing disease syndromes, the toxicity of copper and lead have been implicated in direct lethality and also in effects on growth and reproduction, and physiological processes such as respiration, osmoregulation, and metabolism. Pringle (1968) found copper fatal to sticklebacks down to 20 ugl^{-1}. Some bivalve molluscs are extremely susceptible to copper poisoning; approximately 90% mortality occurred in quahogs (Mercenaria mercenaria) within 20 weeks exposure to 25 ugl^{-1} (Shuster and Pringle, 1968). Copper is toxic to the soft shell clam, Mya arenaria, down to 20 ugl^{-1} (Pringle et al., 1968). Larval stages may be even more sensitive than adults (Conner, 1972; Calabrese, 1972; Calabrese et al., 1973). Gibson et al. (1975) reared shrimp (Pandalus danae) in seawater containing 20 and 50 ugl^{-1} copper. After seven weeks exposure to 20 ugl^{-1}, necroses developed. Calabrese et al (1977) found that at 32.5 ugl^{-1} Cu, only 50% of oyster larvae (Crassostrea virginica) survived whereas for clam larvae (M. mercenaria) 16.4 ugl^{-1} Cu was lethal to 50% of them.

Finally, Sawyer et al. (1976) have been investigating gill fouling in macrocrustaceans by attached protozoa. In addition to the possible effect which might occur to important commercial species, the epibionts may play a role as useful indicator species in regard to deteriorating marine and estuarine habitat quality.

4. Summary

During the past hundred years, the urbanization and industrialization of metropolitan areas have had effects on biological systems. Among the first signs of impact on living resources were discolorations and tainting of seafood products harvested from estuaries receiving wastes from smelters and refineries which were sited on estuarine waters as early as the late 18th century.

By the beginning of the 20th century, early observations indicated that populations of shellfish and other invertebrates were being affected throughout entire areas of major estuarine systems such as the Hudson/Raritan Estuary. Unfortunately, exact causal agents have not been identified although it is suspected that the synergistic effects of petroleum, metals, and other toxic substances were responsible for disappearances or reduction in numbers of many species.

The growing national concern for environmental quality in the 1960s spurred government agencies to initiate comprehensive programs to measure the extent and effects of estuarine and coastal pollution. Studies have shown that the effects of pollution have spread from the estuaries seaward and that, at least in open ocean areas receiving large amounts of gross contaminants such as sewage sludge and contaminated dredged material, there have been measurable effects. The following papers provide additional detals.

5. Bibliography

Atlas, R.M. and Bartha, R. 1973. Abundance, Distribution, and Oil Biodegradation Potential of Microorganisms in Raritan Bay. Environ. Poll. 4:291-300.

Ayers, J.C., B.H. Ketchum, A.C. and Redfield. 1949. Hydrographic Conditions Relative to the Location of Sewer Outfalls in Raritan Bay. Woods Hole Oceanogra. Inst. Ref. No. 49-13, Woods Hole, MA., 41 pp.

Babinchak, J., J. Graikowski, S. Dudley, and M. Nitkowski. 1977. Distribution of Fecal Coliforms in Bottom Sediments from the New York Bight. Mar. Pollut. Bull. 8:150-3.

Blumer, M., J. Sass, G. Souza, H. Sanders, F. Grassle, and G. Hampson. 1970. The West Falmouth Oil Spill; Persistance of the Pollution Eight Months After the Accident. Woods Hole Oceanogr. Inst. Ref. No. 70-44, Woods Hole, MA., 32 pp.

Boehm, P., D. Feist, A. Ekskus. 1979. Petroleum Hydrocarbon Analysis of Fish Collected in the Vicinity of the Argo Merchant Oil Spill -- April to October 1977. Final Report, NOAA Contract NA 79-FAC-00015, to Natl. Mar. Fish. Serv., Narragansett, R.I. Energy Resources Co., Inc. (ERCO), Cambridge, MA.

Buelow, R. 1968. Ocean Disposal of Waste Material. In: Ocean Sciences and Engineering of the Atlantic Shelf. Trans. Natl. Symp., Phila., Pa., 19-20 March 1968, 311-336 pps.

Carmody, D.J., J.B. Pearce, and W.E. Yasso. 1973. Trace Metals in Sediments of New York Bight. Mar. Poll. Bull. 4(9):132-135.

Calabrese, A. 1972. How Some Pollutants Affect Embryos and Larvae of American Oyster and Hardshell Clam. Mar. Fish., Rev. 34, 66-77 pps.

Calabrese, A., R.S. Collier, D.A. Nelson, and J.R. MacInnes. 1973. The Toxicity of Heavy Metals to Embryos of the American Oyster (Crassostrea virginia). Mar. Biol. 18, 162-166 pps.

Calabrese, A., J.R. MacInnes, D.A. Nelson, and J.E. Miller. 1977. Survival and Growth of Bivalve Larvae Under Heavy Metal Stress. Mar. Biol. (In Press).

Conner, P.M. 1972. Acute Toxicity of Heavy Metals to Some Marine Larvae. Mar. Pollut. Bull. 3, 190-192 pps.

Dean, D. 1975. Raritan Bay Macrobenthos Survey, 1957-1960. NMFS Data Report 99, U.S. Dept. of Commerce, NOAA, NMFS, Seattle, WA, 51 pp.

Dean, D. and H. Haskin. 1964. Benthic Repopulation of the Raritan River Estuary Following Pollution Abatement. Limnol. Oceanogr. 9:551-563.

Dickert, T.G. and A. Tuttle. 1985. Cumulative Impact Assessment in Environmental Planning. Environ. Impact Assess. Rev. 5:37-64.

Federal Water Pollution Control Administration. 1967. Summary Report for the Conference on Pollution of Raritan Bay and Adjacent Interstate Waters. Third Session, U.S. Dept. of the Interior, Metuchen, New Jersey, 22 pp.

Gibson, C.I., T.O. Thatcher, and C.W. Apts. 1975. Some Effects of Temperature, Chlorine, and Copper on the Survival and Growth of the Coon Strip Shrimp (Pandalus danae). Battelle Pacific Northwest, Ecosystems Dept., Mar. Res. Lab., Sequim, Wash.

Goode, G. 1887. The Fisheries and Fishing of the U. S. Section II.: A Geographical Review of the Fisheries Industries and Fishing Communities for the Year 1880. U.S. Government Printing Office, 384 pp.

Gopalan, U.K. and J.S. Young. 1975. Incidence of Shell Disease in Shrimp in the New York Bight. Mar. Poll. Bull. 6(10):149-153.

Greig, R.A. and R.A. McGrath. 1977. Trace Metals in Sediments of Raritan Bay. Mar. Poll. Bull. 8(8):188-192.

Jacot, A. 1920. On the Marine Mollusca of Staten Island, New Jersey. Nautilus, 33:111-5.

Jeffries, H.P. 1959. The Plankton Biology of Raritan Bay. Ph.D. Thesis, Rutgers Univ., New Brunswick, New Jersey, 180 pp.

Jeffries, H.P. 1962. Environmental Characteristics of Raritan Bay, A Polluted Estuary. Limnol. Oceanogr. 7:21-31.

Jeffries, H.P. 1962a. Copepod Indicator Species in Estuaries. Ecology 43(4):730-733.

Jeffries, H.P. 1964. Comparative studies on estuarine zooplankton. Limnol. Oceanogr. 9(3):348-358.

Kawamura, T. 1962. Distribution of Phytoplankton Populations in Sandy Hook Bay and Adjacent Areas in Relation to Hydrographic Conditions in June 1962. T Ch. Paper 1, Bureau of Sport Fisheries & Wildlife, Washington, D.C., 37 pp.

Koiditschek, L.K. and P. Guyre. 1974. Antimicrobial - Resistant Coliforms in New York Bight. Mar. Poll. Bull. 5(5):71-74.

Koons, C.B. and J.P. Thomas. 1979. "C_{15+} Hydrocarbons in the Sediments of the New York Bight." Proceedings of 1979 Oil Spill Conference (Prevention, Behavior, Control, Cleanup), 19-22 Mar. 79. Los Angeles, CA. Amer. Petrol. Instit., Wash., DC.

Larsen, P. and L. Doggett. 1979. An Overview of Nearshore Environmental Research in the Gulf of Maine. Marine Environmental Quality Committee, ICES Paper C.M. 1979/E:41.

Lippson, R. and A. Lippson. 1979. The Condition of Chesapeake Bay - An Assessment of Its Present State and Its Future. Marine Environmental Quality Committee, ICES Paper C.M. 1979/E:42.

Litchfield, C.P., J.P. Nakas, and R.H. Vreeland. 1976. "Bacterial Flux in Some New Jersey Estuarine Sediments." In: Amer. Soc. Limnol. and Oceanogr. Spec. Symposium Vol. 2., 340-353 pps.

Longwell, A. 1976. "Chromosome Mutagenesis in Developing Mackerel Eggs Sampled From the New York Bight." NOAA Tech. Memorandum ERL-MESA-7. Boulder, Colo. April 1976, 61 pp.

Mahoney, J. and F. Steimle. 1980. Possible Association of Fishing Gear Clogging With a Diatom Bloom in the Middle Atlantic Bight. Bull. New Jersey Acad. Sci. 25(1):18-21.

Maurer, D. 1979. A Brief Review of the Status of Selected Pollutants (Pesticides, Hydrocarbons, Trace Metals) in Relation to Benthic Invertebrates in Delaware Bay. Marine Environmental Quality Committee, C.M. 1979/E:43, 15 pp.

McCarthy, D., C. Gross , R. Cooper, R. Langton, K. Pecci, and J. Uzman. 1979. Biology and Geology of Jeffreys Ledge and Adjacent Basins: An Unpolluted Inshore Fishing Area, Gulf of Maine, NW Atlantic. Marine Environmental Quality Committee, C.M. 1979/E:44, 12 pp.

McGrath, R.A. 1974. "Benthic Macrofaunal Census of Raritan Bay - Preliminary Results." Pap. No. 24; Proc. 3rd Symp. Hudson River Ecol., Mar. 22-23, 1973, Bear Mt., N.Y., Hudson River Environ. Soc.

Nelson, J. 1909-1916. Reports of Dept. of Biology, Rutgers Univ., New Brunswick, N.J., Agricultural Experiment Station.

Ninivaggi, D. 1979. Marine Food Chains and the Effects of Pollution. Marine Science Research Center Newsletter 4(2). State Univ. of New York, Stony Brook, N.Y.

O'Reilly, J.E., J.P. Thomas, and C. Evans. 1976. Annual Primary Production (Nanoplankton, Netplankton, Dissolved Organic Matter) in the Lower New York Bay. Paper No. 19. In: Proc 4th Symp. Hudson River Ecology, W.H. McKeon & G.J. Tauer (eds.).

Patten, B.C. 1962. Species Diversity in Net Phytoplankton of Raritan Bay., J. Mar. Res. 20(1):57-75.

Pearce, J.B. 1972. The Effects of Solid Waste Disposal on Benthic Communities in the New York Bight. In: M. Ruivo (ed.), Marine Pollution and Sea Life. Fishing News (Books) Ltd., London, 404-411 pps.

Pearce, J.B. 1977. A Report on a New Environmental Assessment and Monitoring Program, Ocean Pulse. ICES, Fisheries Improvement Comm. C.M. 1977/E:65, 12 pp.

Pearce, J.B. 1979. Raritan Bay - A Highly Polluted Estuarine System. Marine Environmental Quality Committee. ICES Paper, C.M. 1979/E:45.

Pearce, J. 1979a. Marine Sand and Gravel Production in Areas Off the Northeast Coast of the United States. Mar. Poll. Bull. 10:14-18.

Pearce, J. 1980. Status of Estuaries and Coastal Waters Between Cape Hatteras and Maine, Review, ICES Paper, C.M. 1980/E:56.

Pearce, J. 1980a. Benthic Fauna. MESA Atlas Monograph #14. New York Sea Grant Institute, Albany, N.Y., (In Press).

Phelps, D.K. 1979. Narragansett Bay - A Gradient of Stress. Marine Environmental Quality Committee, ICES Paper, C.M. 1979/E:46.

Pringle, B., D.E. Hissang, E.L. Katz, and S.T. Mulawka. 1968. Trace Metal Accumulation by Estuarine Molluscs. Amer. Soc. of Civil Engineers Proceed., J. San. Engineering Div., 94(SA3), Paper 5970, 455-475 pps.

Reid, R.N. 1979. Concentrations and Effects of Long Island Sound Contaminants. Marine Environmental Quality Committee, ICES Paper, C.M. 1979/E:47.

Sawyer, T. 1974. Marine Ameoba in Sediment and Sea Water from Selected Sites in New York Harbor. Trans. Am. Micros. Soc. 93:433.

Sawyer, T. 1976. Hosts for the Parasitic Ameoba, Paramoeba perniciosa. Trans. Am. Micros. Soc., 95:271.

Sawyer, T., S. McLean, and J. Ziskowski. 1976. A Report of Ephelota sp. (Ciliata, Suctorida) As An Epibiont on the Gills of Decapod Crustaceans. Trans. Am. Micros. Soc. 95:712-7.

Sawyer, T., G. Visvesvara, and B. Harke. 1977. Pathogenic Ameobas from Brackish and Ocean Sediments, With a Description of Acanthamoeba hatchetti, n. sp. Science, 196:1324-5.

Searl, T.D., H.L. Huffman, Jr., and J.P. Thomas. 1977. "Extractable Organics and Nonvolatile Hydrocarbons in New York Harbors Waters." In: 5th Conference on the Prevention, Behavior, Control, and Clean-up of Oil Pollution, 8-10 Mar. 77, New Orleans, LA., pps. 583-588

Shuster, C.N., and B.H. Pringle. 1968. Effects of Trace Metals on Estuarine Molluscs. Proc. 1st Mid-Atlantic Industrial Water Conf., Univ. of Del. CE-5, 285-304 pps.

Stainken, D., H.G. Multer, and J. Mirecki. 1983. Seasonal Patterns of Sedimentary Hydrocarbons in the Raritan Bay - Lower New York Bay. Environ. Toxicol. Chem. 2:35-42.

Stephens, G.C. 1964. Uptake of Organic Material by Aquatic Invertebrates. III. Uptake of glycine by brackish-water annelids. Biol. Bull. 126(1):150-162.

Swanson, L. 1977. "Status of Ocean Dumping Research in the New York Bight." J. Waterway, Port, Coastal and Ocean Div., ASCE. 103(WW1), Proc. Paper 12722, Feb. 1977, 9-24 pps.

Swanson, L. and C. Sindermann, eds. 1979. Oxygen Depletion and Associated Benthic Mortalities in New York Bight, 1976. National Oceanic and Atmospheric Admin., Prof. Paper 11, Rockville, MD., 354 pp.

Swartz, R.C. 1978. Techniques for Sampling and Analyzing the Marine Macrobenthos. U.S. Environmental Protection Agency, Ecological Research Series, EPA-600/3-78-030, Corvallis, Oregon, 26 pp.

Timoney, J. and J. Port. 1979. Heavy Metals and Antibiotic Resistance in Bacillus and Vibrio from Sediments of New York Bight. In: M. Carriker (ed.), Proceedings of Symposium on the Ecological Effects of Environmental Stress, held 11-15 June 1979, New York City, Marine Ecosystems Analysis (MESA) Program, Stony Brook, NY.

Townsend, C. 1917. The New Exhibition Tanks. Zool. Soc. Bull., 20:1469.

Wenzloff, D., R. Greig, A. Merrill, and J. Ropes. 1978. A Survey of Heavy Metals in Two Bivalve Molluscs of the Mid-Atlantic Coast of the United States. Fish. Bull., 77(1):280-285.

Yamazi, I. 1962. Zooplankton Communities of the Navesink and Shrewsbury Rivers and Sandy Hook Bay, New Jersey. Tech. Paper 1, Bureau of Sport Fisheries and Wildlife, Wash., D.C., 44 pp.

Young, J.S. and J.B. Pearce. 1975. Shell Disease in Crabs and Lobsters from New York Bight., Mar. Poll. Bull., 6(7):101-105.

Ziskowski, J. and R. Murchelano. 1975. Fin Erosion in Winter Flounder., Mar. Poll. Bull., 6(2):26-29.

6. Figures

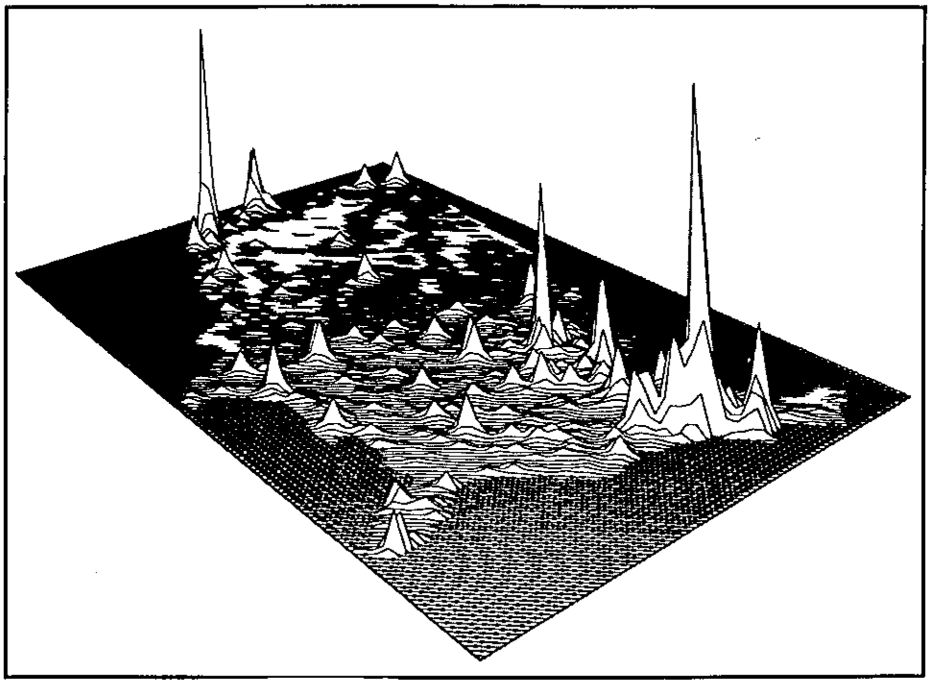


Figure 1.

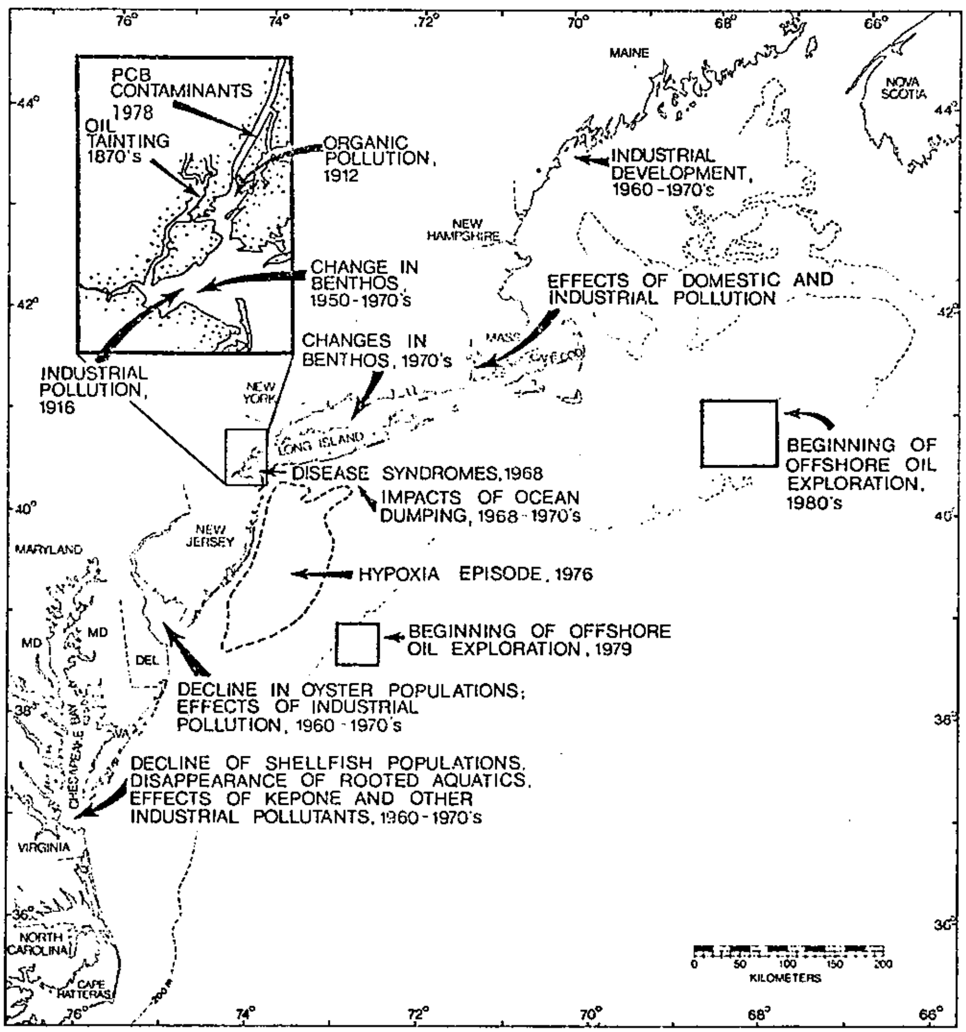


Figure 2.

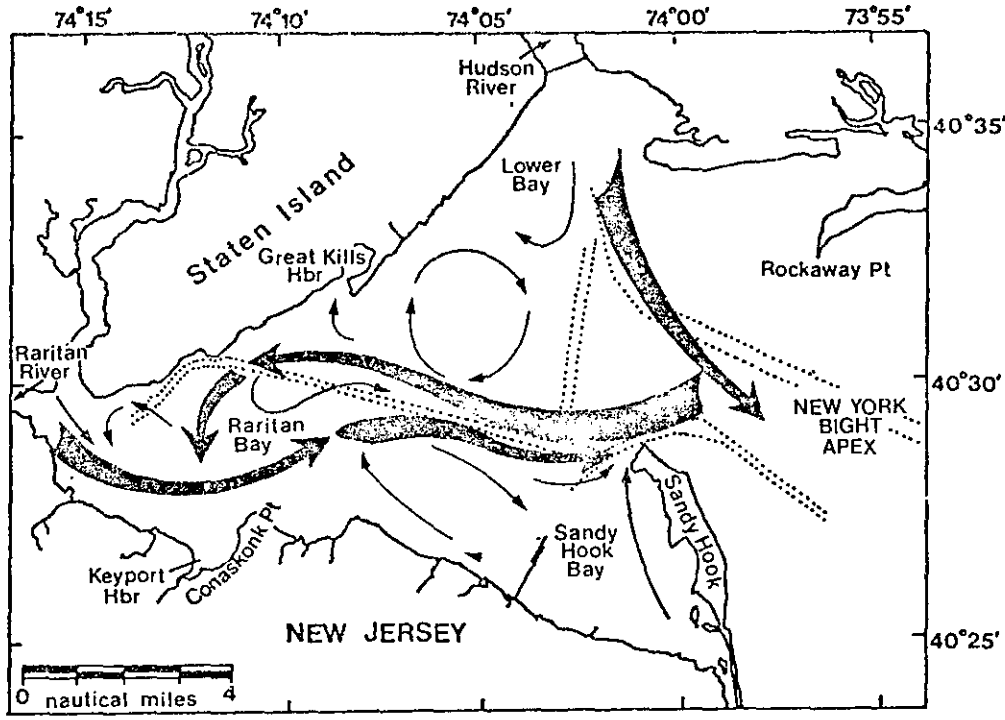


Figure 3.

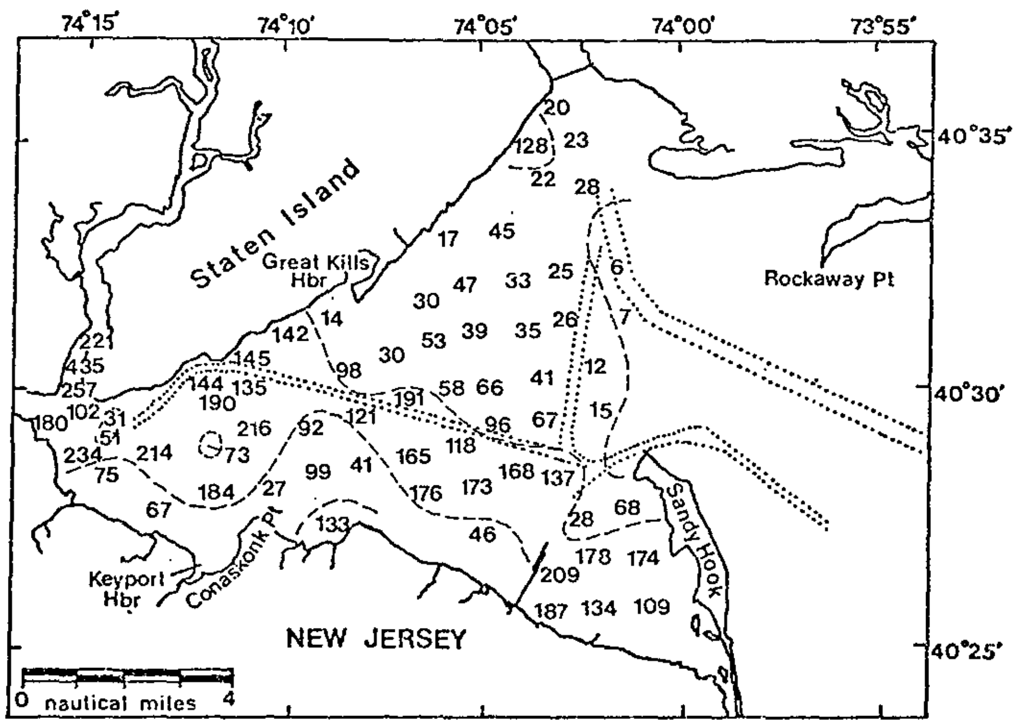


Figure 4.

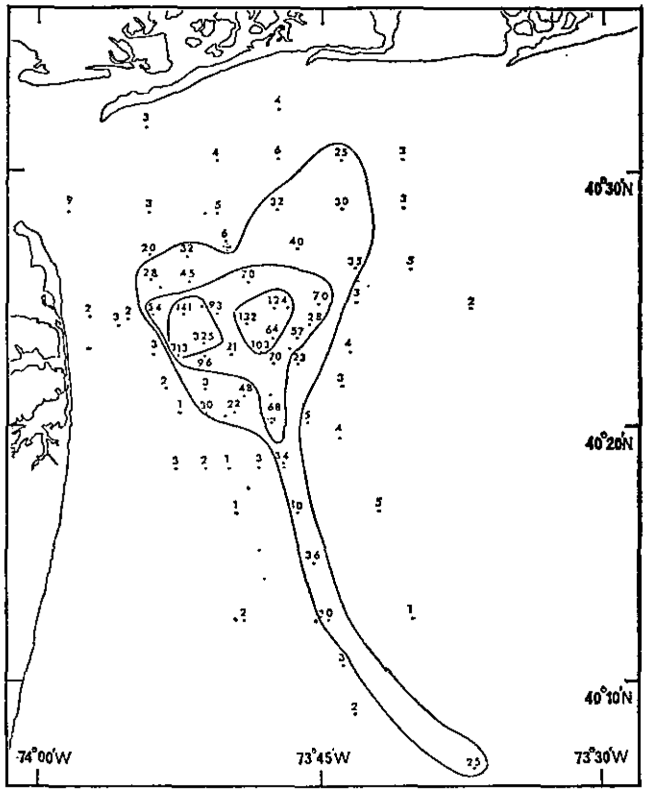


Figure 5a.

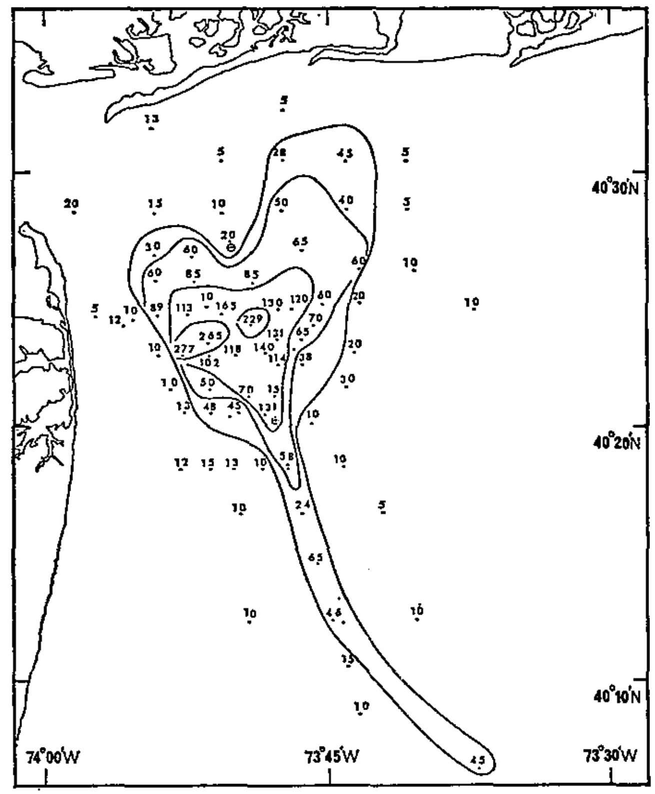


Figure 5b.

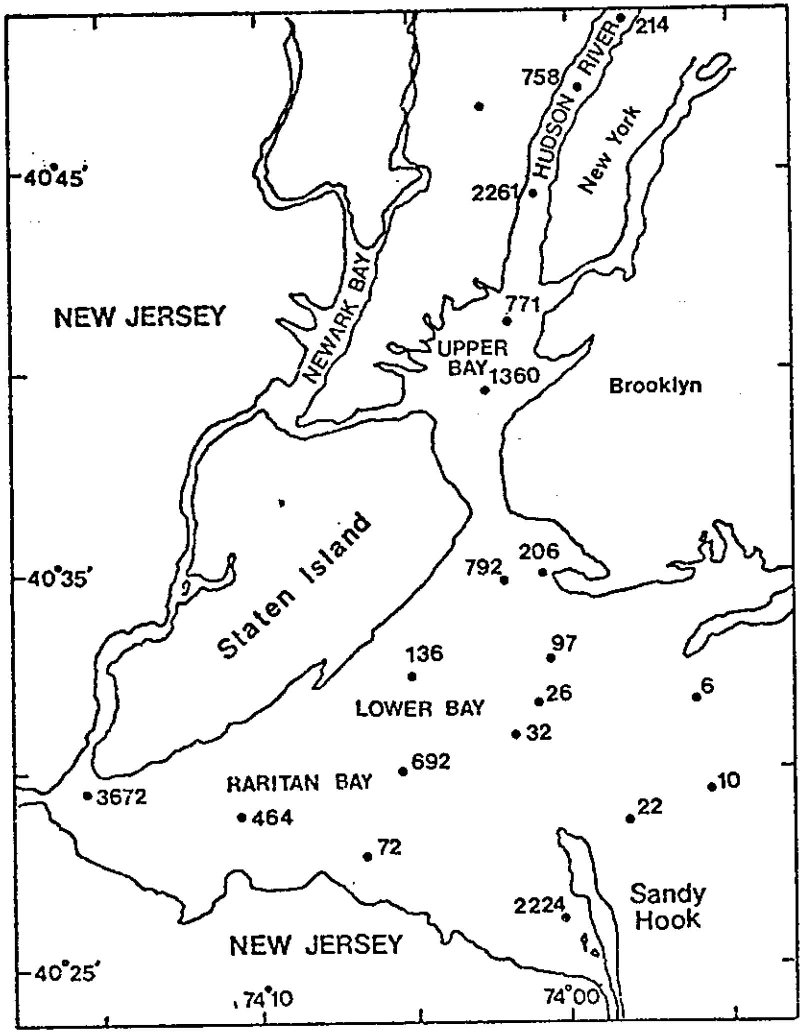


Figure 6.

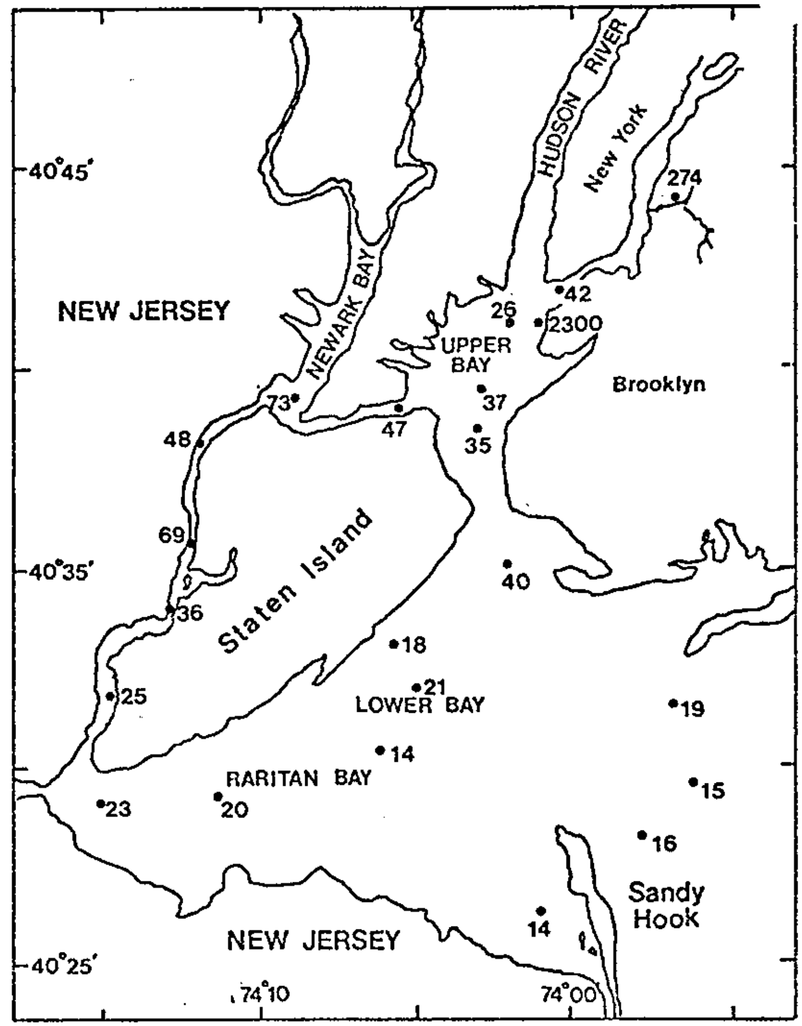
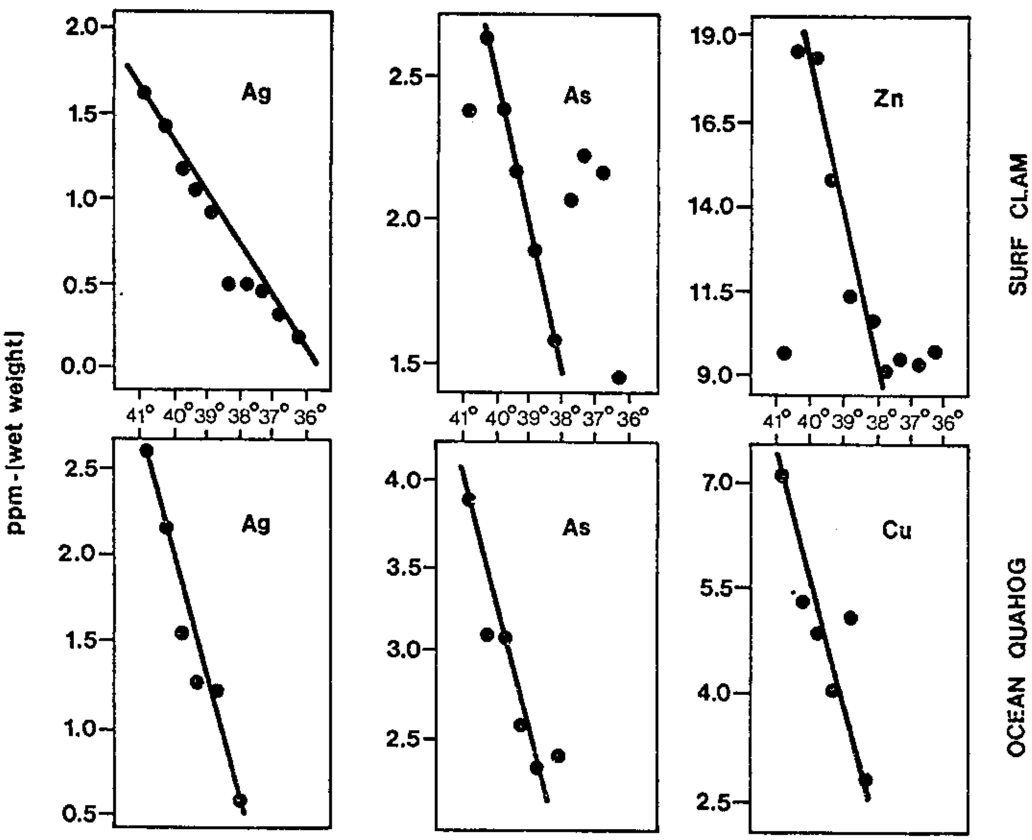


Figure 7.



ppm-(wet weight)
Ag
As
Zn
SURF CLAM
Ag
As
Cu
OCEAN QUAHOG
2.0
1.5
1.0
0.5
0.0
2.5
2.0
1.5
19.0
16.5
14.0
11.5
9.0
41° 40° 39° 38° 37° 36°
2.5
2.0
1.5
1.0
0.5
4.0
3.5
3.0
2.5
7.0
5.5
4.0
2.5

Figure 8.

Numerical Model Studies of Circulation in The Hudson - Raritan Estuary

Richard I. Hires
Department of Civil and Ocean Engineering
Stevens Institute of Technology
Hoboken, New Jersey

George L. Mellor
Geophysical Fluid Dynamics Program
Princeton University
Princeton, New Jersey

ABSTRACT

Recent application of a fully three-dimensional, time dependent numerical model for the prediction of the distribution of velocity and salinity in the Hudson-Raritan Estuary has provided new insights into the circulation in this waterway. An overview of some of the results obtained in the studies reported by Oey. Mellor and Hires (1985a, b and c) is presented. Particular attention has been focused on the residual circulation arising from the tides, winds and fresh water discharge through the esturary. Estimates of the upstream salt flow through the Sandy Hook - Rockaway Point Transect demonstrate the relative magnitude of the several processes which contribute to this transport.

Introduction

A location map for the Hudson-Raritan Estuary is shown in Figure 1. The Estuary exhibits a complicated geometry and bathymetry. It has two connections with the open ocean, one through the Sandy Hook-Rockaway Point transect and the second through the East River to Long Island Sound. There are five significant sources of freshwater discharge through the Estuary: the Hudson, Raritan, Hackensack, and Passaic Rivers, and sewage treatment plant effluent discharges of about 120 m /s (2.75 billion gallons a day). By way of comparison, monthly discharge rates for the Hudson vary from about 100 to 2000 m /s (2.3 to 46 billion gallons a day), while the combined monthly discharge of the three New Jersey rivers average about 10 percent of that of the Hudson. Clearly, during periods of low flow through the rivers, the sewage discharge is a major contributor to the total freshwater flow. The term "fresh" refers here to water with salinity close to zero, as opposed to typical coastal ocean salinity values of 30-33 $^{0}/00$.

The circulation in the Hudson-Raritan Estuary is driven by sea level variations at its connections with the open ocean, by freshwater discharge through it, and by local and regional winds. The response of the Estuary to these driving forces is complex. The irregularities in the bounding coast lines and the bottom topography have important effects. The forcing of the circulation in the Estuary exhibits variability over a broad range of time scales.

A completely three-dimensional, time dependent numerical model for the prediction of tides, circulation and salt intrusion has been successfully applied to the Hudson-Raritan Estuary by Oey, Mellor and Hires (1985 a, b, and c). This model solved finite difference analogs of the primitive equations of motion and the equations for salt and volume continuity. It included a second moment turbulent closure scheme for the determination of stability dependent, vertical mixing coefficients. A sigma co-ordinate system was used to divide the water column into the same number of computational grid points independent of the instantaneous water depth. The model domain was essentially the area shown in Figure 1 and was covered with a 65 by 65 horizontal computational grid with a grid spacing of 535m. The portion of each river upstream of the model domain was treated as a two-dimensional, laterally averaged channel and included in the model computations.

The model required the specification of elevation and salinity at the seaward boundaries, the specification of fresh water discharge at the landward end of the tributary rivers and the specification of the applied wind stress. For some cases the model was exercised with synthetic boundary conditions and in otehrs with observed tides, winds and fresh water discharges.

In the following sections various components of the circulation in the Hudson-Raritan Estuary will be discussed. Whenever appropriate and useful the results of the Oey Mellor and Hires modelling efforts will be used to clarify and illuminate this discussion.

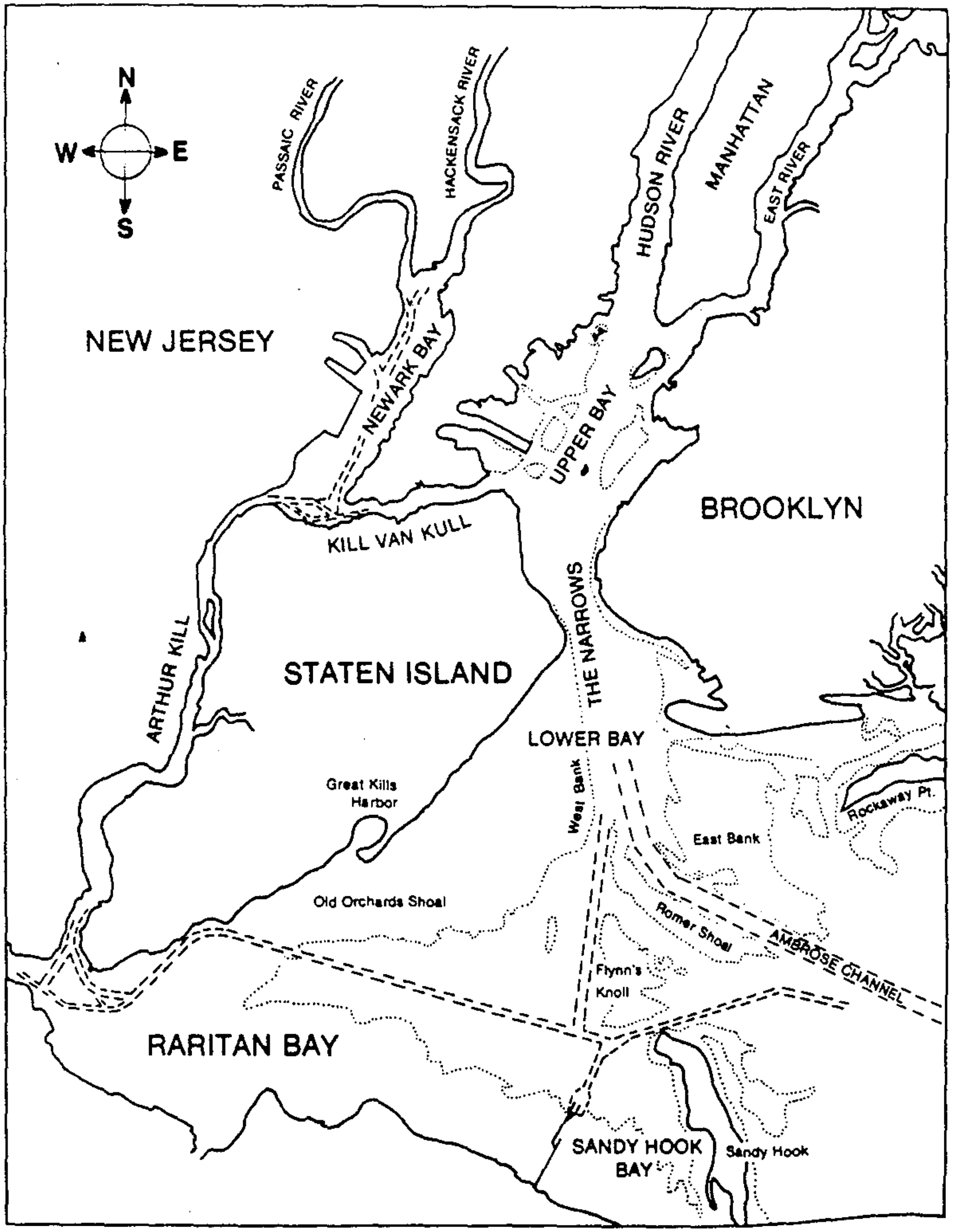


Figure 1. Raritan Bay and the New York/New Jersey harbor complex.

TIDAL CIRCULATION

The periodicities of the forcing due to astronomical tides are well known. Although the M_2 tidal constituent (12.42 hr. period) is clearly dominant in this estuary, the N_2 (12.66 hr.) the S_2 (12.00 hr.), the K_1 (23.93 hr.), and O_1 (25.82 hr.) are all significant and contribute to predictable diurnal, fortnightly and monthly variations in the magnitude of the tides and associated tidal currents. The forcing of the estuarine circulation by the astronomical tides is the only one which lends itself to long-term predictability. Despite the appearance of a somewhat simple oscillatory (reversing) tidal current regime of ebb currents for about six hours followed by six hours of flood currents, there exists a net or average circulation induced by the tidal forcing independent of any other forcing of the Estuary. This residual tidal circulation, combined with residual or net circulation driven by other mechanisms, effects the transport of contaminants through the Estuary, and exchanges the estuarine waters with adjacent coastal ocean waters to bring about a flushing and renewal of the Estuary. From the viewpoint of water quality, the net or residual circulation is of primary concern and will be the chief focus of this chapter.

Before turning in subsequent sections to a discussion of residual circulation patterns and variability, it is useful to characterize the tidal currents. These currents generally exhibit peak ebb or flood speeds an order of magnitude greater than the residual circulation. Along the longitudinal axis of the Estuary, consisting of Ambrose Channel, the Narrows, and the naturally deep channel through Upper Bay and into the Lower Hudson River (see Figure 1 for locations and Figure 2 for bathymetry), the peak ebb and flood currents for mean spring tides vary from 2 to 3 knots (1 to 1.5 m/s). Also, for this longitudinal axis the tide exhibits characteristics similar to a progressive shallow water wave, in that peak flood (upstream) currents coincide (nearly) with the occurrence of high water; peak ebb currents occur at about the time of low water.

Three other notes concerning the tidal currents are significant. First, the East River is a tidal strait driven by the differences in tide between its two ends, i.e., the East River connects Upper Bay in New York Harbor to the western end of Long Island Sound. Tidal currents are strong throughout most of the East River with maximum current exceeding 5 knots in the west channel between Manhattan and Roosevelt Island. The phase relationship between elevation and tidal currents in the East River suggests that there is a persistent tidally-induced transport towards the Harbor. This net transport, combined with the flushing of the East River through tidal exchange, helps enormously to ameliorate the deleterious effect of the discharge of 40 m^3/s of sewage effluent to this waterway from treatment plants located along its shores. The second note concerns two other tidal straits, the Kill van Kull and the Arthur Kill, which separate Staten Island from New Jersey.

Figure 2. Current distribution through the Sandy Hook-Rockaway Point transect.

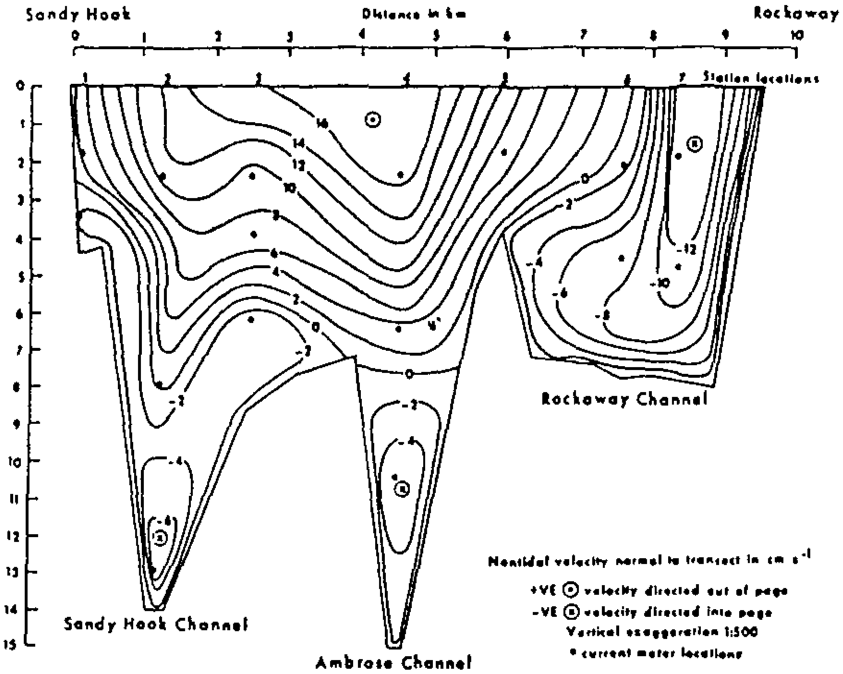


Figure 2a. Observed velocity averaged over several tidal cycles along the Sandy Hook-Rockaway Point transect (from Kao 1975).

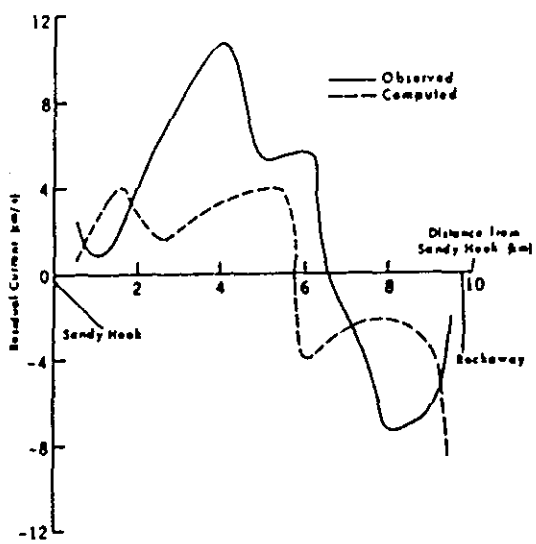


Figure 2b. Comparison of computed depth-averaged residual currents with the average-over-depth of the observed residual velocities (from Figure 2a) along the Sandy Hook-Rockaway Point transect (from Oey et al. 1985a).

The Kill van Kull is relatively short and has a vigorous tidal circulation. In contrast, the longer Arthur Kill has a sluggish tidal regime and a barely perceptible net circulation. As a consequence of poor exchange characteristics and intense industrialization, the Arthur Kill exhibits low water quality. A final note concerns the nature of the tide in Raritan Bay. Here, the tide is similar to a standing shallow water wave, so that peak currents tend to occur midway between high and low water. Also, the peak ebb and flood currents are significantly less intense (with typical speeds of 0.5-0.7 knots) than those along the longitudinal axis of the Estuary.

The residual or tidal-averaged current at a fixed location, the "Eulerian" mean velocity, does not, in general, represent the mean transport velocity, which is called the "Lagrangian" mean velocity. The distinction between Lagrangian and Eluerian mean velocity has been carefully delineated by Lonquet-Higgins (1969). The difference between these two mean velocities has been labeled "Stokes" transport. Although this Stokes transport may be calculated to a first order approximation from a knowledge of spatial gradients in the Eulerian velocity field, the tide and tidal currents along the longitudinal axis of the estuary provide a far simpler example of why a Stokes transport exists. As stated above, peak flood currents along this axis nearly coincide with the occurrence of high water and peak ebb currents with low water. Since, in general, the tidal currents, by themselves, cannot result in a net transport through a cross-section of the estuary, then the tidal Lagrangian mean velocity averaged over the cross-section must be zero. The Eulerian mean velocity averaged over this cross-section, arising solely from the tides, will <u>not</u> be zero. The reason for a non-zero Eulerian mean is that during flood currents, the cross sectional area will be greater than that expected during ebb currents. Hence, in order to have the same volume of water transported upstream on a flood current as that transported downstream on an ebb, the flood current speeds must be less than the ebb current speeds. Thus, there will be an Eulerian mean velocity arising solely from the tidal action, which is directed downstream in the direction of the ebb currents. Since we have insisted on a tidal Lagrangian mean velocity of zero, then the Stokes transport must be directed upstream. Figure 2 shows the distribution of Eulerian mean currents in the Sandy Hook-Rockaway Point transect derived from current meter observations. The large apparent seaward net volume flux of about 3×10^3 m^3/s is misleading; the Lagrangian transport is less than half of this Eulerian flux. Much of our knowledge of the circulation in the Hudson-Raritan Estuary is essentially "Eulerian" whereas most of our applications of this knowledge requires "Lagrangian" measures.

One method of exposing the residual circulation arising solely from the astronomical tides is through the use of numerical models. Oey, Mellor, and Hires (1985a) have calculated vertically averaged currents for the Hudson-Raritan Estuary using a numerical model in which circulation was forced through the imposition of tides at the ocean boundaries. For this tidal hydraulics study, the freshwater discharge and winds were set to zero and the M_2 tidal constituent was specified at the boundaries with an amplitude set equal to one-half the observed mean tidal range at each boundary. Good agreement between model predictions and observed tides and tidal currents was obtained by Oey, Mellor, and Hires. This agreement lends credibility to the predicted tidal residual currents. Their computed Eulerian residual currents are shown in Figure 3.

The residual flow shown in Figure 3 is complicated with several eddies evident. These residual eddies arise from the irregularities in the coastline geometry and in the bottom topography. The computed tidal residual currents (averaged over depth) through the Sandy Hook-Rockaway Point transect are compared with observed residuals at the transect in the bottom panel of Figure 2. It appears that a significant fraction of the transect residual currents arise solely from tidal forcing. It is important to realize that there is a significant residual circulation in the Estuary forced by the tides alone, independent of the freshwater discharge and the winds.

DENSITY-DRIVEN RESIDUAL CIRCULATION

The classical description of the net circulation in partially mixed estuaries was provided by Pritchard (1952). Freshwater enters the Estuary at its upsteam end and flows seaward over an inflow of salt water from the ocean end of the Estuary. The tidal currents serve as a source of energy to effect vertical mixing between the fresh and salt layers. During periods of low freshwater discharge through the Hudson, the top to bottom salinity differences in the lower estuary is reduced to about 1-2 $^0/_{00}$. During these low flow periods, salt water may intrude over 100 kilometers upstream from the Battery. In contrast, during periods of high discharge, the top to bottom salinity differences increase to 5-10 $^0/_{00}$ in the lower bays and the limit of salt intrusion decreases to as low as 20 kilometers above the Battery.

Some consequences of this classical view of estuarine circulation are: (1) there is a net upstream transport in the saltier lower layer; (2) there is a net outflow in the upper layer, and most importantly, this outflux is many times larger than the freshwater discharge rate; and (3) since the degree of vertical mixing is dependent on the magnitude of the tides, then it follows that, for the same freshwater discharge, vertical stratification will be less during spring tides than during neaps. There is indeed a net upstream transport in the deeper layer

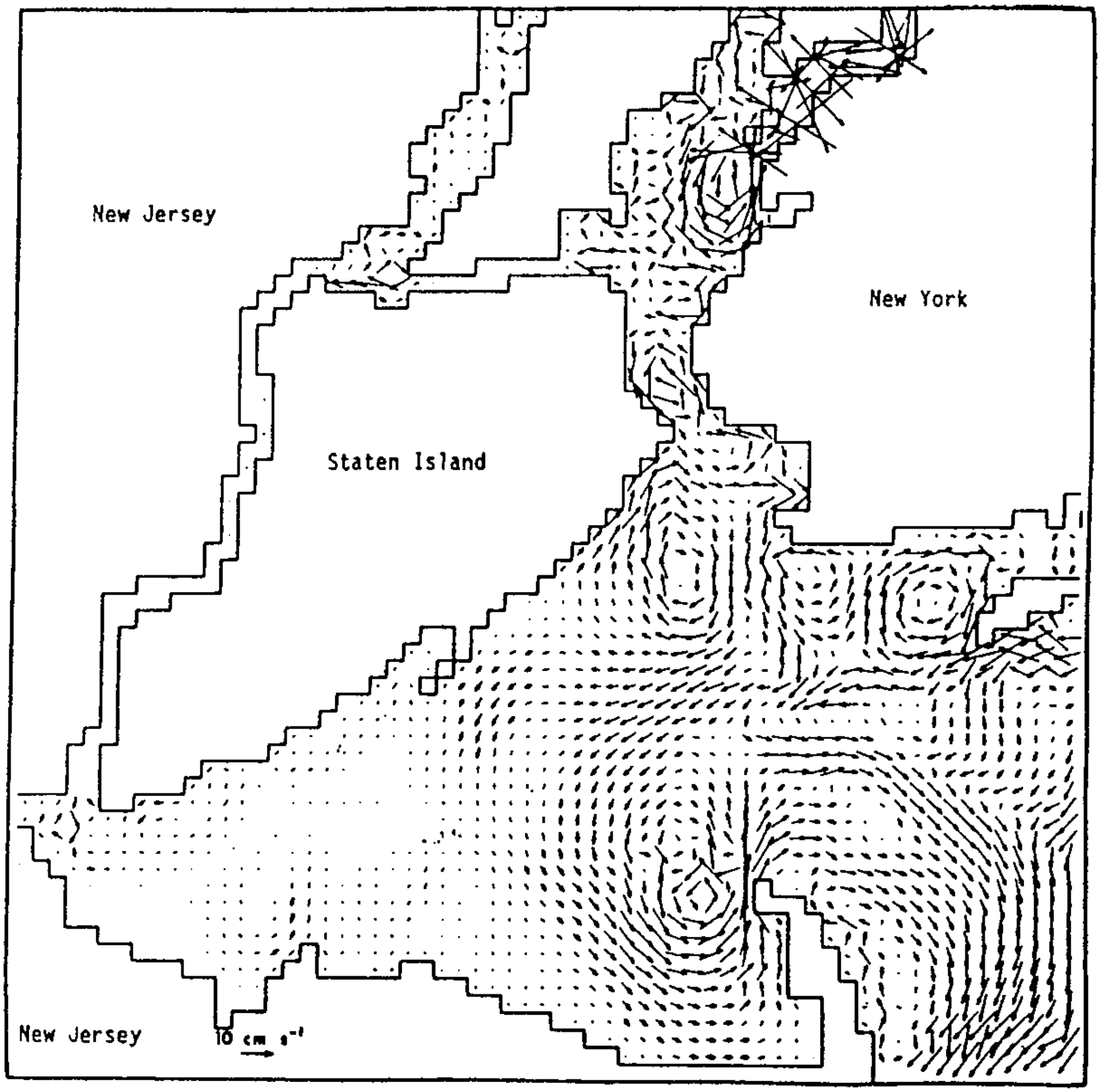


Figure 3. Computed Eulerian residual currents.

Figure 4. Tidal residual currents.

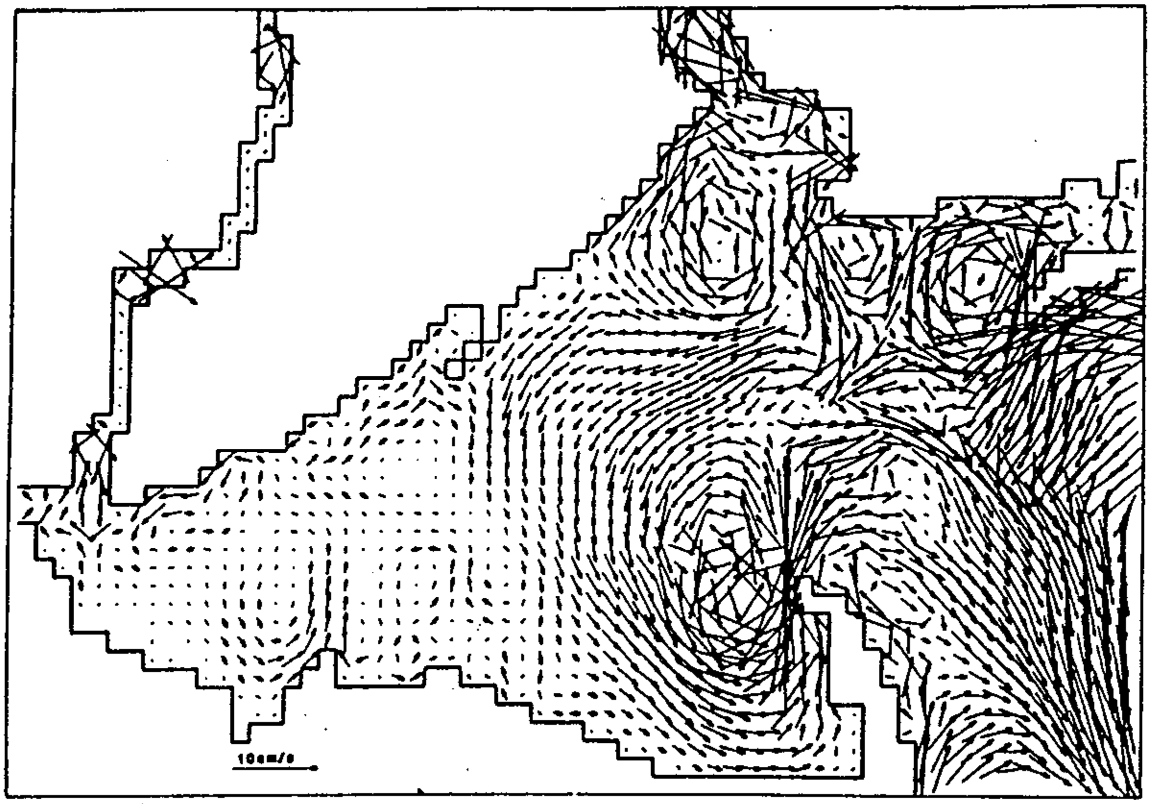


Figure 4a. Tidal residual currents in Raritan Bay.

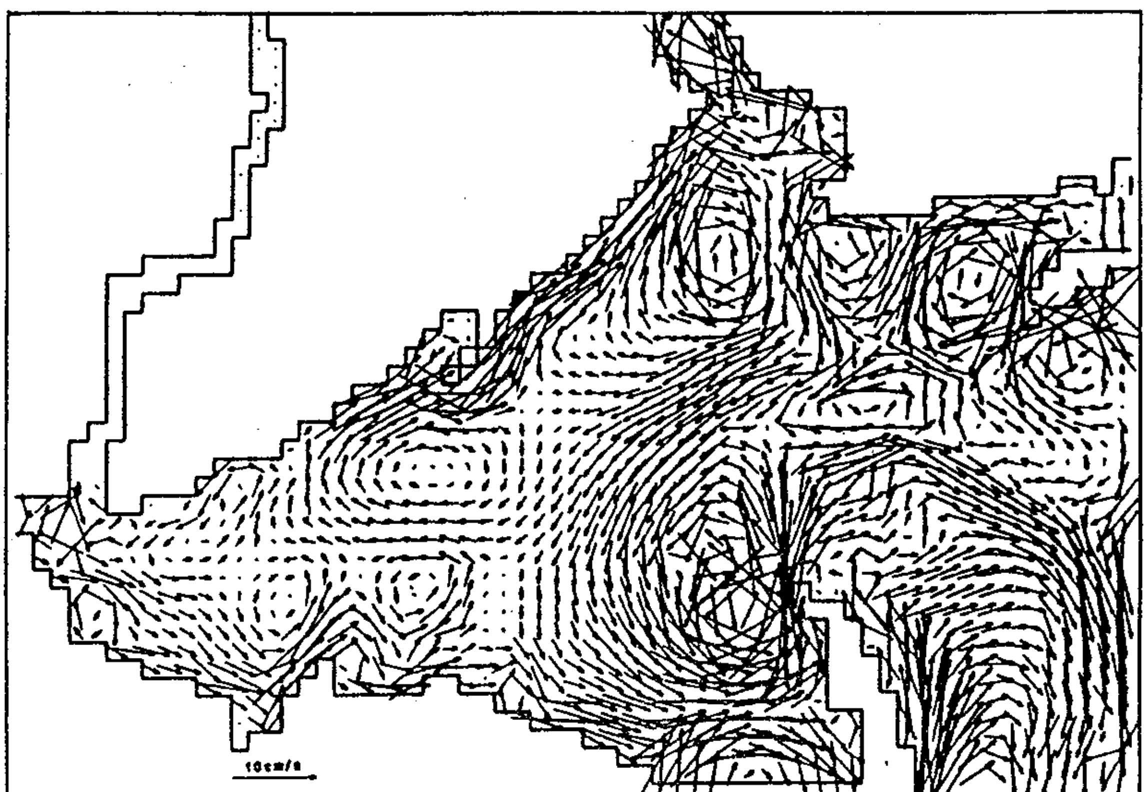


Figure 4b. Residual currents in Raritan Bay with a south westly wind.

within both the Sandy Hook and Ambrose Channels at the Sandy Hook-Rockaway Point transect which is clearly shown in Figure 2a. We refer to this situation of a net outflow overlying a net inflow as a "vertical" net circulation pattern. In contradistinction, the net inflow in the Rockaway Channel at all depths shown in Figure 2 is a feature of the net "horizontal" circulation pattern.

In wide estuaries such as Raritan Bay, there may be both a vertical and a horizontal residual circulation driven by density differences. The horizontal residual results from the effect of the earth's rotation (the Coriolis force) which tends to concentrate the seaward moving fresher water on the righthand side (looking seaward) of the Estuary. Salinity distributions in Raritan Bay confirm that the freshwater is consistently along the righthand side of the Bay. In contrast with the apparent effect of Coriolis force on the density-driven horizontal residual circulation, we should note that it has no effect on the tidal residual currents. Thus, the net inflow in the Rockaway Channel of the Sandy Hook-Rockaway Point transect is not a result of Coriolis effects; it arises from the interaction of the tide with the irregular bottom topography.

The classical view of the residual density-driven estuarine circulation suggests that at any point in the Estuary, the water there is a simple mixture of upstream freshwater and intruding ocean water. The fraction of freshwater in this mixture is readily obtained from its salinity. It is interesting to note that, along the longitudinal axis of the Hudson River and continuing seaward through upper and lower bays, there exists, at any time, a high degree of correlation between measured salinities and temperatures. In the summer, there is a persistent correlation of high salinities with low temperatures and low salinities with high temperature. In contrast, in the fall, the correlation is reversed, with higher salinity waters exhibiting higher temperatures. A straight line correlation of temperature and salinity suggests that temperature is nearly a conservative property; i.e., there is no significant local heating of the water during its passage through the Estuary. Similar straight-line temperature-salinity correlations can be found for the East River and for Newark Bay and Kill Van Kull. In the sluggish Arthur Kill, however, the straight-line correlation breaks down due to the local heating of these waters from power plant discharges.

WIND EFFECTS

It is well established that winds may play a significant role in forcing the residual circulation in estuaries. It is usual to distinguish between the local effect of the direct action of the wind on the surface waters of the estuary and the regional effect due to wind action over the adjacent coastal ocean. We begin with a brief discussion of regional wind effects.

The important effect for the Hudson-Raritan Estuary of winds over the adjacent coastal ocean is to produce variations in sea level at the ocean entrance which are called meteorological tides. These are superimposed on the astronomical tides and may, for severe storm events, completely overshadow the astronomical tides. The propagation of this storm surge through the Estuary may produce severe flooding and considerable property damage. On the positive side, the occurrence of episodic storm surge events can lead to a substantial and rapid flushing of the Estuary. Less dramatic but more persistent meteorological tides contribute significantly to net transport processes in the Hudson-Raritan Estuary.

We may assess the local effect of the wind through the aid of numerical models such as the vertically-averaged model by Oey, Mellor, and Hires (1985a), previously discussed, and a completely three-dimensional model of the Hudson-Raritan Estuary also developed by Oey, Mellor, and Hires (1985b). This latter model calculates currents and salinities at ten depths as well as the horizontal variation of these variables throughout the Estuary.

The effect of a persistent southwesterly wind (imposing a northeasterly wind stress of 1.0 dyne/cm^2 on Raritan Bay) on the vertically-averaged residual currents is shown in Figure 4, adapted from Hires, Oey, and Mellor (1984). The effect of the wind is to intensify residual eddies and to create coastal jets. This result for the vertically-averaged currents belies the actual complexity of the wind effect on the three dimensional circulation. Oey, Mellor, and Hires (1985b) forced their three-dimensional model with observed tides, freshwater discharge, and winds for July, August, and September 1980. An example of the residual current response in the near surface and near bottom layers to changing winds is shown in Figure 5, together with the salinity distributions. The following description of the sequence of residual flow over the 7-day interval is taken directly from Oey, Mellor, and Hires (1985b):

> Circulation and sea level in the estuary are correlated with winds at time scales of a few days to weeks (Parts II and III). Figure 5 shows some examples of subtidal wind response of velocity and salinity from 15 through 22 August. On 15 August (Fig. 5a), winds were eastward and weak ($\sim$ 0.2 dyn cm^{-2}). One sees two-layer estuarine flows occurring throughout the harbor: in the Narrows, near the mouths of Jamaica Bay and all four rivers and in most regions of Raritan Bay. The surface-to-bottom salinity difference is about 1 $^0/_{00}$ in most parts of the harbor, but exceeds values of 2 $^0/_{00}$ in particular places close to freshwater sources.

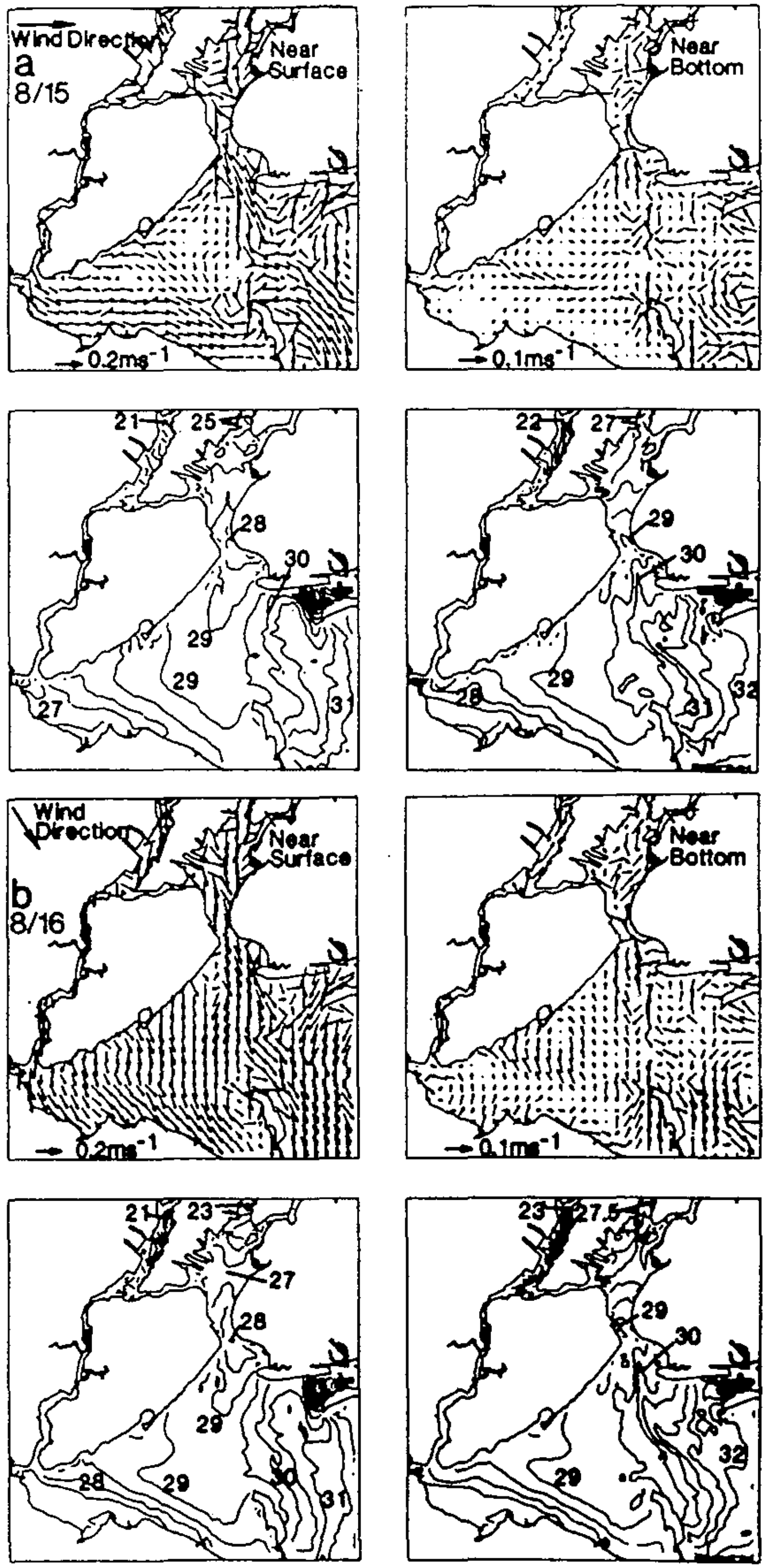


Figure 5. Computed 25-hour average of surface and bottom velocity vectors and salinity contours centered at 1700 GMT on (a) 15; (b) 16; (c) 18 and (d) 22 August. Average wind direction for each period is also shown. Arrows are plotted at every other grid point.

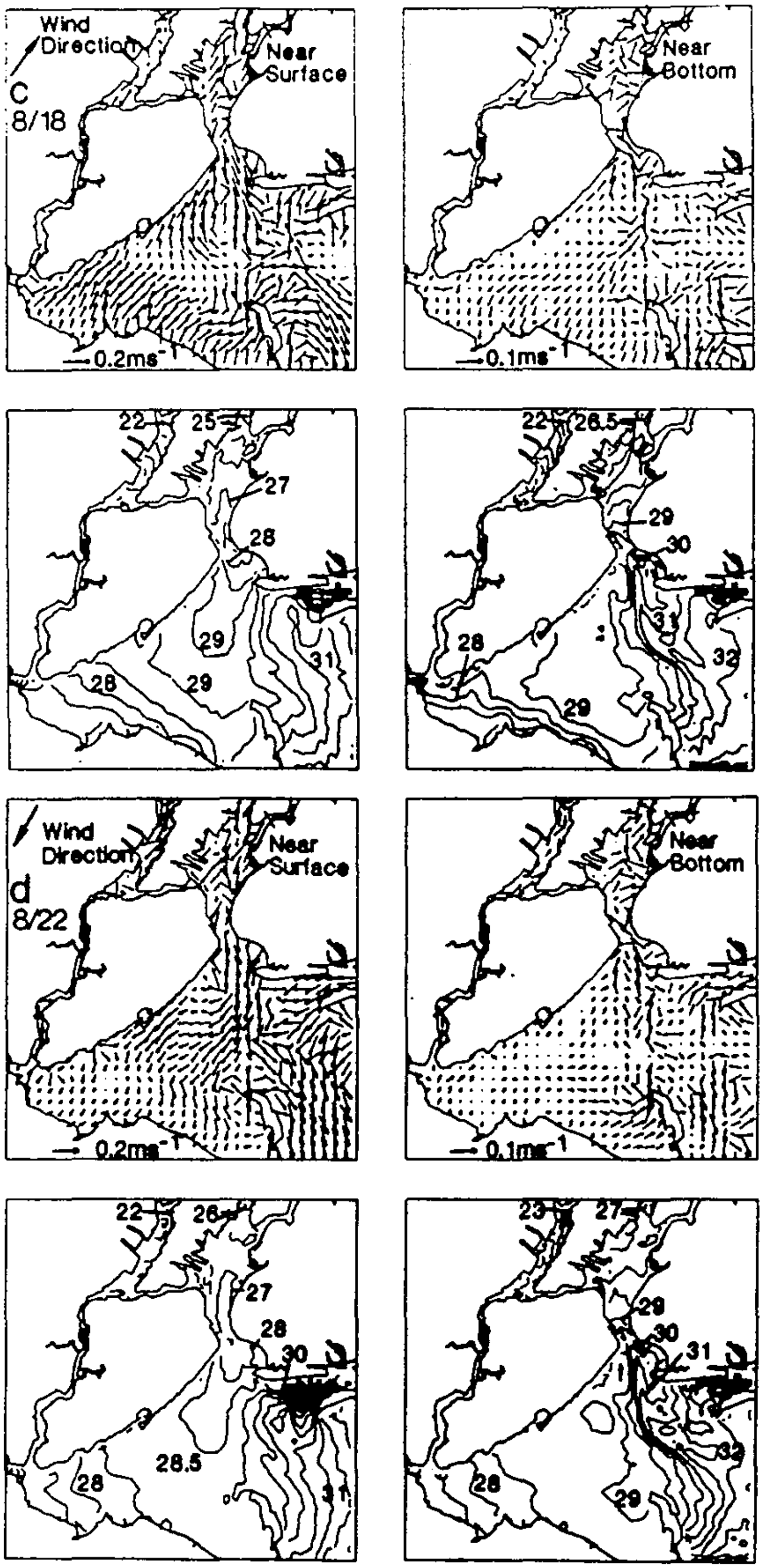


Figure 5 (continued).

On 16 August (Fig. 5b), winds became south-south-eastward and fairly strong (~1 dyn cm^{-2}). The surface current in Raritan Bay responds quickly and turns from an eastward flowing to a southward flowing direction, and there is a corresponding compensating northward flowing bottom current. In Raritan Bay salinity contours pack closer together at the southern shore. Along the Ambrose Channel bottom high-salinity water is seen to intrude farther north into the Estuary, driven now by a stronger, two-layer gravitional flow in response to the southward wind.

On 18 August (Fig. 5c), winds became weak (~0.2 dyn cm^{-2}) and north-northeastward. Currents in Raritan Bay again responded rapidly and the salinity has also relaxed back to its original distribution, show in Fig. 5a. The response in deeper regions is slower. For example, note that a short surface tongue of 29 $^0/_{00}$, just south of the Narrows in Fig. 5a, has now elongated farther southward and that the bottom high-salinity water in Ambrose Channel has intruded farther north into the estuary, both in response to the strong southward wind two days previously.

Winds remained light and north-northeastward until 20-23 August (Fig. 5d) when they became southwestward and stronger (~0.5 dyn cm^{-2}).

The salinity in Raritan Bay became more homogeneous vertically and axially (east-west) and the current structure changed to a "reversed" two-layer circulation, with landward surface and seaward bottom flows. The increase in turbulent mixing will be shown to be caused by unstably stratified water columns inducted by the up-estuary (the westward) wind. Note again the up-estuary intrusion of bottom saline (32 $^0/_{00}$) water along the Ambrose Channel and also the formation of a new tongue of less-saline (28.5 $^0/_{00}$) water just south of the Narrows.

TRANSPORT PROCESSES

The calculation of time-averaged, cross-sectionally averaged, net transport is difficult to achieve with observational data from the Estuary, but can be accomplished with the aid of a three dimensional model. Oey, Mellor, and Hires (1985c) have used their numerical model results to calculate the salt transport processes through the Sandy Hook-Rockaway Point transect. They used an averaging interval of 50 days in order to achieve (nearly) a steady state equilibrium. The simulation period was for the summer of 1980 when freshwater discharge was very low. The cross-sectionally averaged, long term average volume flux through the Sandy Hook-Rockaway Point transect was 180 m^3/s directed seaward, the correspondingly averaged salinity was 30.64 $^0/_{00}$ and the average cross-sectional area is 7.8 x $10^4 m^2$. Thus, we find an overall average seaward advective flux of salt of 5.25 x 10^4 $^0/_{00}$ m^3/s.

We now turn to the various processes which serve to transport salt upstream. A mathematical definition of these processes is provided in Oey, Mellor, and Hires (1985c). Here we will identify by physical process the chief processes which act to balance the downstream adrective transport. We summarize these processes and their magnitude in Table 1. We note that the upstream Stokes transport and the tidal correlation of velocity and salinity variations account for about 90 percent of the total. The steady vertical and horizontal residual circulations are about 0.5 percent and 1.0 percent of the total, respectively.

Table 1

Relative Magnitude of Terms Contributing to an Upstream Flux of Salt Through the Sandy Hook-Rockaway Point Transect

	Description of Process	Magnitude $^0/_{00}$ m^3/s
1.	Stokes transports due to correlation of tidal velocity with cross-sectional area	46,000
2.	Tidal correlation of sectionally-averaged salinity with sectionally-averaged velocity	5,800
3.	Steady vertical residual circulation	240
4.	Steady horizontal residual circulation	500
5.	Unsteady vertical residual circulation (due to variable wind effects)	886

We conclude this chapter by repeating the overall observation made in the introduction; that the residual circulation and transport in the Hudson-Raritan Estuary is complex. The intervening text has been intended to illustrate the processes that contribute to this complexity. From the standpoint of water quality, most of the processes enhance the rate at which wastes are flushed from the Estuary to the adjacent ocean waters. If this waterway were simply a river system without tides and seawater intrusion, then the mean residence time, defined as the volume of the waterway divided by the freshwater discharged through it, would be of the order of 3-6 months for low flow conditions in the Hudson. For the actual Estuary, the mean residence time may be defined as its total volume divided by the net volume discharge rate of estuarine waters to the adjacent ocean. Since for periods of low river discharge the salinity of the outflowing water is only 5-10% less than that for the inflowing ocean water, then simple volume and salt continuity require a net outflow 10-20 times greater than the river discharge. Hence, the mean residence time is of the order of 1-2 weeks. The importance of this reduction of residence time on water quality in the Estuary is obvious.

REFERENCES

Hires, R. L., Oey, L. Y., and Mellor, G. L. 1984. Numerical model studies of the tidal hydraulics of Raritan Bay. Bull. N.J. Acad. Sci. 29(2):59-68.

Kao, A. 1975. A study of the current structure in the Sandy Hook-Rockaway Point transect. Unpublished research paper. Marine Science Research Center, State University of New York, Stony Brook.

Lonquet-Higgins, M. S. 1969. On the transport of mass by time varying currents. Deep Sea Res. 16:481-447.

Oey, L. Y., Mellor, G. L., and Hires, R. L. 1985a. Tidal modeling of the Hudson Raritan Estuary. Estuarine, Coastal and Shelf Science. 20:511-527.

Oey, L. Y., Mellor, G. L., and Hires, R. L. 1985b. A three dimensional simulation of the Hudson Raritan Estuary. Part I: Description of the model and model simulations. J. Phys. Oceanogr. 15(12):1676-1692.

Oey, L. Y., Mellor, G. L., and Hires, R. L. 1985c. A three dimensional simulation of the Hudson Raritan Estuary. Part III. Salt flux analyses. J. Phys. Oceanogr. 15 (12):1711-1720.

Pritchard, D. W., 1952. Salinity distribution and circulation in the Chesapeake Bay estuarine system. J. Mar. Res. 11(2).

A BRIEF SUMMARY OF THE GEOLOGY OF RARITAN BAY

Henry Bokuniewicz
Marine Sciences Research Center
State University of New York
Stony Brook, NY 11794-5000

Introduction

Raritan Bay is part of a interconnected series of bays, rivers, estuaries, and tidal straits that form the Hudson-Raritan estuarine system (Fig. 1). Raritan Bay and its two neighboring bays, the Lower Bay of New York Harbor and Sandy Hook Bay, compose the Lower Bay complex which covers an area of about 250 km^2. The other components of this estuarine system include the Arthur Kill, the Upper Bay of New York Harbor, the Kill van Kull, Newark Bay, the Hackensack and Passaic rivers, the East River, and the Hudson River estuary.

The Hudson-Raritan estuarine system spans two major geologic boundaries (Fig. 2). The first boundary is the landward limit of the coastal plain separating the young fringe of coastal plain sediments from the old continental rocks of the interior of North America. It lies between the ancient crystalline rocks of the Piedmont and New England physiographic provinces, and the geologically younger, thick sediment layers of the Coastal Plain Province and their extension on the continental shelf. This boundary cuts northasterly across Staten Island then along the East River to Long Island Sound. To the north and west lie Triassic and Paleozoic rocks that are 190 to 570 million years old, and Pre-cambrian rocks which are greater than 570 million years old. To the south and east are the coastal plain sedimentary layers. These are all younger than 136 million years.

The second major geologic boundary is the Harbor Hill Moraine. This is a ridge of mixed, poorly sorted, unconsolidated particles of all sizes, from boulders to fine clay. This moraine was formed at the edge of the great ice sheet during the last, or Wisconsin, glaciation. The moraine forms the northern backbone of Long Island. It is breeched by the Narrows and continues westwardly across Staten Island to where it is cut by the Arthur Kill at Wards Point at the southern tip of Staten Island. Crossing into New Jersey, it serves as the north bank of the Raritan River for a short distance before heading further west across the state and beyond. To the north of the moraine

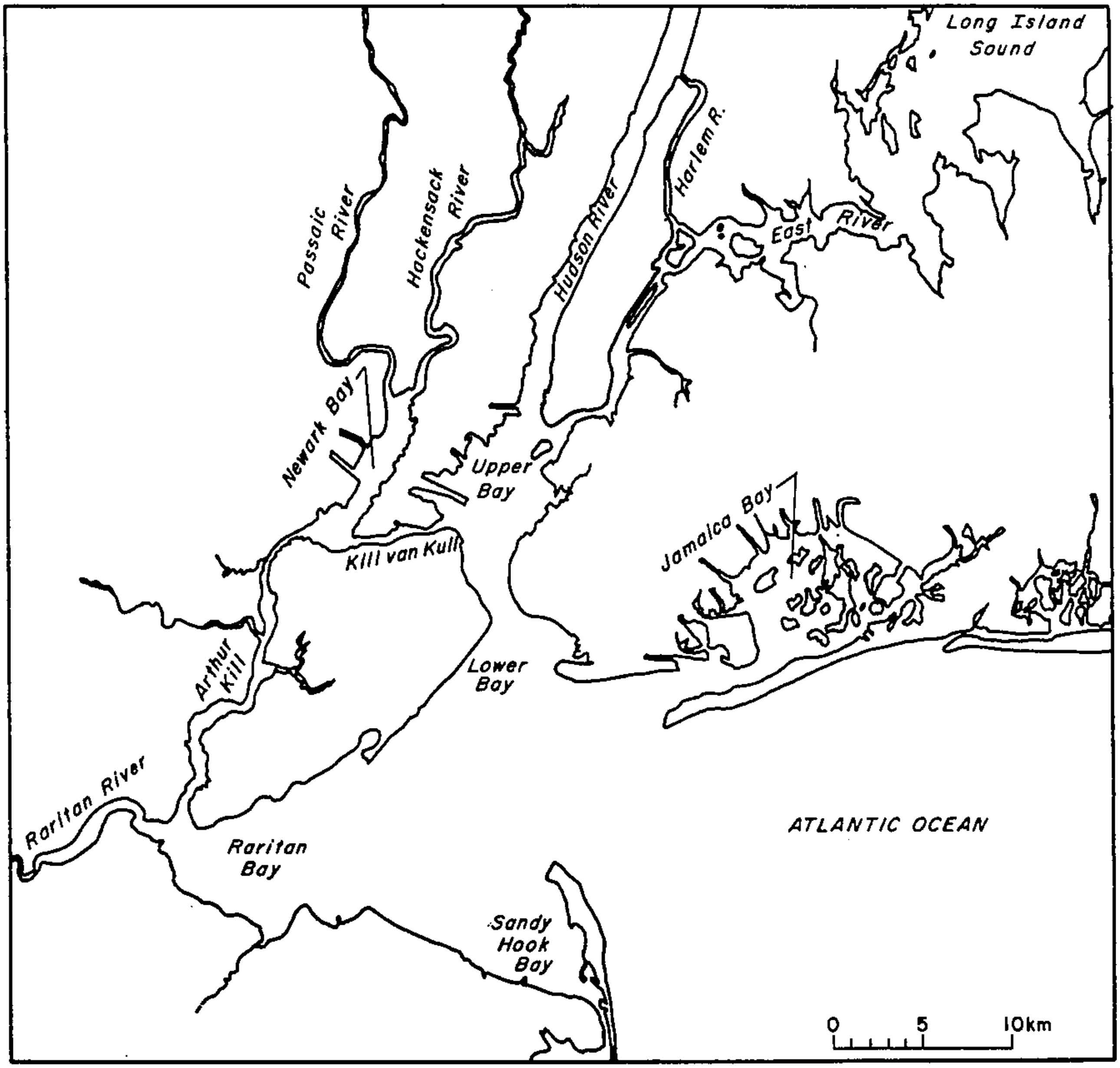


Figure 1. Geographic index map of the Hudson-Raritan estuarine system.

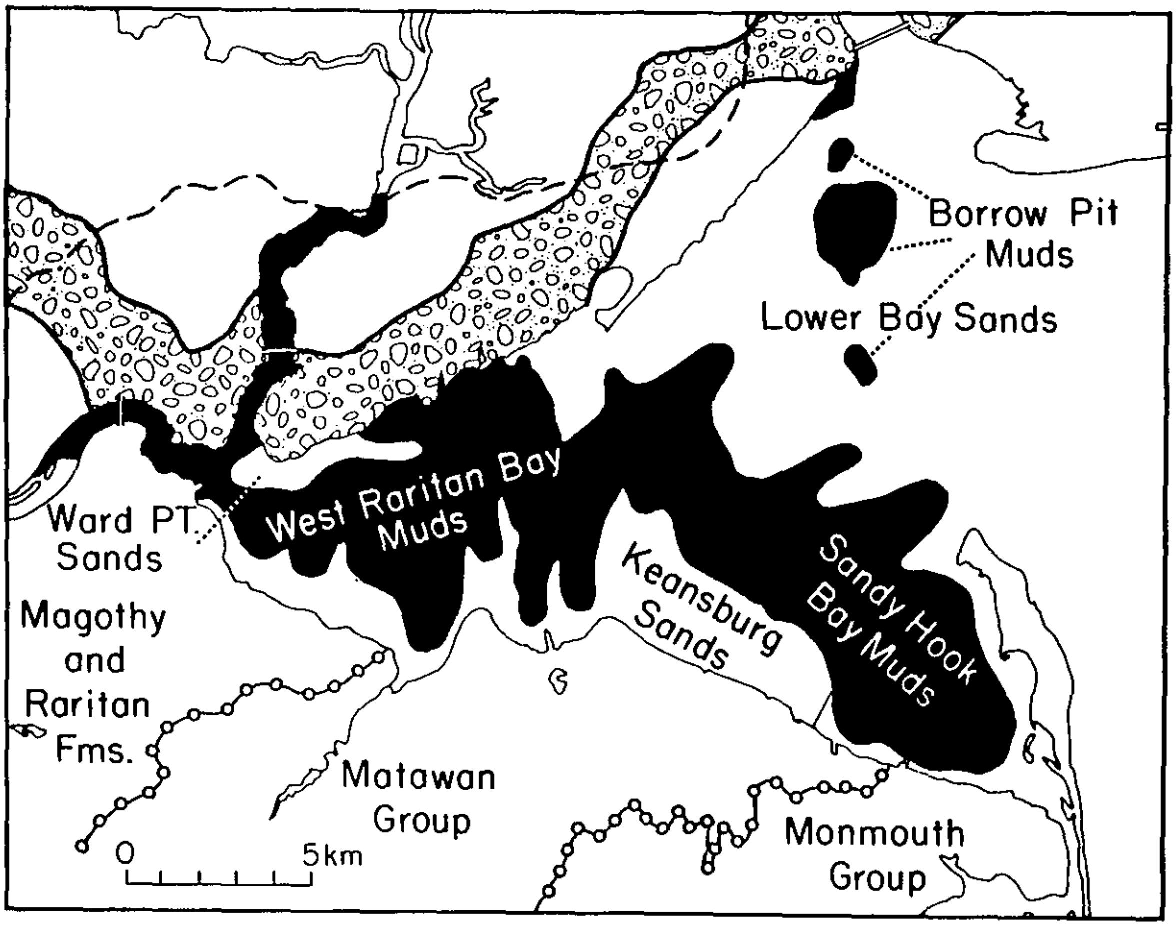


Figure 2. Summary of geologic features in and around the Hudson-Raritan estuarine system. The heavy dashed line marks the landward limit of the Coastal Plain Province and the ornamented band represents the Harbor Hill Moraine. The approximate distribution of marine mud is shown by the darkened areas of the estuarine floor and, in New Jersey, the outcropping of the Cretaceous Raritan and Magothy formations and Matawan and Monmouth groups are indicated.

the terrain has been sculptured directly by the slowly moving glaciers and then blanketed with sediments from melting ice. These sediments are called glacial till and typically contain not only sand and gravel, but also large rock fragments and boulders as well as silt and clay. South of the moraine, however, thick layers of sand and gravel were deposited by streams that drained the melting ice. These deposits are callled outwash sand and the sand grains in the outwash sands are more uniform in size. Boulders that could not be carried by streams were left north of the moraine and very fine-grained silts and clays were, for the most part, washed out to sea. Because so much of the world's water was frozen in the glacial ice caps, sea level at that time was much lower than it is today. The outwash sands were deposited far out on what is now the continental shelf. The area that is today covered by Raritan Bay was then dry land crossed by an ancestral Raritan River that predates the Hudson.

The shores of Raritan Bay lie entirely on the coastal plain. Its northern shore is formed by the moraine reaching down along the Staten Island coast to the Arthur Kill. The southern coast is much older. Except for two small patches of glacial outwash sand, the southern shore of the bay is cut into Cretaceous ands and clays between 75 and 66 million years old. The oldest strata is called the Raritan Formation and stacked on top of that layer are, in order, the Magothy Formation, the Matawan Group, and the Monmouth Group. These layers have been tilted toward the sea, so that the surface of New Jersey cuts across their ends with the oldest sediments being found in the west and the youngest in the east. All of these strata have also been truncated by erosion at the shores of Raritan and Sandy Hook bays.

The character of the southern coastline also changes markedly from west to east. The lowlands and marshes of the western south shore of Raritan Bay give way to the high bluffs of the Highlands of Navesink (also called the Atlantic Highlands) which boarder Sandy Hook Bay. Sandy Hook Bay terminates at its eastern end with the youngest stretch of shoreline in this region. The sand spit of Sandy Hook has been formed over the last few thousand years by wave-driven sand from New Jersey's Atlantic coast.

The Bay Floor

Despite the fact that Raritan Bay has long served the needs of a large population, systematic and comprehensive studies of the Bay floor have only recently been completed. Four major sedimentary regions were first defined by Nagle in 1967. These sediment bodies are called the Sandy Hook Bay Muds, the West Raritan Bay Muds, the Keansburg Sands, and the Lower Bay Sands. Subsequent investigations were done by Yuan (1976); Kastens, Fray, and Schubel (1978); Jones, Fray, and Schubel (1979); Bokuniewicz and Fray (1979); Multer, Stainken, McCormick, and Berger (1984); and, most recently, Coch (1986). The sophistication and detail added by these researchers are indispensable to geologists studying the Bay's estuarine system. For a more general discussion, however, the basic classification of Nagle remains a valid description with relatively minor modifications (Fig. 2). The division of the bay floor into areas of sand and areas of mud is also meaningful. The accumulation of fine-grained sediments is usually indicative of lower energy conditions and a protected environment. In contrast, the presence of sand often characterizes high energy conditions and an environment exposed to vigorous waves or strong tidal currents. In addition, many of the most troublesome contaminants are associated with fine-grained sediments. As a result, the distribution of these contaminants is governed by the occurrence of fine-grained sediment.

The principal area of mud accumulation extends from Raritan Bay into Sandy Hook Bay. The sediment generally becomes finer to the west towards the mouth of the Raritan River estuary (Coch, 1986). South of the mud deposit, sand is found along the New Jersey coast. This sand appears to be derived from the erosion of the Cretaceous beds of sand at the New Jersey shore; apparently the prevailing winter northwesterly winds can raise waves of sufficient energy to prevent the deposition of fine-grained sediment near this coast (Multer et al., 1984).

North of the muds of Raritan Bay and Sandy Hook Bay, extensive sand banks are found (Coch, 1986; Kastens et al., 1978; Jones et al., 1979). These sediments are primarily relict glacial sands and they cover almost the entire floor of the Lower Bay. Strong tidal currents at the mouth of the Lower Bay have reworked these deposits into large shoals and the penetration of ocean waves into the Lower Bay prevent the retention of fine-grained sediment except at a few small but significant sites (Multer et al., 1984). These sites are borrow pits that were produced by sand mining operations. Within the pits, mud accumulates at rapid rates, even though conditions prevent its deposition on the surrounding sand banks (Olsen et al., 1984).

Post-Glacier History

At the peak of the Wisconsin glaciation, about 20,000 years ago, ice covered New England, New York, and Northern New Jersey to the position marked by the Harbor Hill moraine. The ice cover was probably about 500 m thick at its southern margin. The volume of water contained in the glacial ice caps was sufficiently extensive so that sea level at the time was about 130 m below its present level. At the edge of the ice in New Jersey a large lake had formed, called Glacial Lake Passaic. Water from the lake, and numerous streams carrying meltwater from the glacier into the Raritan drainage basin, fed the ancestral Raritan River. The ancestral Raritan River was likely to be one of the principal rivers of its time crossing 175 km of the exposed continental shelf to reach the ocean.

The glacier retreated from this region no later than 15,000 years ago. The size of Lake Passaic increased and other large lakes were formed north of the moraine (Reeds, 1930). Glacial Lake Hackensack developed behind the moraine on Staten Island covering the present site of Newark Bay and the Hackensack Meadowlands. The Narrows were damed by the moraine and Glacial Lake Hudson extended over what is now the Upper Bay of New York Harbor and the Hudson River estuary. The sites of the East River and western Long Island Sound were submerged beneath Glacial Lake Flushing. Since the Narrows were blocked, much, if not most, of the drainage from these lakes may have found a path to the sea in the ancestral Raritan River.

Although the timing is uncertain, a very large river certainly flowed eastward south of Staten Island, across the present day sites of Raritan Bay, Sandy Hook Bay, and Sandy Hook and out onto the exposed shelf. Borings between Staten Island and New Jersey disclosed a narrow channel, reaching a depth of about 46 m, buried in the muds of Raritan Bay (MacClintock and Richards, 1936). The Highlands of Navesink were probably formed as the southern wall of a large river valley; this landform is known as a cuesta. Under Sandy Hook, about midway along its length, two mud bodies are found (Minard, 1969). These deposits are about 10,000 years old and they lie at depths of -30 and -40 m. On the ocean side of Sandy Hook, the Highland Channel extends southwestwardly from the midpoint of Sandy Hook. This channel appears to be the remnant of the ancient Raritan River valley (Willans and Duane, 1974). It seems likely that the mud deposits under Sandy Hook are remnants of the mud infillings of the old channel that have subsequently been eroded and overlain with the beach sands of Sandy Hook.

The high water era of the Raritan River was nearing its end about 12,500 years ago (Newman et al., 1969). Around that time, the Harbor Hill Moraine was breeched further to the north, and drained through this gap, perhaps catastrophically. This discharge established the lower reaches of the ancestral Hudson River which ran through what is now the Lower Bay (Kastens et al., 1978) and down the Hudson Channel to the sea.

The channels of the ancient Raritan and Hudson rivers were deep, and long before rising sea level had pushed the ocean shoreline near its present position, these channels became arms of the sea. Estuarine conditions were established in the Hudson about 12,000 years ago when sea level was still 28 m below its present position (Newman et aal., 1969). The channel of the Raritan which reaches a depth of -46 m south of Staten Island would have similarly flooded at this time. The formation of estuaries was probably accompanied by the widespread deposition of marine mud.

The ability of estuaries to trap fine-grained sediment is well documented (eg., Schubel and Carter, 1984; Biggs and Howell, 1984). The characteristic estuarine circulation carries saline bottom water into the estuary while fresher surface water flows outwardly. The estuary's protected nature coupled with this recirculation enhances the retention of fine-grained sediment on the estuary floor. Many estuarys not only appear to be 100% efficient in trapping the sediment supplied by their rivers but also seem to import additional material from adjacent coastal waters. Such estuaries include not only the Raritan River estuary (Renwick and Ashley, 1984) but also Long Island Sound (Bokuniewicz, Gerbert and Gordon, 1976), Chesapeake Bay (Schubel and Carter, 1977), Newark Bay (Suszkowski, 1978), and the Hudson River estuary (Ellsworth, 1986). As a result, it is likely that the deposition of estuarine mud began early in both the Hudson River estuary and the ancestral Raritan River estuary.

As estuarine muds began to fill the Raritan River estuary under the present-day site of Raritan Bay, rising sea level gradually flooded its banks and invaded larger areas of the Lower Bay complex. Simultaneously, as the shoreline was pushed back over the coastal plain, sediments and layers of outwash sand, waves drove sand northward along the New Jersey shore to form Sandy Hook. The sand spit eventually crossed the ancient river valley and the continued deposition of mud obliterated its relief.

At the present time, fine-grained sediment is accumulating on the floor of the Raritan Bay at a rate of about 0.15 cm/yr (Olsen et al., 1984). Particles are resuspended, dispersed, and redeposited many times, however, before they are finally buried in sediment deposits. Sediment traps in the Lower Bay show that particles rain onto the bay floor at a rate of 16 $mg/cm^2/day$, but the long-term rate of accumulation in Raritan Bay is only 0.3 $mg/cm^2/day$. More than 98% of the particles that settle to the bay floor are resuspended. It should be noted that this activity does not mean that particles escape from the estuarine system, it is still an effective sediment trap. Deposition in the estuarine system can accommodate all the sediment that is delivered to it (Bokuniewicz and Ellsworth, 1986).

Anthropogenic Influences

The next significant changes were human-made ones - the dredging of navigation channels, subaqueous sand mining and the introduction of contaminants. There are over 380 km of dredged channels in the Hudson-Raritan estuarine system (Conners et al., 1979). These require the dredging and disposal of over 6 million cubic meters of sediment every year (Schubel and Summers, 1985). The removal of dredged sediment from navigation channels to disposal areas, primarily on the Atlantic Shelf, could account for as much as two-thirds of all the fine-grained sediments removed from transport in the Hudson-Raritan estuarine system (Bokuniewicz and Ellsworth, 1986). Dredging and disposal activity is probably also the principal mechanism for the transport of contaminants from the estuarine system (Gross, 1972).

The rate of deposition of sediment in dredged areas greatly exceeds the rate of deposition in undisturbed areas (Olsen, 1979; Tavolaro, 1986). Based on the dredged records the rate of desposition in the Raritan Bay Channel is about 17 cm/yr or up to 100 times the rate of deposition on the ambient bay floor. The conventional wisdom is that the deposition rates are so high because the dredged areas are not in equilibrium with the ambient sea floor but the exact nature of the disequilibrium is unknown and rates of deposition cannot be predicted.

All of the sediment deposited in navigation channels is eventually dredged and removed to a disposal site outside of the estuarine system. Some dredged areas are not maintained, however, and serve as sites for the formation of permanent mud deposits. The most important of these sites are borrow pits resulting from subaqueous sand mining operations. The glacial outwash sands that are submerged beneath the Lower Bay are a valuable, natural resource. Sand and gravel are needed for construction aggregate, landfill, and beach nourishment, and about 42 million cubic meters of sand were removed from the Lower Bay between 1950 and 1979 (Bokuniewcz, 1987). The pits that remain from these operations cover more than 4 km^2 and fine-grained sediment is now accumulating in these pits at rates as high as several centimeters per year (Olsen et al., 1984). These features may account for more than 75% of all the fine-grained sediment that accumulates in the Lower Bay complex, including Raritan and Sandy Hook bays. They are capable of absorbing a full 3% of the entire amount of sediment supplied annually by the Hudson River. Human activity has substantially modified and continues to influence the geological processes in the Hudson-Raritan estuarine system.

The composition of the sediment in the Hudson-Raritan estuarine system has also been dramatically altered anthropogenically by the introduction of many particle-associated contaminants such as pesticides, polychlorinated biphenyls, petroleum hydrocarbons, trace metals, and radionuclides. Because of the multiplicity of sources for these contaminants and because of the high degree of interconnection between water bodies in the Hudson-Raritan estuarine system, elevated levels of contaminants are likely to be found wherever fine-grained sediments are accumulating (Bokuniewcz and Coch, 1986; Olsen et al., 1984). In the old, presumably pristine sediments of New York Harbor, for example, lead levels may be about 25 ppm but lead concentrations are about 390 ppm in fine-grained sediments of the Upper Bay, 340 ppm in Newark Bay and 195 ppm in Raritan Bay (Olsen et al., 1984). The average concentration of copper is 280 ppm in Raritan Bay or about 14 times higher than the unpolluted background levels (Olsen et al., 1984). This magnitude of enrichment is common and, generally, contaminant levels increase toward the Raritan River (eg., Grieg and McGrath, 1977). Such a distribution is related to the decrease in grain-size in western Raritan Bay and perhaps, in part, to the influence of local sources.

The total accumulation of contaminants is disparate both among different components of the Hudson-Raritan system and among different areas of the same component. The annual accumulation of lead, for example, is 475 tons in the inner Harbor of New York, 60 tons in Newark Bay and 25 tons in Raritan Bay; copper accumulates at a rate of 270 tons/years in the inner Harbor but only 35 tons/year in Raritan Bay (Olsen et al., 1984). These differences arise because the rate of accumulation is dependent not only on the concentration of contaminant, but also on the area covered by fine-grained deposits and the sedimentation rate. Furthermore, because of the very great differences in sedimentation rate between dredged areas of the bay floor and undredged areas, dredged areas accumulate a disportionately large amount of the total contaminant load to particular area. As a result, undredged areas of Raritan Bay are not a significant sink for contaminants (Olsen et al., 1984). The contaminant burden that accumulates in navigation channels will eventually be removed to a disposal site (Gross, 1976) but the rapidly accumulating deposits in borrow pits or similar regions will be major, permanent, regional sinks for particle-associated contaminants.

Sewage plays only a minor role as a source of particles to the estuarine system. Less than 10% of the total supply of particles is due to sewage (Olsen et al., 1984; Bokuniewcz, and Ellsworth, 1986). Sewage, however, carries a disportionately large concentration of contaminants (Olsen et al, 1984). It is also a source of nutrients and organic matter resulting in increased production in the water column and high demands of dissolved oxygen).

Conclusion

The fate of Raritan Bay cannot be divorced from that of its neighbors in the Hudson-Raritan estuarine system. The estuarine nature of the Bay makes it a trap for fine-grained particles and their associated contaminants. Within the estuarine system, however, the sedimentary processes are dispersive and the fates of sediment particles is dominated by human ability to relocate large quantities of sediment.

On the floor of Raritan Bay, the sedimentation rate is only 1 to 2 cm/yr. Particles that do settle on the sea floor are likely to be resuspended, dispersed, and redeposited many times before they are finally buried in a permanent deposit. During this process, particles can be interchanged among the different bodies of water in the Hudson-Raritan estuarine system because of the high degree of connectiveness which characterizes this system. As a result, it seems likely that a change in the magnitude of any particular source of contamination in one area will not have a large local impact but rather should have a smaller impact throughout the system. Furthermore, because of generally low sediment rates, the effects of reductions in the supply of contaminants to the system is unlikely to be detectable on the sea floor for many years.

Most of the contaminated sediment is deposited in dredged channels, anchorages, and borrow pits. Although some of the deposits (e.g., those borrow pits) must be considered to be permanent additions to the estuary floor, almost all of this material is eventually removed from the system by maintenance dredging operations.

REFERENCES

Biggs, R.B. and Howell, B.A. 1984. The estuary as a sediment trap: Alternate approaches to estimating its filtering efficiency. IN: Kennedy (ed.), The Estuary as a Filter. Academic Press, NY: 107-129.

Bokuniewicz, H.J. 1987. Sand mining in New York Harbor: a chronology. Jour. Marine Mining: in press.

Bokuniewicz, H.J. and Conch, N.K. 1986. Some management implications of sedimentation in the Hudson-Raritan estuarine system. Jour. NE Geology, 8:165-170.

Bokuniewicz, H.J. and Ellsworth, J.M. 1986. Some management implications of sedimentation in the Hudson-Raritan estuarine system. Jour. NE Geology, 8:156-164.

Bokuniewicz, H.J. and Fray, C.T. 1979. The volume of sand and gravel resources in the Lower Bay of New York Harbor. Marine Sciences Research Center, Spec. Rpt. 32, State University of New York, Stony Brook, NY: 34 pp.

Bokuniewicz, H.J., Gebert, J.A., and Gordon, R.B. 1976. Sediment mass balance in a large estuary: Long Island Sound. Estuarine and Coastal Marine Science, 4:523-536.

Coch, N.K., 1986. Sediment characteristics and facies distribution in the Hudson system. Jour. NE Geology, 8:109-129.

Conners, W.G., Aurand, D., Leslie, M., Slaughter, J., Amr, A., and Ravenscroft, F.I. 1979. Disposal of dredged material within the New York District: Vol. 1 - Present practices and candidate alternatives. MITRE Corporation, McLean, VA: 362 pp.

Ellsworth, J.M. 1986. Sources and sinks for fine-grained sediments in the Lower Hudson River. Jour. NE Geology, 8:141-155.

Gross, M.G., 1972. Geological aspects of waste solids and marine waste disposal in the New York metroplitan region. Geological Society of American Bulletin 83:3163-3176.

Jones, C.R., Fray, C.T., and Schubel, J.R. 1979. Textural properties of surficial sediments of Lower Bay of New York Harbor. Marine Sciences Research Center, Spec. Rpt. 21, State University of New York, Stony Brook, NY: 113 pp.

Kastens, K.A., Fray, C.T. and, Schubel, J.R. 1978. Environmental effects of sand mining in the Lower Bay of New York Harbor. Marine Sciences Research Center, Spec. Rpt. 15, State University of New York, Stony Brook, NY: 139 pp.

MacClintock, P. and Richards, H.G. 1936. Correlation of Late Pleistocene marine and glacial deposits of New Jersey and New York. Geological Society of America Bulletin, 47:289-338.

Minard, J.P. 1969. Gelogy of the Sandy Hook Quadrangle in Monmouth County, New Jersey. U.S. Geological Survey Bulletin, 1276: 43 pp.

Multer, H.G., Staiken, D.M., McCormick, J.M., and Berger, K.J. 1984. Sediments in the Raritan Bay - Lower New York Bay Complex. Bulletin of the New Jersey Academy of Sciences, 29:79-96.

Nagle, J.S. 1967. Geology of Raritan Bay. In: The report for the conference on pollution of Raritan Bay and adjacent interstate waters, third session Volume III - appendices. Federal Water Pollution Control Administration.

Newman, W.S., Thurber, D.H., Zeiss, H.S., Rokach, A., and Musich, L. 1969. Late Quarternary geology of the Hudson River estu- ary: A preliminary report. Transactions of the New York Academy of Sciences, 31:548-570.

Olsen, C.R., 1979. Radionuclides, sedimentation, and the accumulation of pollutants in the Hudson estuary. Ph.D. thesis, Columbia University, New York, NY: 343 pp.

Olsen, C.R., Larsen, I.L., Brewster, R.H., Cutshall, N.H., Bopp, R.F., and Simpson, H.J., 1984. A geochemical assessment of sedimentation and contaminant distributions in the Hudson-Raritan estuary. National Oceanic and Atmospheric Administration, Tech. Rpt. NOS OMS 2:101 pp.

Reeds, C.A. 1930. The geology of New York City and vicinity. American Museum of Natural History Guide Leaflet Series 56:1-36.

Renwick, W.H. and Ashley, G.M., 1984. Sources, storage, and sinks of fine-grained sediment in a fluvial-estuarine system. Geological Society of American Bulletin 94:1343-1348.

Schubel, J.R. and Carter, H.H., 1977. Suspended sediment budget for Chesapeake Bay. In: Wiley (ed.), Estuarine Processes Vol. II - Circulation, Sediments, and Transfer of Material in the Estuary. Academic Press, NY:48-62.

Schubel, J.R. and Carter, H.H., 1984. The estuary as a filter for fine-grained suspended sediment. In: Kennedy (ed), The Estuary as a Filter, Academic Press, NTY: 81-105.

Schubel, J.R., and Summers, R.M., 1985. Volume 1. Dredging and dredged material disposal in the Port of New York and New Jersey: A case study and an assessment of alternatives. Marine Sciences Research Center, Spec. Rpt. 60, State University of New York, Stony Brook, NY: 125 pp.

Suszkowski, D.J., 1978. Sedimentology of Newark Bay, New Jersey: an urban estuarine bay. Ph.D. thesis, University of Delaware: 222 pp.

Tavolaro, J., 1986. Sedimentology in the upper East River: an urban tidal strait. Unpublished Masters thesis. Queens College, City University of New York, New York, NY: 218 pp.

Williams, S.J., and Duane, D.B., 1974. Geomorphology and sediments of the inner New York Bight Continental Shelf. U.S. Army Corps of Engineers Coastal Engineering Research Center, Tech. Mem. No. 45: 81 pp.

Yuan, J., 1976. Sediments in the Lower New York and Raritan Bays. Ph.D. thesis, Lehigh University, Bethleham, PA, 202 pp.

AN OVERVIEW OF THE BIOLOGICAL RESOURCES OF THE HUDSON-RARITAN ESTUARY

Anne L. Studholme
US Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Center
Sandy Hook Laboratory
Highlands, NJ 07732

Development of strategies for conserving and managing living resources in inshore coastal and estuarine areas is a complex, and at times confusing, process. Information needs identified by those charged with policy planning and implementation may not be met directly by those engaged in research. Nevertheless, with over 65% of coastal finfish and 90% of shellfish dependent on the estuary for all or part of their life cycle (Weinstein, 1977), there is general agreement that informed decisions on the risks associated with multiple-use must be predicted on an understanding of the status and function of these resources.

The aim of this paper is to present an overview of biological resources in the Hudson-Raritan estuary--a system surrounded by the most heavily populated region in the country (Fig. 1). Extending from the freshwater portions of the Hudson River, past brackish waters along Manhattan and the Upper Bay, through the Narrows and into the triangular complex of Lower, Raritan, and Sandy Hook bays, this estuary presents varied and challenging environments for living organisms.

A wide range of habitats in this system attracts and supports a diverse biota (Table 1). These include numerous species of microscopic phytoplankton and zooplankton; the polychaetes, molluscs, crustaceans, and other species which comprise the benthic fauna; and over a hundred species of finfish, ranging from the anadromous spawners and marine migrants to the juveniles which depend upon these protected habitats during critical periods in their development. In contrast with the relative stability of oceanic waters, these species are subject to wide fluctuations in salinity, dissolved oxygen, and temperature, as well as other natural factors. As a consequence, many estuarine species are naturally resilient to changes in their environment--even some of those which result from anthropogenic activities.

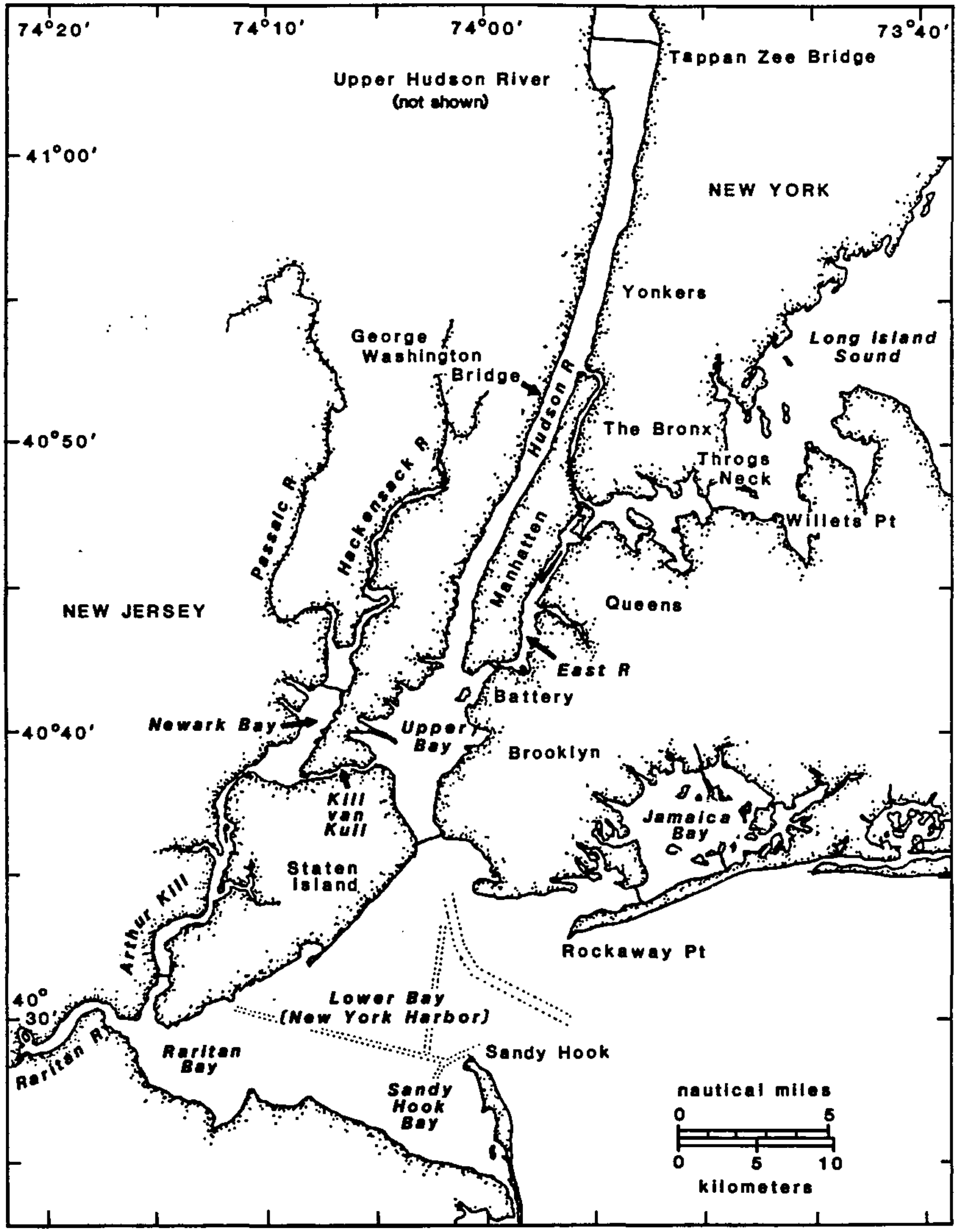


Figure 1. The Hudson-Raritan Estuary.

Table 1. Maximum number of taxa recorded in the Hudson-Raritan estuary.

Category	Area	Number of Taxa	Reference
Phytoplankton	Lower Bay	313	Olsen and Cohn, 1979
Zooplankton	Lower Bay	38	Sage and Herman, 1972
Benthos	Lower Bay	179	Gandarillas and Brinkhuis, 1981
	Hudson River	105	Ristich et al., 1977
Fishes	Lower Bay	117	Walford, 1971
	Hudson River	113	Texas Instruments, 1977

Nevertheless, multiple-use over many decades has altered this estuary, affecting not only the diversity and abundance of its natural resources but also their uses.

Typically, as is characteristic of estuaries in general, productivity, which is an expression of its energy output, is higher than in other ecological systems (Armstrong, 1984). Pri mary production begins with the phytoplankton, which through photosynthesis, produce organic material which can be used as food. In the Hudson-Raritan system, rooted aquatic vegetation is currently sparse and consequently most productivity is attributed to the other, smaller forms. Estimates of annual production in the Hudson and upper reaches of New York Harbor range from 100-200 g $Cm^{-2}y^{-1}$, comparable to that of other East Coast estuaries (Berg and Levinton, 1985). As noted by Pearce (this volume), total primary production in Sandy Hook and Raritan Bays (Fig. 2) can reach from 550 to 775 g $Cm^{-2}y^{-1}$ (O'Reilly et al., 1976, pers. comm.) and exceeds values of most other marine environments where phytoplankton are major organic producers.

Communities of phytoplankton vary seasonally. The netplankton which include large and chained diatoms, e.g., _Skeletonema_, predominate in the winter, spring, and fall, while smaller forms, such as nanoplankton, are most abundant in the summer and contribute 80-90% of the annual productivity (Patten, 1962; O'Reilly, pers. comm.). Shifts from larger diatoms to smaller nanoplankton may have direct consequences on utilization of phytoplankton by herbivorous secondary consumers. Certain copepods and filter-feeding bivalves, which depend on netplankton, cannot effectively use these smaller cells, and, in fact, starve (Pearce, 1979).

A principal limiting factor for primary production is the depth to which light penetrates. This depends on the quality and quantity of suspended particulate matter, i.e., turbidity. Processes of resuspension, high densities of phytoplankton and natural loading of seston and other matter contribute to high levels of turbidity in the Hudson-Raritan system and effectively reduce the euphotic zone to depths of only 2-3 m. This contrasts with depths of 50-100 m in offshore coastal waters.

High levels of nutrients are always available since this estuarine system is the receiving body for raw and processed sewage from 15 million people in the metropolitan area. Phytoplankton, however, use only about 10%, with the remainder of the

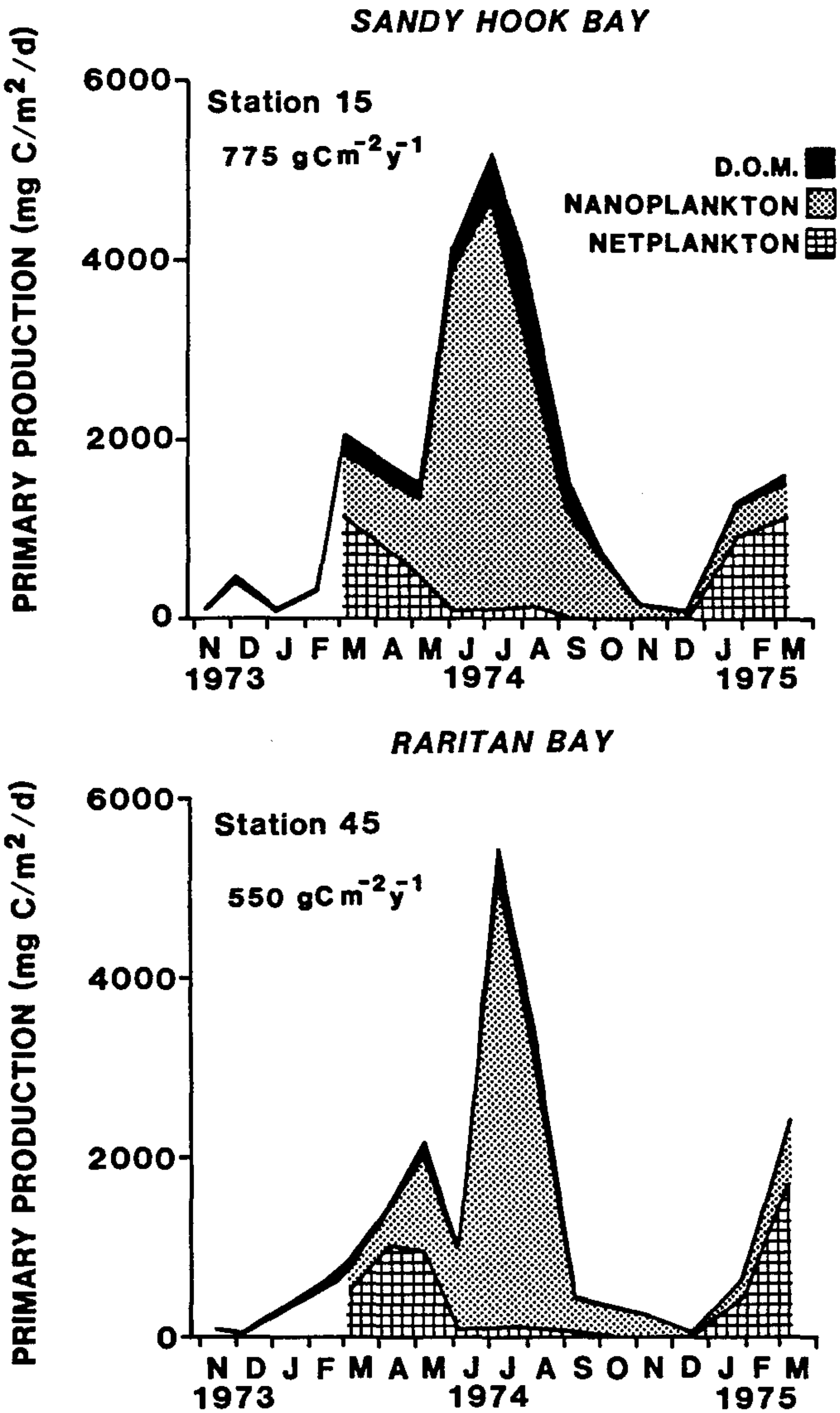


Figure 2. Seasonal changes in primary productivity at selected stations in Sandy Hook and Raritan Bays (after O'Reilly et al., 1976; pers. comm.).

nutrient load discharged into the coastal plume. This plume plays a major role in affecting water quality along the New Jersey coast.

Zooplankton in the Hudson-Raritan system represent nearly every major taxonomic group typical of other eastern North American estuaries (Berg and Levington, 1985). In Sandy Hook Bay, peaks occur from May to September (Fig. 3) but whether these are correlated with phytoplankton shifts is not clear. In Sandy Hook Bay, abundance can reach 50,000 organisms m^{-2}; in the Arthur Kill, maximum levels may reach 120,000 organisms m^{-2}. Calanoid copepods are usually the dominant organisms in Raritan Bay and the Arthur Kill. In the Hudson River, they can comprise 70-90% of the zooplankton and function as a major link between primary producers and fishes (Weinstein, 1977). In this system, there appears to be a synchronization of biological activity with changing seasonal patterns mediated through changes in zooplankton abundance. For example, populations of copepods, *Eurytemora affinis*, are high in March, April, and May when larval herring, stripped bass, white perch, smelt, and menhaden begin feeding actively (Fig. 4). These copepods are most abundant at salinities of 5-12‰, coinciding with the riverine portion in which the larval fish reside. During the summer, *Acartia tonsa* replaces *E. affinis* in the warmer, more saline (10-20‰) downsteam waters. This, in turn, corresponds to the movement of the young fish downstream and provides a continuing food supply for juveniles as they develop in the estuary.

Benthic organisms, e.g., crustaceans, molluscs, and polychaetes, are a major component in estuarine productivity, serving as prey for demersal fishes and epibenthic invertebrates and as consumers of plankton. Benthic communities also function in the energy flow and nutrient recycling in the seabed. In addition, the relative "health" or condition of an estuarine system can often be used to assess habitat quality by examining changes in benthic diversity and abundance.

Prior to the mid-50's, there is little quantitative data available on the status of benthic organisms in the Hudson-Raritan estuary. There is, however, documentation that indicates a decline in diversity of molluscan species had occurred in areas around Staten Island by 1920 (Jacot, 1920; Franz, 1982). This was attributed, in part, to development of sewage outfalls, use of petroleum driven vessels, and disappearance of eelgrass beds. The earliest extensive benthic survey was conducted from 1957-1960; 193 stations were sampled in the Lower Bay complex each summer (Dean and Haskin, 1964; Dean, 1975).

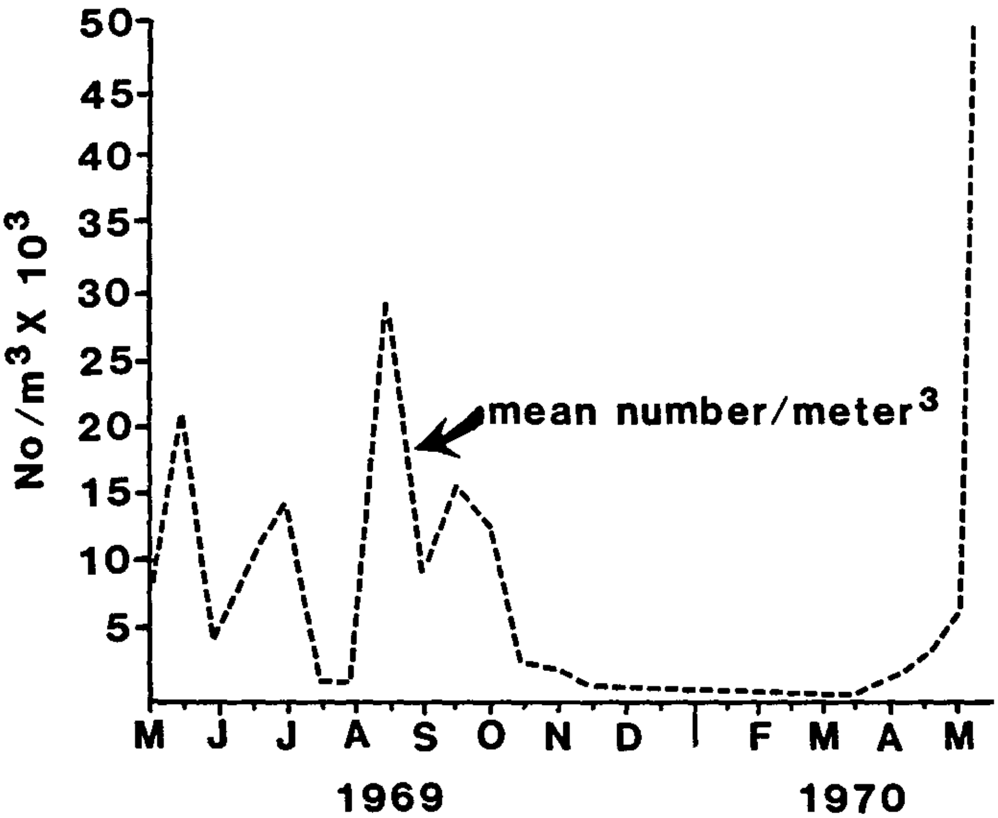


Figure 3. Mean number of zooplankton per cubic meter in Sandy Hook Bay (after Sage and Herman, 1972; adapted from Berg and Levinton, 1985).

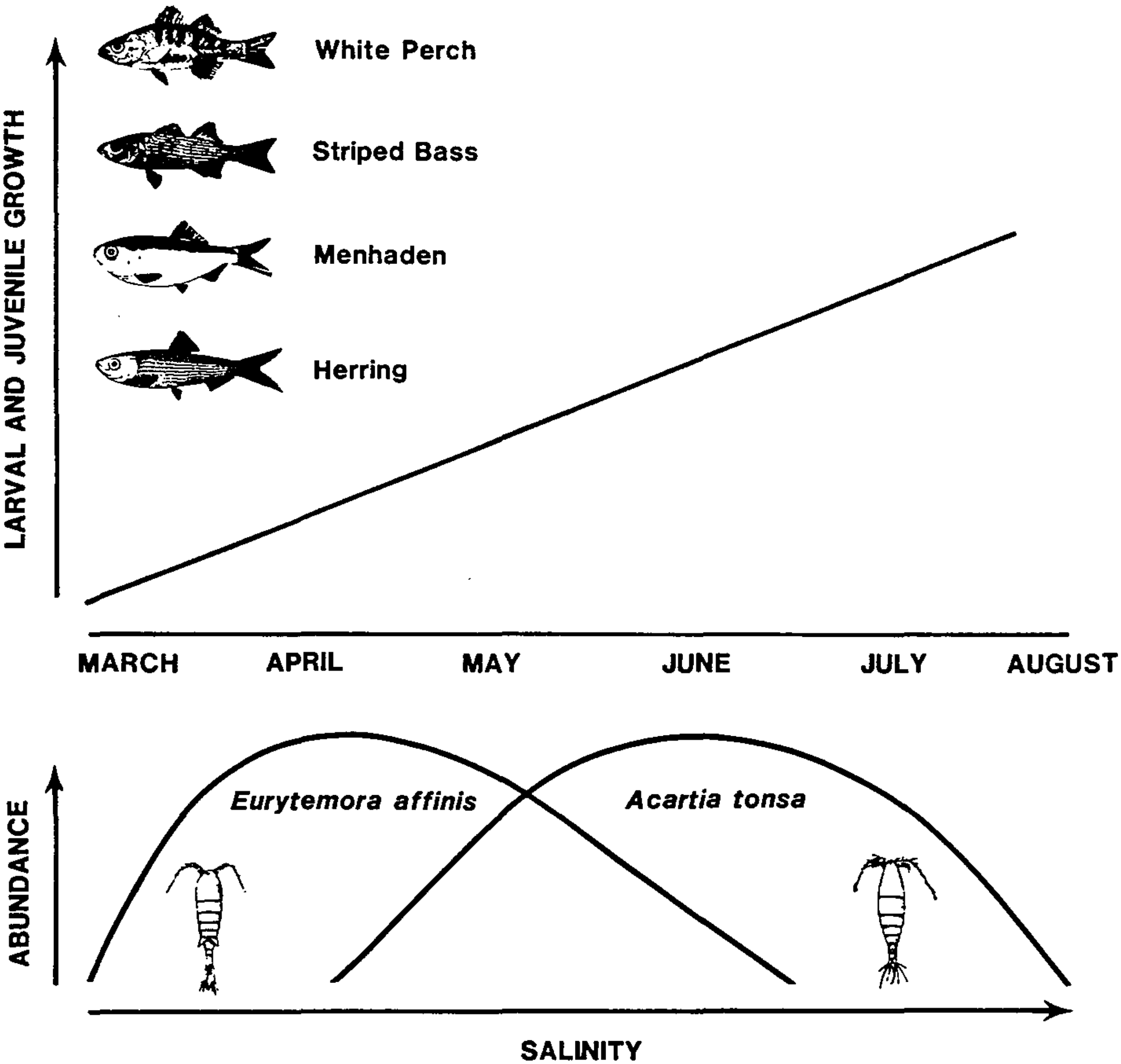


Figure 4. Correlation among seasonal changes in populations of copepods, larval fish and salinity in the Hudson River.

Designed to determine changes in benthic communities before and following installation of a sewage outfall at the head of Raritan Bay, this study established a benchmark for evaluating long-term shifts in benthic abundance and diversity. Considering the 127 taxa recorded during those summer surveys, diversity varied from 8-40 species per station throughout Raritan Bay (Fig. 5, Dean, 1975). Soft clams were temporally most abundant, occurring on average 88% of the time, while ampeliscidamphipods, an important dietary component for bottom feeders such as winter flounder (Boesch, 1982), were present 60% of the time.

By 1973, in a survey conducted during the winter months, it appeared that significant changes had occurred (McGrath, 1974). The first obvious difference was a decrease in observed numbers of species, particularly in the western portion of Raritan Bay (Fig. 6, McGrath, 1974). The total number of taxa recorded was only 78 (Pearce, 1974), substantially lower than the 127 recorded 16 years earlier or the 143 species found in 1972 in South Jersey in the cleaner Mullica-Great Bay estuary (Durand and Nadeau, 1972; Franz, 1982). Soft clams were far less abundant and ampeliscid amphipods had virtually disappeared. These latter organisms are known to be sensitive to petroleum hydrocarbons (Blumer et al., 1970) which have been found in sediments at concentrations over 3500 ppm in this estuary (Koons and Thomas, 1979). Coupled with the decrease in numbers of taxa was a decrease in abundance. Although differences in mesh size precluded a direct comparison, in the late '50s numbers of individuals ranged from an average of over 400 m^{-2} in 1958 to 4,000 m^{-2} in 1959 (Fig. 7; Dean, 1975). By 1973, abundance decreased to a little over 100 m^{-2} (Fig. 8; McGrath, 1974). Some of this decrease may be attributable to natural winter declines in density.

Can a determination be made accurately as to the present status of the benthic populations in the estuary? The picture is far from complete although there is some evidence that species diversity may, in fact, be substantially similar to that seen in 1957. In a survey conducted in the summer and fall in 1977 in the Raritan Bay-Lower New York Bay area, 126 taxa were present with the mollusc, crustacean, and polychaete species similar to those identified 20 years previously (Stainken, 1984). Soft clams again appeared as one of the dominant organisms although ampeliscid amphipods were still absent. In a 1979-1980 survey of East Bank-Romer Shoal-Old Orchard Shoal, 179

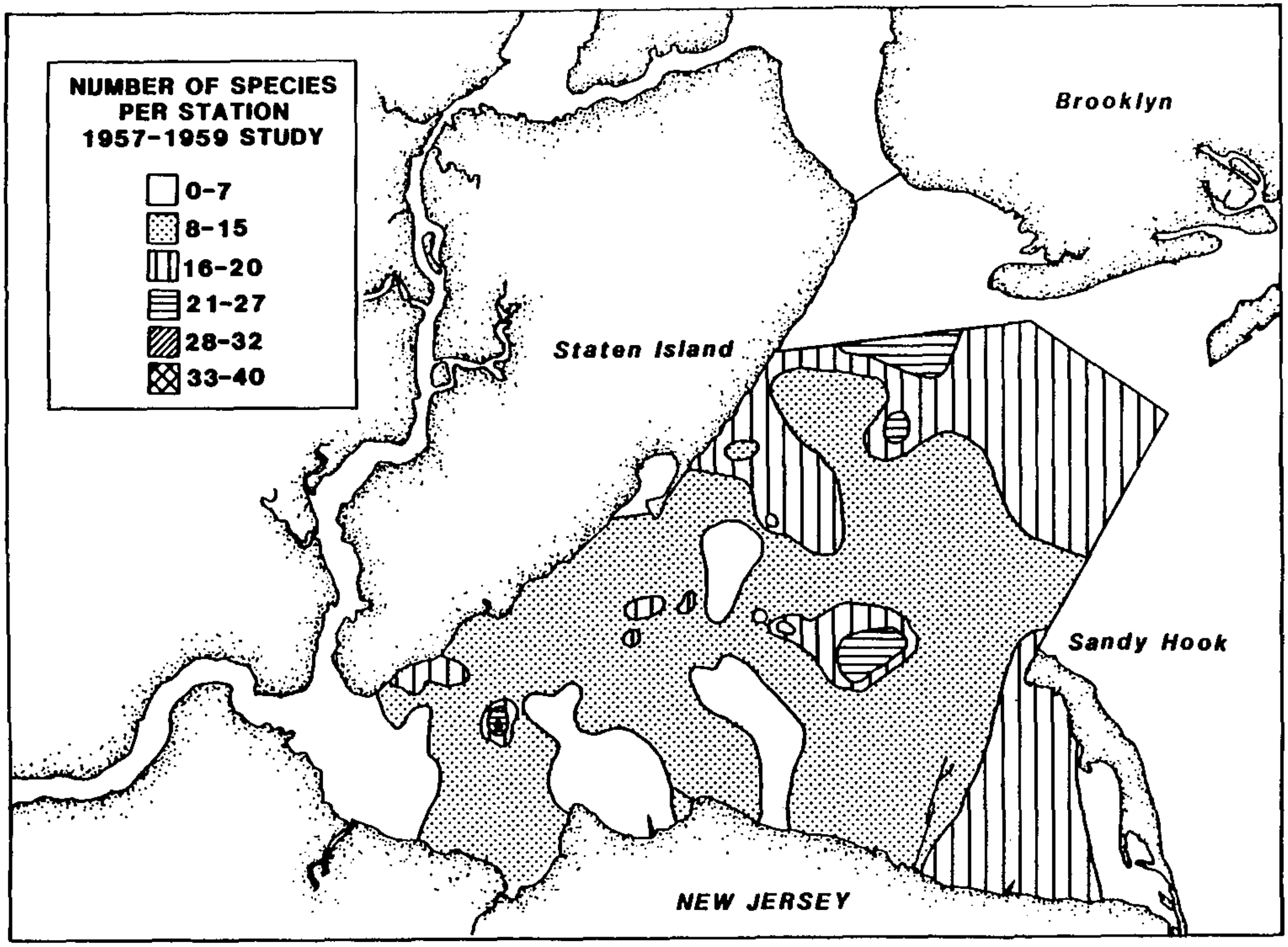


Figure 5. Number of benthic species per station in the Lower Bay Complex (from the data of Dean, 1975; after Berg and Levinton, 1985).

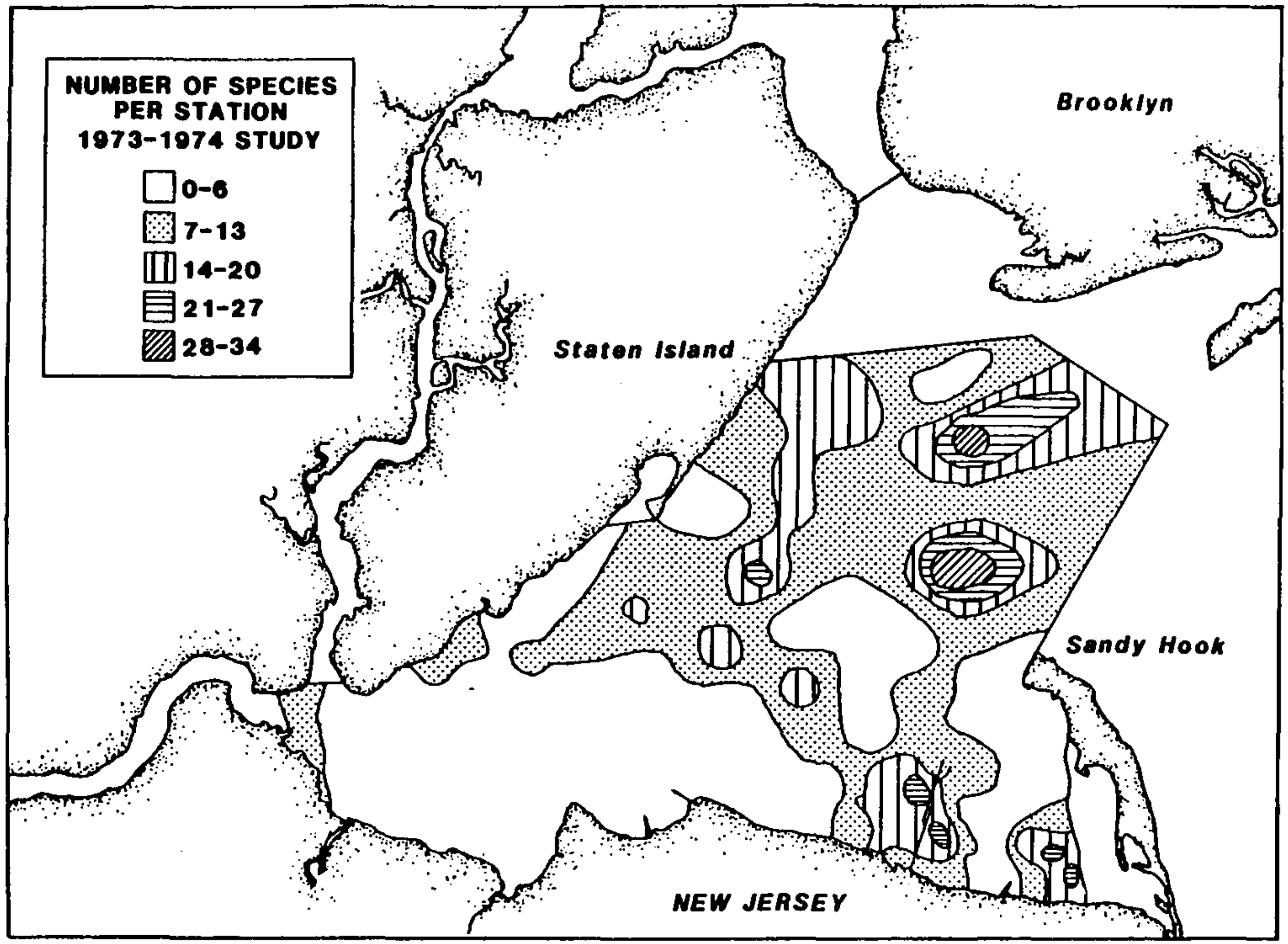


Figure 6. Number of benthic species per station in the Lower Bay Complex, 1973-1974 (from the data of McGrath, 1974; after Berg and Levinton, 1985).

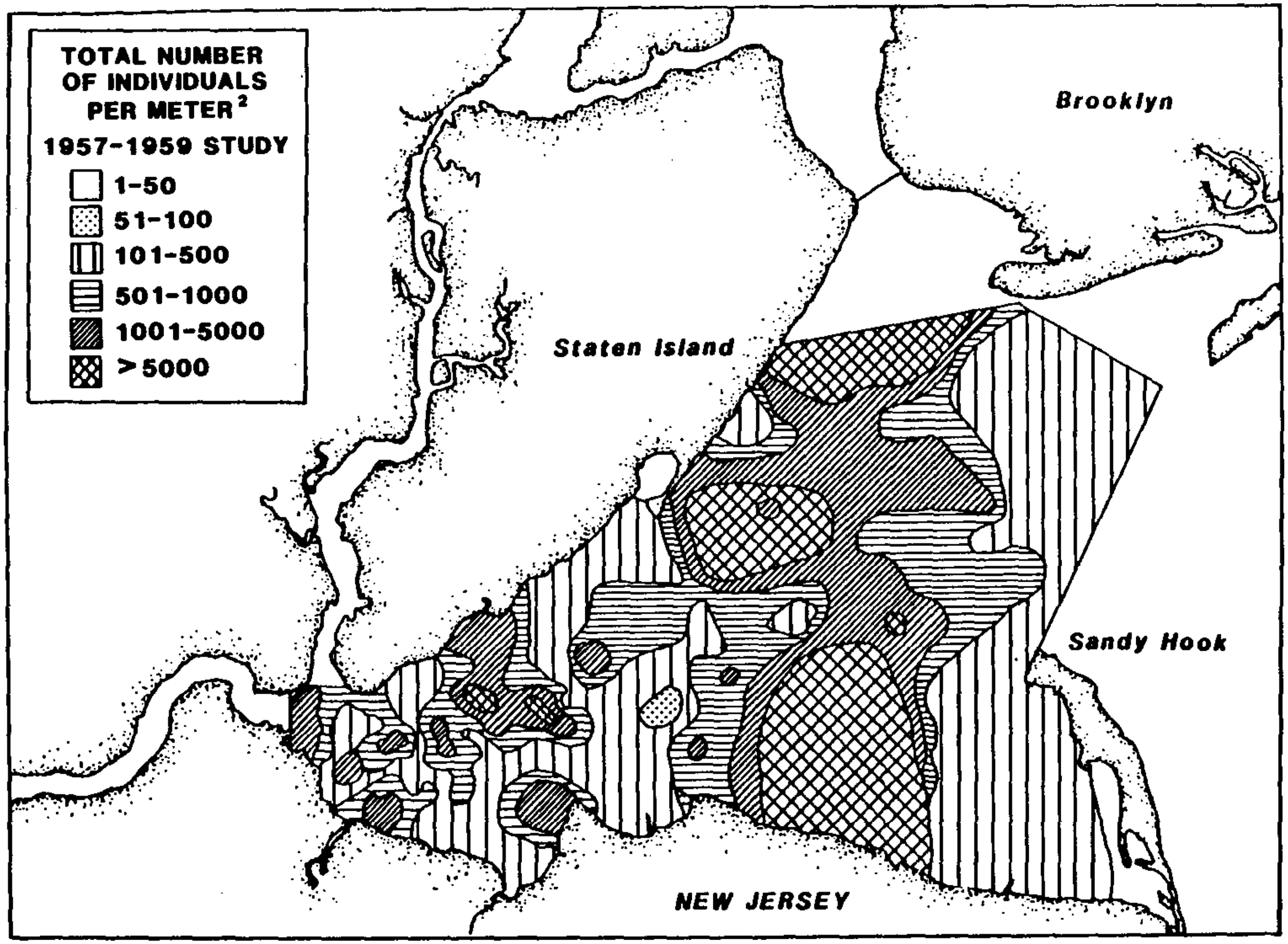


Figure 7. Number of individuals in benthic populations collected in the Lower Bay Complex, 1957-1959 (from the data of Dean, 1975; after Berg and Levinton, 1985).

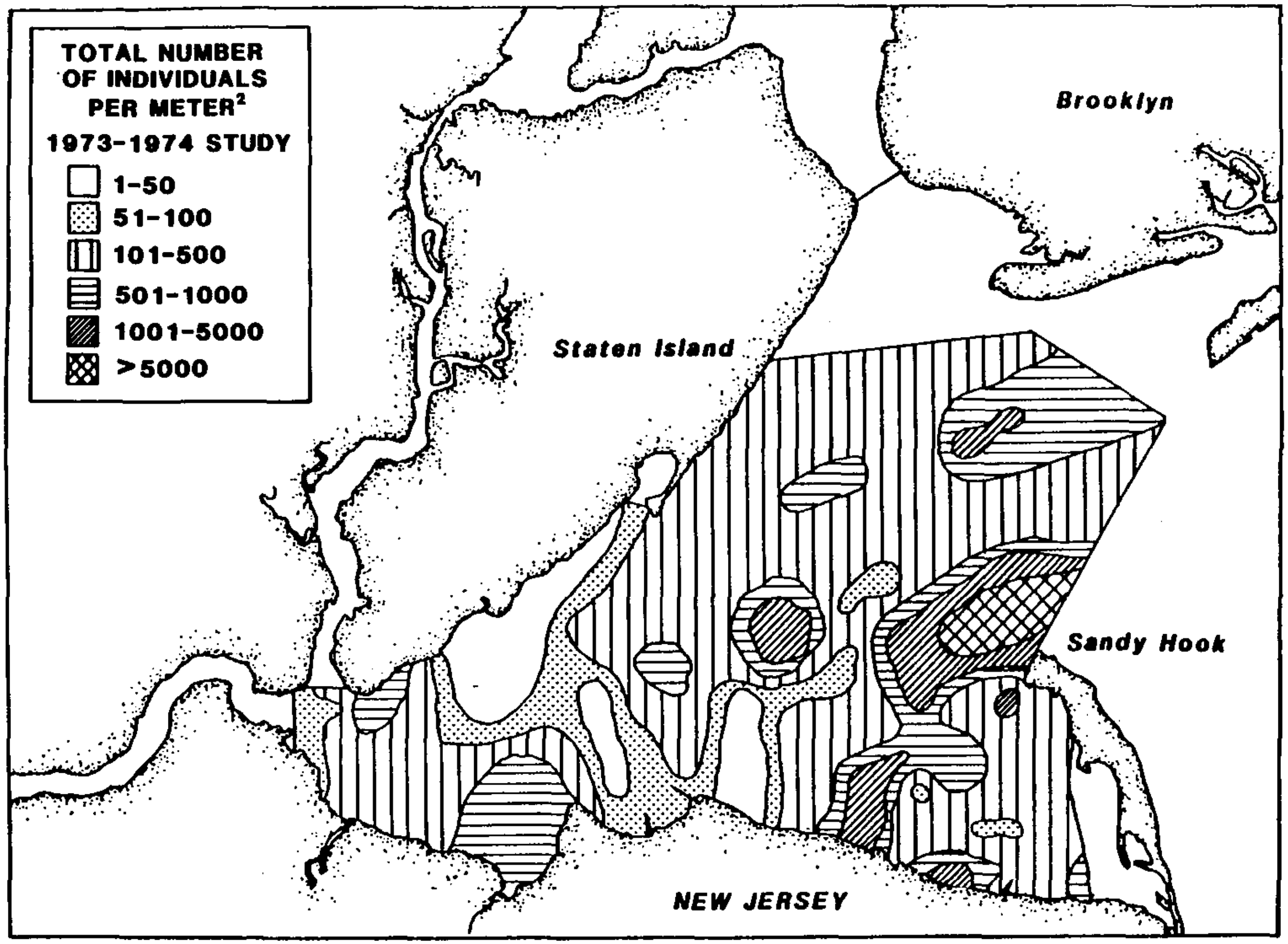


Figure 8. Number of individuals in benthic populations collected in the Lower Bay Complex, 1973-1974 (from the data of McGrath, 1974; after Berg and Levinton, 1985).

taxa were found, 57 of which were previously unreported (Gandarillas and Brinkhuis, 1981). In this part of the estuary, different sediment types, better flushing capacity and hence better water quality may support more diverse benthic communities. Nevertheless, density was relatively low, averaging 340 individuals m^{-2}.

Are these conditions indicative of anthropogenic stress, natural variability or both? Even though seasonal fluctuations in abundance can be assigned a causal role, the disappearance of sensitive species, i.e., Ampelisca, and significantly reduced numbers of individuals, indicates the effects of anthropogenic activities (Diaz and Boesch, MS).

How then does this estuary compare with others? Based on a comparison of molluscan species in similar muddy, sandy habitats, there is less diversity in Raritan Bay as well as in the New York Bight in general (Table 2; Franz, 1982).

Raritan Bay also supports reduced densities of individuals. For example, eelgrass communities in Chesapeake Bay can average 14,000 individuals m^{-2}; the cleaner Mullica-Great Bay system, 4,000 individuals m^{-2} (Table 3; Franz, 1982). A word of caution is necessary, however, on relying strictly on abundance since organic enrichment can result in large numbers of opportunistic species. It does appear, however, that the macrobenthos of the HudsonRaritan estuary has indeed been significantly altered (Boesch, 1982).

Trophically, this alteration in distribution and abundance of benthic species, many of which are key forage organisms, can result in reduced estuarine production available to fishes and macroinvertebrates. Although predators may be able to switch from "preferred" food types as their abundance diminishes, their benthic successors may not provide as viable an alternative. Behavioral and physical constraints may limit the extent to which predators can use alternate resources.

From a resource management viewpoint, the loss of the commercial shellfisheries in the estuary has been of greatest concern. In colonial times, extensive beds of oysters were common in the Hudson-Raritan estuary, extending from the "Great Beds" at the western end of the Bay into the Raritan River and Arthur Kill (Fig. 9; Franz, 1982; MacKenzie, 1984). On the New Jersey side, they were common even up into the Hudson and Shrewsbury Rivers. This natural abundance, plus the development of the technology for planting "seed" oysters on beds in Raritan Bay, nearly 20 sq miles off Staten Island and 2.5 sq miles along

Table 2. Molluscan species richness in muddy sand habitats (from Franz, 1982).

	Total	References
Fishers Island Sound	24	Franz, 1976
Buzzards Bay (Station "R"	23	Sanders, 1960
Central Long Island Sound	12	Sanders, 1956
Central Long Island Sound	14	Franz, unpublished[a]
Central Long Island Sound	13	McCall, 1977
New York Bight Apex	9	Franz, unpublished[b]
Raritan Bay	4	McGrath, 1974
Mullica River/Great Bay	11	Durand and Nadeau, 1972
New York Bight off southwestern Long Island	12	Steimle and Stone, 1973

[a]Data for 1972.

[b]Data for 1973.

Table 3. Comparison of average macrobenthic densities in selected Atlantic estuaries. Data based on 1-mm screen size. Mullica River/Great Bay density estimated from graphical data (from Franz, 1982; Gandarillas and Brinkhuis, 1981).

	Number/m^2	Reference
Mystic River (Connecticut)	3,000	Rowe et al., 1972
Moriches Bay (New York)	1,300	O'Connor, 1972
Raritan Bay (New Jersey)	109	McGrath, 1974
Lower Bay (New Jersey)	340	Gandarillas and Brinkhuis, 1981
Mullica River/Great Bay (New Jersey)	4,000	Durand and Nadeau, 1972
Delaware Bay (New Jersey/Delaware	722	Maurer et al., 1978
Chesapeake Bay (eelgrass) (Virginia)	14,000	Orth, 1973
Tampa Bay (Florida)	510	Bloom et al., 1972

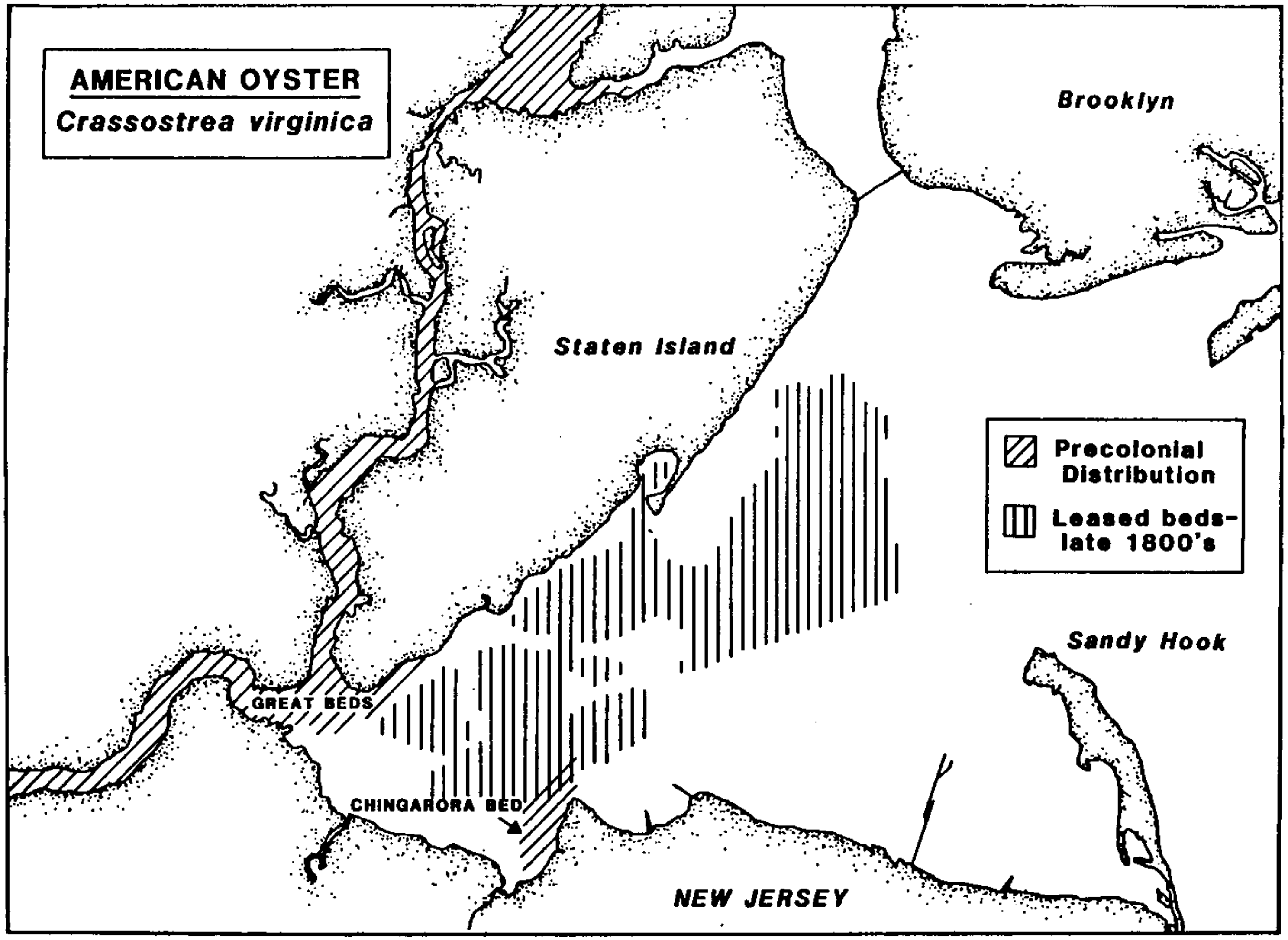


Figure 9. Distribution of oysters in the Lower Bay Complex (Franz, 1982; MacKenzie, 1984).

Keyport, led to the development of a major commercial oyster industry. Beginning about 1825 and lasting nearly 100 years, the oyster industry in Raritan Bay produced 1-2% of the total oyster crop in the northeastern United States and in the late 1880s, production in Raritan Bay alone ranged from 300,000 to 500,000 bu annually (MacKenzie, 1984). By this time, however, channels needed to accommodate heavy port traffic were cut through the beds, not only destroying existing areas but also increasing siltation which suffocated adjacent beds. Eventually, the "Great Beds" and all the channel bottoms in Raritan Bay were covered by soft muds and destroyed. A few beds, however, still have small residual populations.

While there were undoubtedly natural contributing factors, including changes in salinity, low dissolved oxygen concentrations, and predation, primary causes for the demise of the fishery included contamination which created a threat to human health (Franz, 1982; MacKenzie, 1984). Outbreaks of typhoid in 1904, traced to contamination of oysters from Jamaica Bay, and further outbreaks in 1918 attributable to Raritan Bay oysters, resulted in closure of the fishery and, effectively, the end of the industry by around 1925.

Oysters were not the only shellfish important to the economy. Along with oysters, the Indians and early colonists relied on hard clams which were available in inshore shallow waters of the Lower Harbor, with extensive populations throughout Raritan Bay (Fig. 10; Brinkhuis, 1980; MacKenzie, MS). Unlike the oyster industry which flourished until 1925, the peak of hard clam harvesting was reached in the mid-30's when 700 men could be found digging during a given day (MacKenzie, MS). Not only were market sizes harvested, but seed as well, for sale to South Jersey and Chincoteague Bay watermen. In 1963, the US Public Health Service estimated a standing population of nearly 5 million bu in the estuary which, under optimum water quality conditions could yield a potential harvest of up to 550,000 bu annually (Jacobson and Gharrett, 1967). The industry never reached the economic value the oyster fishery achieved and both New York and New Jersey waters have been gradually closed to harvesting due to industrial and domestic pollution and unacceptable levels of coliforms.

In 1983, the New Jersey Department of Environmental Protection allowed collection of clams from Sandy Hook Bay for transport to leased beds in Barnegat Bay, where, after 30 days of depuration, the clams could be marketed. At the same time, a depuration plant for hard clams was opened in Highlands, NJ and

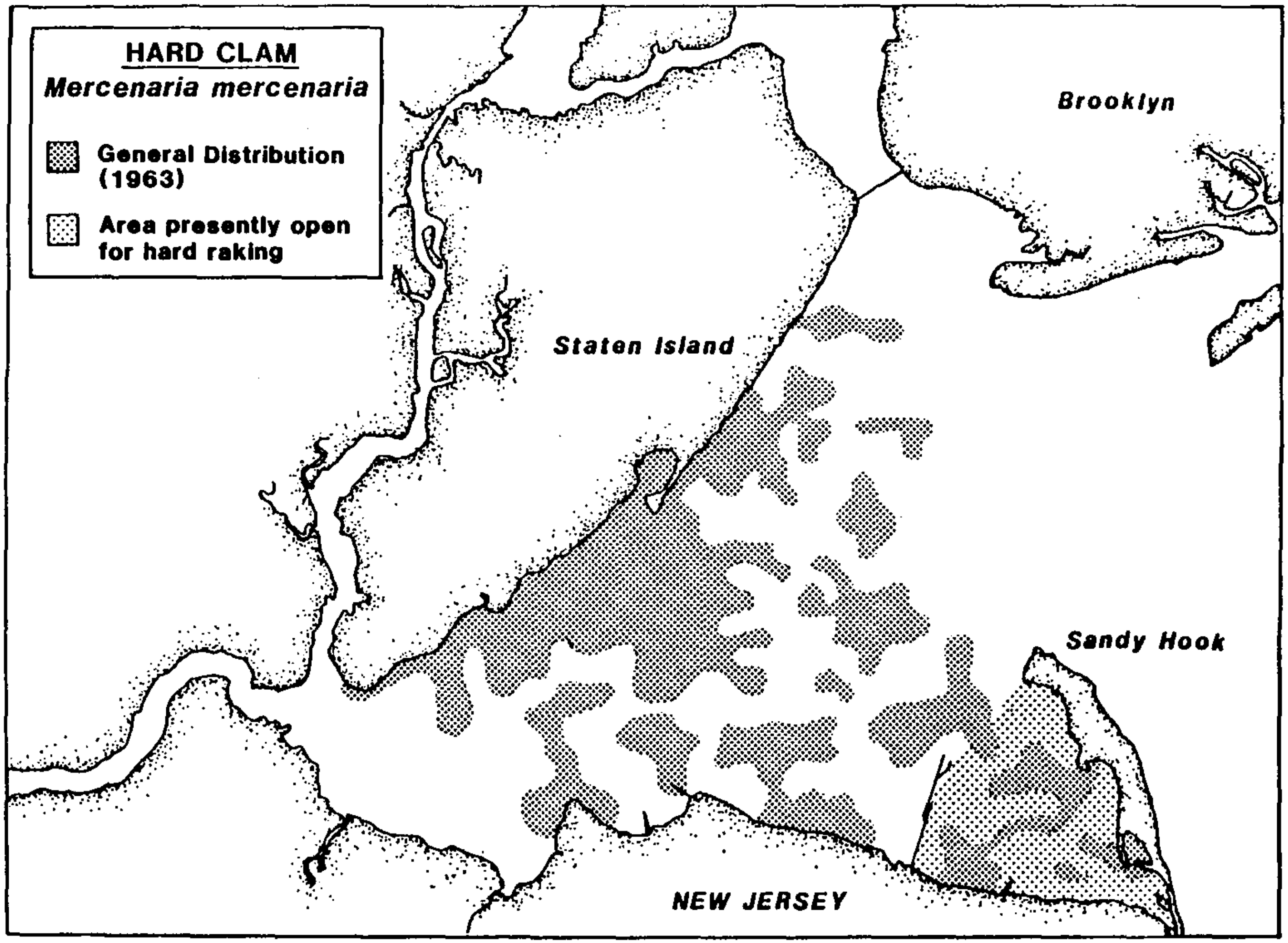


Figure 10. General distribution of hard clams in the Lower Bay Complex in 1963 (from deFalco, 1967; after Berg and Levinton, 1985; MacKenzie, pers. comm.).

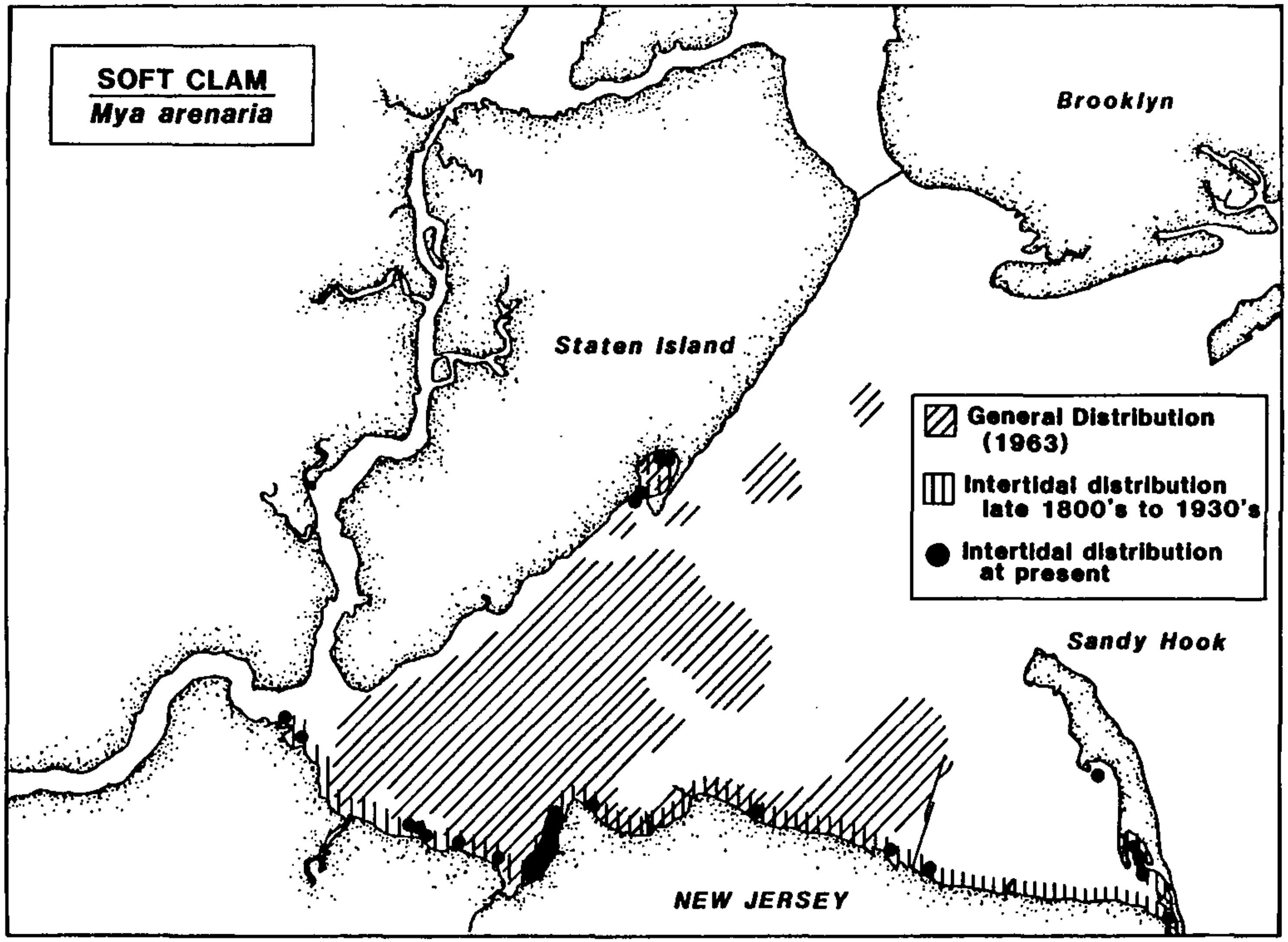


Figure 11. Historical and present distribution of soft clams in the Lower Bay Complex (from deFalco, 1967; MacKenzie, in prep.).

Blue crabs have been collected recreationally since the late 1800's in the Navesink and Shrewsbury rivers and other tributaries while a commercial dredge fishery operated in the eastern end of the bay throughout the winters (Fig. 12; Figley, 1987; MacKenzie, MS). Legally, New Jersey sets a dredging season from late October through March, but since temporal or seasonal abundance varies from year to year, this has always resulted in an erratic fishery. Commercial fishermen dredge crabs in areas where they bed down for the winter and a summer sport fishery concentrates in the tributary rivers and creeks as well as portions of the Hudson and Arthur Kill.

The decline in the bluecrab fisheries was reflected in a decline in the catch. In 1930, the fishery consisted of about 40 boats (MacKenzie, MS). Catch, which in the '20s through '40s would average 25-100 bu boat^{-1}d^{-1} now ranges from 4-30 bu boat $^{-1}$d^{-1}. The decrease in catch may be due to reduced abundance, attributable to loss of critical habitats, such as eelgrass beds which serve as a refuge for this species during the warmer months (MacKenzie and Stehlik, MS). Declines in abundance have also been linked to toxic chemicals, particularly DDT/DDE (Summers et al., 1986).

Apart from shellfish, of greatest interest from a management perspective is the status of the finfishes. Typically, the Hudson-Raritan estuary supports a wide range of fish species with seasonal occurrence and distribution related to life history patterns (Fig. 13; Esser, 1982; Deegan and Day, 1984; Berg and Levinton, 1985). Freshwater species; i.e., bluegills, carp, catfish, and largemouth bass reside in the upper Hudson and its tributaries. Year-round residents, i.e., fish that spawn and remain within the estuary for their entire life cycle, include the silversides, killifish or mummichog, white perch, and bay anchovy, one of the most abundant species in the Lower Bay complex (Wilk et al., 1977; Berg and Levinton, 1985). Many of these fishes are important forage organisms for seasonally abundant carnivores and an abundance of prey may attract opportunistic coastal species into the estuary.

Fishes of particular interest are those which move in and out of the estuary seasonally and support both commercial and recreational fisheries. These include the anadromous species, i.e., shad, alewife and blueback herring, Atlantic sturgeon, tomcod, and smelt, which make spawning runs into the fresh and brackish waters during the spring. Catadromous eels migrate in as juveniles, remaining several years before reaching sexual maturity and swimming back to the ocean. Striped bass are also

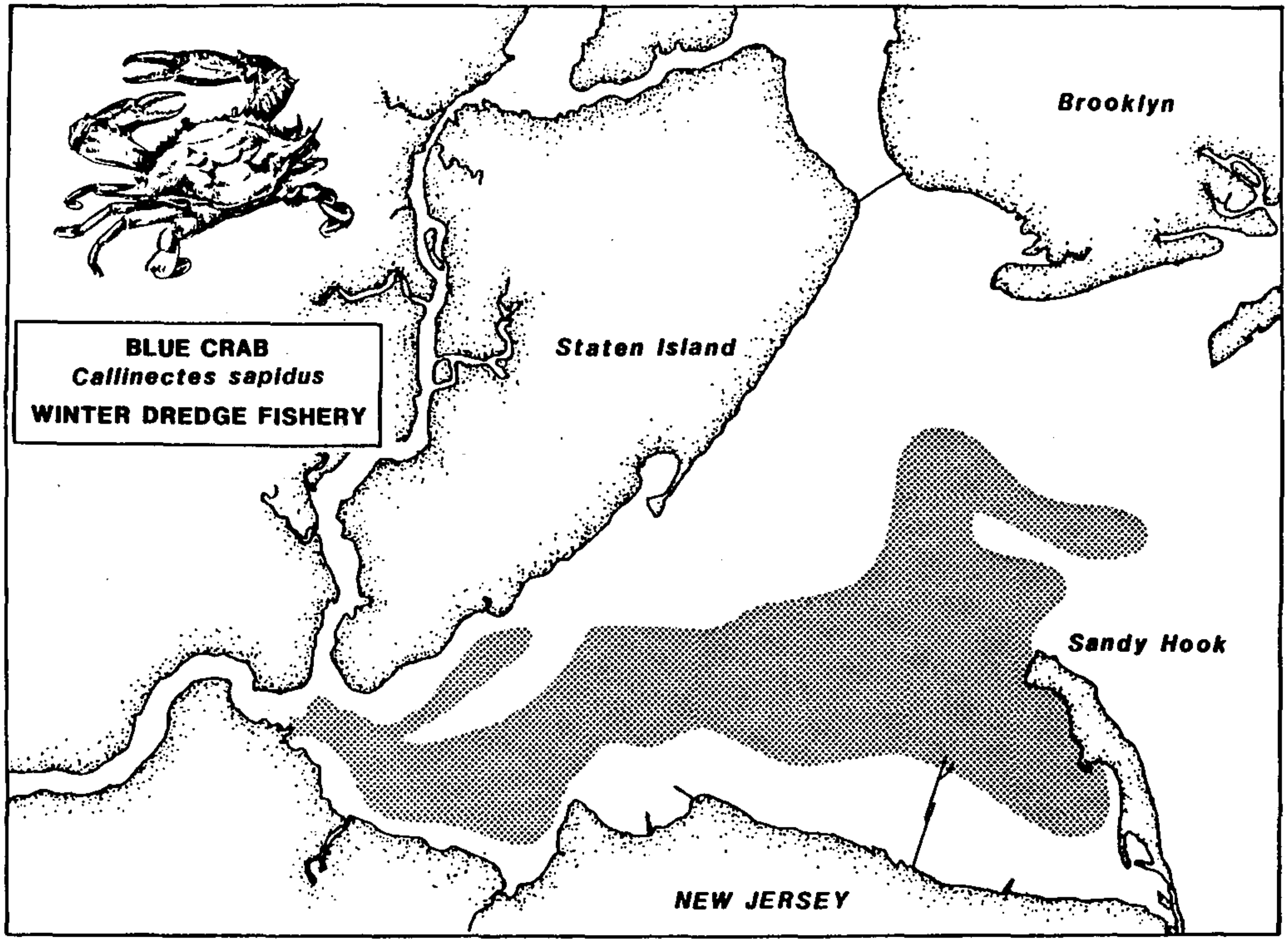


Figure 12. Winter dredge fishery in the Lower Bay Complex (after Figley, 1987).

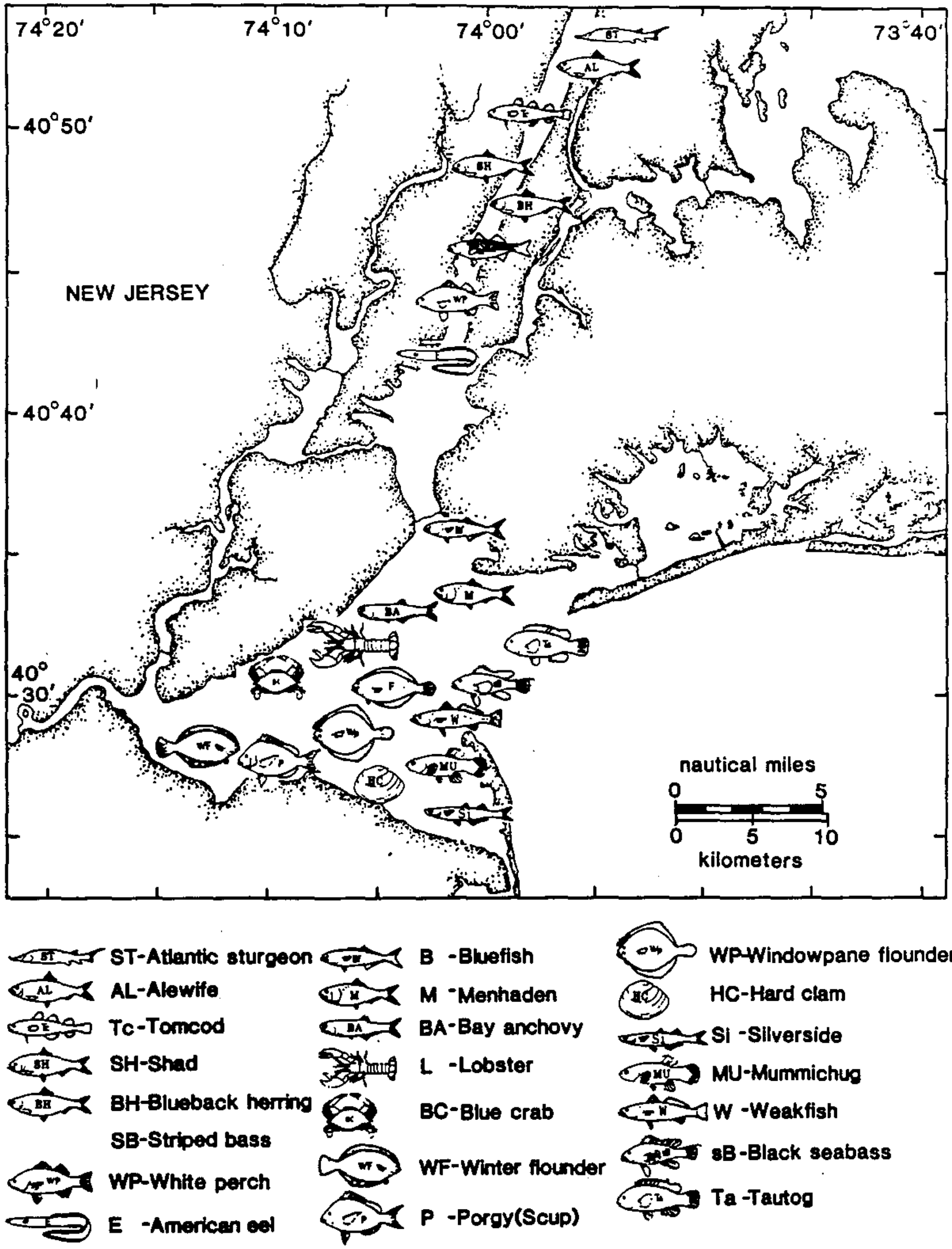


Figure 13. Distribution of some typical Hudson-Raritan estuarine invertebrates and fishes.

part of the spring contingent, with the stretch between Bear Mountain and Kingston serving as prime spawning habitat (Esser, 1982). Young stripers remain in the estuary until their second year, overwintering in the interpier areas of Manhattan, the northern reaches of Arthur Kill, Newark Bay, and other habitats. In contrast with other populations of striped bass along the Atlantic coast, stocks in the Hudson not only have maintained themselves but may have increased. Always a valuable fishery, in 1975 over 1.1 million lbs worth over $600,000 were landed commercially in New York State with 4% of the catch coming from the Hudson (Berg and Levinton, 1985). By 1976, an advisory was issued which closed the commercial fishery due to high levels of PCBs and last spring, the entire fishery was closed in New York. The recreational fishery continued to be strong in New Jersey with a catch estimated at over 5,000 fish fish during a 2-month period in 1980 (Smith et al., 1985). Recent regulations designed to protect the 1982 year class have restricted the fishery by increasing the size limit; by 1988, only fish 33 inches or longer could be kept.

Other species depend on both estuarine and marine habitats during different portions of their life history, as adults using them for spawning areas and as juveniles, feeding on abundant prey and using the protection of the estuary to reduce predation before taking up their adult residency in the marine environment. These include bluefish, scup, weakfish, summer flounder, and winter flounder, among others. Also in the estuary are species which move in and out opportunistically, either to forage or seek more optimal habitats. These include red and silver hake, tautog, and adult bluefish. These continuing fluctuations in occurrence provide a diverse and exploitable resource which has been the basis for both commercial and recreational fishing since the early 1800s. But while recreational fishing flourishes and continues to increase, the commercial fishery has declined steadily since its peak in the 1940s.

Dependent in the 1800s on abundant shad, Atlantic sturgeon, and menhaden, in 1889, the fisheries involved nearly 500,000 nets, mostly stake gill nets, along with fykes, pounds, and seines, which were set throughout the estuary (Esser, 1982). In 1880, 90 mt of sturgeon were caught in the Hudson but value of the landings dropped from $46,500 in 1898 to $1,000 by 1904. Smelt were also fished commercially in the Passaic and Hackensack Rivers in the mid-1800s; overfishing and destruction of spawning grounds from industrial pollution led to the demise of the fishery and by 1937 smelt were considered "rare" in the lower Hudson River.

Although shad are recreationally still important, the commercial fishery has decreased significantly from its peak in the late 19th century when production in New York reached 1,700 mt in 1889 (Esser, 1982). As early as 1880, however, pollution effects were evident with shad from Newark Bay considered unpalatable due to tainting by coal oil (Goode, 1987). The fishery has fluctuated with sizeable catches recorded in the late '30s and '40s. Landings in 1977 for the Hudson, however, were only 83 mt (Fig. 14). Nominal commercial catches in states along the Atlantic coast have been the lowest on record since the early 1980s (US Department of Commerce, 1986). The most critical factors determining abundance appear to be the size of the spawning stock and/or spawning success as well as interference with migration, i.e. dam construction. A modeling approach designed to assess the impact of natural as well as anthropogenic variables on stock abundance in selected estuaries, indicates that success may be tempered by larval mortality rates, which in turn, can be influenced by poor water quality (Summers et al., 1986). The effort in the fishery is, of course, also influenced by economic factors; early marketing of shad from southern states often saturates the market before northern catches are made.

Historically, as shad runs waned in the late spring, the fishery switched to menhaden. This was the most abundant species caught in pound nets, with catches in peak years reaching 20,000-30,000 bu boat^{-1} or crew which tended 2 or 3 pound nets (MacKenzie, MS). In the mid-1800s, the market was primarily for fertilizer but by 1880, demand for fish oil and meal led to the development of a processing plant in Belford, NJ. On average, Belford processed 200 million fish per year with pound nets contributing 10%--the rest supplied by purse seiners operating primarily in coastal waters from Virginia to Maine, although some fish were caught in the bay. Subsequent to the extremely productive 1958 year class being fished out, the fishery has waned. In 1981, the plant closed as operations shifted to the Gulf. Although a variety of anthropogenic causes have been postulated as affecting juvenile nursery habitats, and subsequent stock declines, the initial decrease in landings was due probably to poor year classes in the late '50s and early '60s. Failure of the fishery was caused by overfishing on reduced stocks--the results of changes in technology by American and foreign fleets (Summers et al., 1986).

While commercial fisheries in the bay system have declined, due in large part to gear restrictions within the estuary and a shift to trawling offshore, recreational fishing continues to be a major activity in the estuary. In 1979, estimates indicated

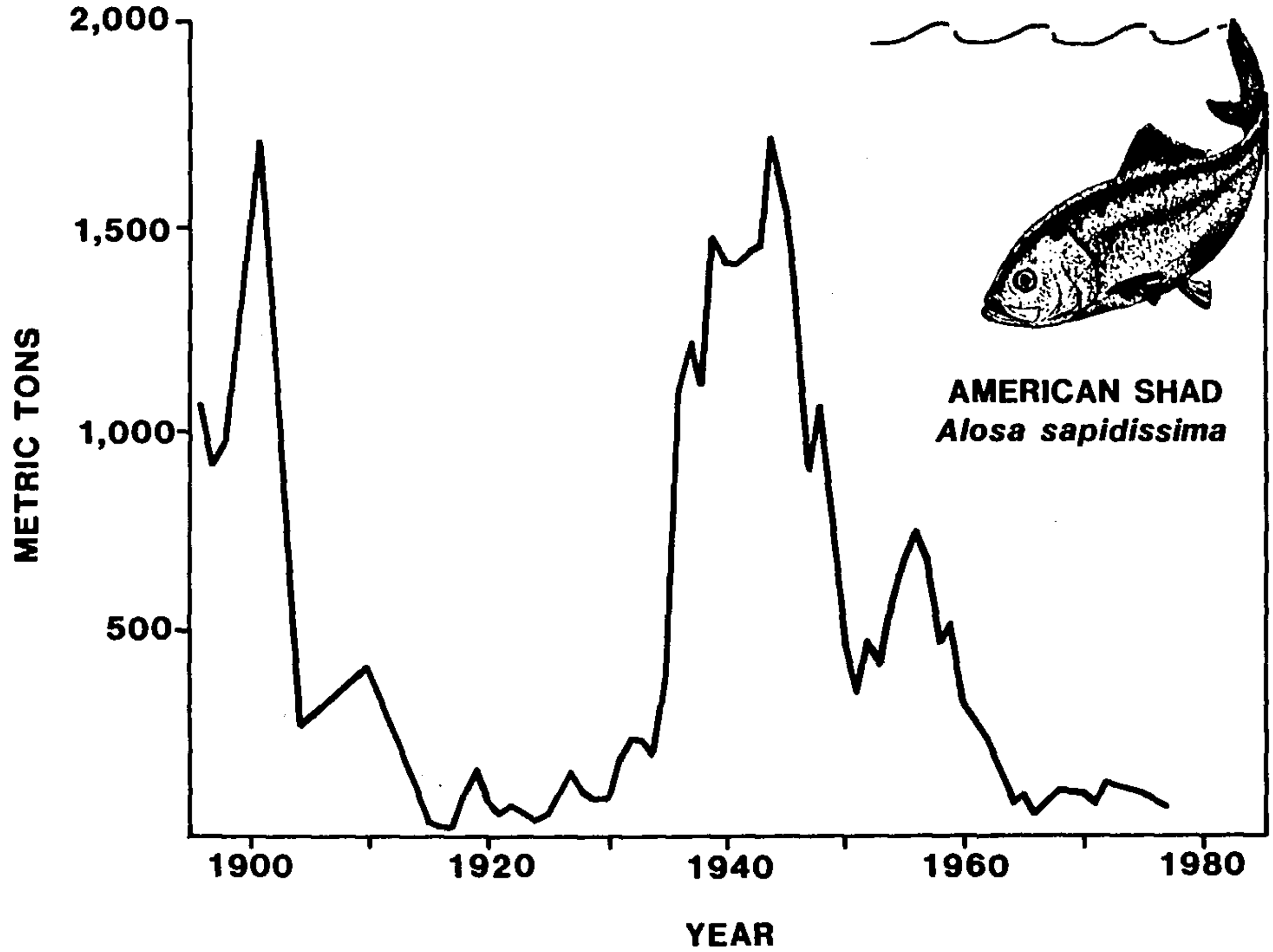


Figure 14. Hudson River commercial shad landings (after Esser, 1982).

that 9.6 million fish were landed, with fishing effort totaling nearly 2,000,000 trips (Table 4, Smith et al., 1985). This was higher than in four other estuaries where similar surveys were undertaken. Party boats today are more modest than the 200-ft vessels which at the turn of the century, carried from the metropolitan area crews of 50 and from 800-1,200 customers to fish for fluke (summer flounder), winter flounder, blackfish (tautog), porgy (scup), weakfish, red hake (ling), silver hake (whiting), and sheepshead (Barrett, 1985). Recent surveys of the recreational fishery, however, indicate that, with the exception of sheepshead which have become scarce, most of the same species are caught today. In a 1979 survey, summer flounder, winter flounder, and 1.5 million bluefish were landed from March through December (Smith et al., 1985). Continued interest in recreational fishing--through party boats, pier catch, surf fishing, or private boats--generates an estimated $30 million in annual gross sales from marinas, boat sales and services, charter and party boats, tackle, etc., in the Raritan Bay area alone (Barrett, 1985).

We were requested to present a review of the status of this estuary which could serve as a baseline from which future changes might be assessed. As I have indicated, phytoplankton based primary productivity is exceptionally high and zooplankton populations provide abundant potential food for larval and juvenile species. The improvised condition of benthic communities speaks to the effects of a variety of anthropogenic activities although the trophic consequences of such alternations have yet to be assessed fully. Shellfisheries have suffered - both from habitat loss and contamination which compromises utilization; however, hard clams are still abundant and soft clams are still dug in the rivers and nearshore areas. Lobsters and blue crabs support reduced but ongoing commercial efforts. The decline in commercial fisheries has resulted from reduced abundance of some species, restricted catches and closures of fisheries as well as changes in gear and fishing effort. In contrast, recreational fisheries flourish, exploiting both seasonally available fishes and blue crabs. While there have obviously been significant impacts on the biota, it is evident that this estuary continues to support diverse, and in many instances, abundant biological resources.

Of necessity, this overview has been drafted based on the fragmentary and sometimes anecdotal nature of available information. Unlike other estuaries, such as the Chesapeake, where substantial and reliable data have been assembled over many years, this estuary has suffered from a "brush fire"

Table 4. Estimated recreational catch and fishing effort for five eastern estuaries in 1979 (after Smith et al., 1985).

	CATCH	EFFORT
Estuary	Number	Fishing Trips
	------thousands------	
Hudson/Raritan	9,609	1,994
Delaware Bay	3,900	930
Potomac River	3,527	540
Narragansett Bay	2,397	770
Connecticut River	547	153

approach to assessing its resources. While some benthic and fishery surveys were conducted with the intention of establishing baseline data sets, most studies have been prompted as a response to specific requests for information or interests of the principal investigators. Thus, proposed Westway construction supports funding to determine what happens in the Hudson River; borrow pits are trawled and grab sampled to answer concerns by the Corps of Engineers and environmentalists to develop strategies for disposal of contaminated sediment and information or data bases. What results are mismatched surveys; data which cannot be compared due to inconsistencies in methodology and masses of statistics and figures which may or may not provide fully relevant information for developing assessments or making informed decisions.

A recent review of research required for managing the nation's estuaries stressed the importance of shallow inshore areas in fisheries production and emphasized the need to answer major questions on the relationships between critical habitat requirements and productivity (Copeland et al., 1984). Such an effort requires an understanding of the complexities of natural variability to determine the effects of anthropogenic activities. What is needed is a coordinated, multidisciplinary approach to manage and promote continued utilization of the living marine resources of the Hudson-Raritan system. Only then can realistic decisions be made to resolve conflicts growing out of the multiple-use concept.

Acknowledgements

Preparation of this paper would not have been possible without the help of many of the Sandy Hook Laboratory staff, including A. Pacheco, A. Bejda, R. Reid, J.O'Reilly, J. Mahoney, S. Wilk, B. Valdes, F. Steimle, and S. Gorski. Special thanks to to C. MacKenzie for permitting me to read his draft manuscript as well as to M. Cox for her fine graphics and K. Melkers who patiently typed the numerous drafts. Support from D. Bennett, American Littoral Society; J. O'Connors, Oceans Assessment Division; and G. Mahoney, NMFS, is also gratefully acknowledged.

REFERENCES

Armstrong, N.E. 1984. Water management and estuarine productivity, 27-42 pps. In Copeland, B.J., Hart, K., Davis, N., and Friday, S. (eds.), Research for Managing the Nation's Estuaries: Proceedings of a Conference in Raleigh, North Carolina. UNC Sea Grant College Publication, UNC-SG-84-08. UNC Sea Grant College Program. North Carolina State University, Raleigh.

Barrett, P. 1985. Fishing for fun and profit, 87-91 pps. in Pacheco, A.L. (ed.), Fish and Bricks - Plans, Processes, and Problems of the Lower Hudson and Raritan Estuary. Proceedings of the Walford Memorial Convocation, Sandy Hook Laboratory, Tech. Ser. Rep. 31, Sandy Hook, New Jersey.

Berg, D.L. and Levinton, J.S. 1985. The biology of the Hudson-Raritan Estuary, with emphasis on fishes. NOAA Technical Memorandum NOS OMA 16. Rockville, 170 pp.

Bloom, S.A., Simon, J.L., and Hunter, V.D. 1972. Animal-sediment relation and community analysis of a Florida estuary. Mar. Biol. 13:43-56.

Blumer, M., Sass, J., Souza, G., Sanders, H., Grassle, F., and Hampson, G. 1970. The West Falmouth oil spill; persistance of pollution eight months after the accident. Woods Hole Oceanogr. Inst. Technical Rep. WHOI-70-44, 32 pp.

Boesch, D.F. 1982. Ecosystem consequences of alternations of benthic community structure and function in the New York Bight region, 543-568 pps. In Mayer, G.F. (ed.), Ecological Stress and the New York Bight: Science and Management. Estuarine Research Federation, Columbia.

Brinkhuis, B.H. 1980. Biological effects of sand and gravel mining in the Lower Bay of New York Harbor: An assessment from the literature. Marine Sciences Research Center, State University of New York Special Rep. 34, Ref. No. 80-1, Stony Brook, 193 pp.

Copeland, B.J., Hart, K., Davis, N., and Friday, S. (eds.). 1984. Research for Managing the Nation's Estuaries: Proceedings of a Conference in Raleigh, North Carolina. UNC Sea Grant College Program. North Carolina State University, Raleigh, 200 pp.

Dean, D. 1975. Raritan Bay macrobenthos survey, 1957-1960. National Marine Fisheries Service Data Rep. 99, Seattle, 51 pp.

Dean, D. and Haskin, H. 1964. Benthic repopulation of the Raritan River estuary following pollution abatement. Limnol. Oceanogr. 9:551-563.

Deegan, L.A. and Day, J.W., Jr. 1984. Estuarine fishery habitat requirements, 315-336 pps. In Copeland, B.J., Hart, K., Davis, N., and Friday, S. (eds.), Research for Managing the Nation's Estuaries: Proceedings of a Conference in Raleigh, North Carolina. UNC Sea Grant College Publication, UNC-SG-84-08. UNC Sea Grant College Program. North Carolina State University, Raleigh.

deFalco, P. 1967. Report for the conference on pollution of Raritan Bay and adjacent interstate waters. Third Session. Fed. Wat. Pollut. Contrt. Admin. N.Y., 815-865 pp.

Diaz, R.J. and Boesch, D.F. MS. The macrobenthos of the Hudson-Raritan estuary. In Boesch, D.F. (ed.), The Ecology of the Macrobenthos of the New York Bight Region. NOAA Technical Rep.

Durand, J.B. and Nadeau, R.J. 1972. Water resources development in the Mullica River-Great Bay Estuary. New Jersey Water Resources Research Institute, Rutgers University, New Brunswick, 138 pp.

Esser, S.C. 1982. Long-term changes in some finfishes of the Hudson-Raritan Estuary, 299-314 pps. In Mayer, G.F. (ed.), EcologicalFigley, W. 1987. The recreational and commercial fishing grounds of Raritan, Sandy Hook, and Delaware Bays. New Jersey Marine Fisheries Admin. Tech. Ser. 87-1, CN400, Trenton, 44 pp.

Franz, D.R. 1982. An historical perspective on molluscs in Lower New York Harbor, with emphasis on oysters, 181-197 pps. In Mayer, G.F. (ed.), Ecological Stress and the New York Bight: Science and Management. Estuarine Research Federation, Columbia.

Gandarillas, E.F. and Brinkhuis, B.H. 1981. Benthic faunal assemblages in the Lower Bay of New York Harbor. Marine Sciences Research Center, State University of New York Special Rep. 44, Ref. No. 81-8, Stony Brook, 129 pp.

Goode, G.B. 1887. The fisheries and fishing industries of the United States. Section II. A geological review of the fisheries industries and fishing communities for the year 1880. U.S. Government Printing Office, Washington, D.C., 787 pp.

Jacobson, F.L. and Gharrett, J.T. 1967. Fish and wildlife - Raritan Bay. 683-698 pps. in deFalco, P. (ed.), Report for the Conference on Pollution of Raritan Bay and Adjacent Interstate Waters, Third Session. Fed. Wat. Pollut. Contr. Admin. Northeast Region, Metuchen, N.J.

Jacot, A. 1920. On the marine mollusca of Staten Island, New York. Nautilus 23:111-115.

Koons, C.B. and Thomas, J.P. 1979. C_{15+} hydrocarbons in the sediments of the New York Bight, 625-628 pps. In Proceedings of the 1979 Oil Spill Conference (Prevention, Behavior, Control, Cleanup). American Petroleum Institute, Washington, D.C.

MacKenzie, C.L., Jr. 1984. A history of oystering in Raritan Bay, with environmental observations, 37-66 pps. In Pacheco, A.L. (ed.), Raritan Bay - It's Multiple Uses and Abuses. Proceedings of the Walford Memorial Convocation, Sandy Hook Laboratory, Tech. Ser. Rep. 30, Sandy Hook, New Jersey.

MacKenzie, C.L., Jr. (MS). A history of shellfishing and finfishing in Raritan Bay, with effects of man-made changes in the Bay's environment.

MacKenzie, C.L., Jr. and Stehlik, L.L. (MS). Past and present distributions of soft clams, *Mya arenaria*, and eelgrass, *Zostera marina*, in Raritan Bay.

Maurer, D., Watling, L., Kinner, P., and Wethe, C. 1978. Benthic invertebrate assemblages of Delaware Bay. Mar. Biol. 45:65-78.

McCall, P.L. 1977. Community patterns and adaptive strategies of the infaunal benthos of Long Island Sound. Mar. Res. 35:221-266.

McGrath, R.A. 1974. Benthic macrofaunal census of Raritan Bay - preliminary results. Paper No. 24, In Hudson River Ecology, Proceedings Third Symposium on Hudson River Ecology, March 22-23, 1973, Hudson River Environmental Society, Inc., Bear Mountain, 40 pp.

National Marine Fisheries Service. 1984. Seasonal occurrence of finfish and larger invertebrates at eight locations in Lower and Sandy Hook Bays, 1982- 1983. Report to the New York District, U.S. Army Corps of Engineers, 79 pp.

O'Connor, J.S. 1972. The macrofauna of Moriches Bay, New York. Biol. Bull. 142:84-102.

Olson, P. and Cohn, A. 1979. Phytoplankton in Lower New York Bay and adjacent New Jersey estuarine and coastal areas. Bull. N.J. Acad. Sci. 24:59-70.

O'Reilly, J.E. Thomas, J.P., and Evans, C. 1976. Annual primary production (nannoplankton, netplankton, dissolved organic matter) in the Lower New York Bay. Paper No. 19, In McKeon, W.H. and Lauer, G.J. (eds.). Proceedings Fourth Symposium on Hudson River Ecology, Hudson River Environmental Society, Inc. New York, 39 pp.

Orth, R.J. 1973. Benthic infauna of eelgrass, Zostera marina, beds. Chesapeake Sci. 14:258-269.

Patten, B.C. 1962. Species diversity in net phytoplankton of Raritan Bay. J. mar. Res. 20:57-75.

Pearce, J.B. 1974. Invertebrates of the Hudson River estuary. Ann. N.Y. Acad. Sci. 250:137-143.

Pearce, J.B. 1979. Raritan Bay - a highly polluted estuarine system. International Council for the Exploration of the Sea, Marine Environmental Quality Committee, C.M.1979/E:45, 16 pp.

Ristich, S.S., Crandal, M., and Fortier, J. 1977. Benthic and epibenthic macroinvertebrates of the Hudson River. I. Distribution, natural history and community structure. Estuarine Coastal Mar. Sci. 5:255-266.

Rowe, G.T., Polloni, P.T., and Rowe, J.I. 1972. Benthic community parameters in the lower Mystic River. Int. Rev. Gesellschaft Hydrobiol. 57:573-584.

Sage, L.E. and Herman, S.S. 1972. Zooplankton of the Sandy Hook Bay area, N.J. Chesapeake Sci. 13:25-39.

Sanders, H.L. 1956. Oceanography of Long Island Sound, 1952-54. X. Biology of marine bottom communities. Bull. Bingham Oceanogr. Collect. 15:345-414.

Sanders, H.L. 1960. Benthic studies in Buzzards Bay. III. The structure of the soft-bottom community. Limnol. Oceanogr. 5:138-153.

Smith, T.P., Lipton, D.W., and Norton, V.J. 1985. Final report Hudson/Raritan Estuary project (HREP): Partitioning of the national survey of recreational fishing statistics. University of Maryland, Department of Agricultural and Resource Economics, College Park, 34 pp.

Stainken, D.M. 1984. Organic pollution and the macrobenthos of Raritan Bay. Environ. Toxicol. Chem. 3:95-111.

Steimle, F.W. Jr. and Stone, R.B. 1973. Abundance and distribution of inshore benthic fauna off southwestern Long Island, N.Y. NOAA Technical Rep. NMFS SSRF-673, Seattle, 50 pp.

Summers, J.K., Polgar, T.T., Rose, K.A., Cummings, R.A., Ross, R.N., and Heimbuch, D.G. 1986. Assessment of the relationships among hydrographic conditions, macropollution histories, and fish and shellfish stocks in major northeastern estuaries. Rep. for NOAA/OAD prepared by Martin Marietta Environmental Systems, Columbia, Maryland. 226 pp.

Texas Instruments, Inc. 1977. Influence of Indian Point Unit 2 and other steam generating plants on the Hudson River estuary, with emphasis on striped bass and other fish populations. Lawer, Matusky, and Skelly, Engineers, Inc. New York University Medical Center. Con. Edison, New York. 1049 pp.

U.S. Army Corps of Engineers. 1984. Subaqueous borrow pit demonstration project Lower Bay of New York Harbor, Richmond County, N.Y. Draft Environmental Impact Statement for New York State Dept. of Environmental Conservation, Region 2, New York. 133 pp.

U.S. Department of Commerce. 1986. Status of the fishery resources off the Northeastern United States for 1986. NOAA Technical Memorandum NMFS-F/NEC-43. Woods Hole, 130 pp.

Walford, L.A. 1971. Review of aquatic resources and hydrographic characteristics of Raritan, Lower New York and Sandy Hook Bays. Rep. for Battelle Institute. Sandy Hook Sport Fisheries Marine Lab. NMFS, 80 pp.

Weinstein, L.H. (ed.). 1977. An atlas of the biologic resources of the Hudson Estuary. Boyce Thompson Inst. for Plant Res., Yonkers. 104 pp.

Wilk, S.J., Morse, W.W., Ralph, D.E., and Azarovitz, T.R. 1977. Fishes and associated environmental data collected in New York Bight, June 1974-June 1975. NOAA Technical Rep. NMFS SSRF-726, 53 pp.

STRESS NATURAL AND ANTHROPOGENIC DISEASES

Ann Cali, Ph.D.
Department of Biological Sciences
Rutgers University
Newark, NJ 07102

What can possibly go wrong with a fish? A fish, like any other living organism, is in balance with everything around it and the various parts of the fish are in balance with each other. This means that the health of a fish is determined by how well it maintains a complex system of functioning. The fish must maintain a balance with the demands and changes of its environment, the various organs must maintain the range of internal physiological processes, in balance with the needs of the organism as a whole, and the individual cells must function in a balance with the developmental patterns of the fish as it goes through life. At any of these levels, the balances can be disturbed and, if the disturbance is adequate to impair the stability of the fish (its ability to return to balance after disturbance), the survival and reproductive potential of the fish may be threatened.

These balances are fluid within certain ranges; however, once they are exceeded, adjustments are necessary to modify the functioning of the entire organism so that balance may be restored. The general state of the organism during such a modification of functioning is called stress. Factors that create imbalances are called stressors.

While natural changes in the fish's environment involve numerous stressors, other stressors are related to the influence of human activity on water quality (anthropogenic stressors). Natural and anthropogenic stressors can interact; this interaction, or synergism, greatly increases the risk of the organism of being in a stressed state. This stress increases the potential for serious disturbance at various levels of balance, which in turn increases the possibility of disease.

Diseases may be divided into two general types: infectious and non-infectious. Infectious diseases are caused by living agents such as viruses, bacteria, protozoa, etc. Non-infectious diseases are caused by genetic, nutritional, environmental, and chemical or other non-living factors which adversely affect life.

Synergisms may also occur between infectious and non-infectious agents resulting in additional stress and a pathology not caused by either on its own but resulting from the combined effect. This interaction makes it very difficult to separate the individual components of complex disease situations. All organisms are constantly interacting with their environment and encountering organisms that have the potential for pathogenicity but it usually takes an imbalance in the system to produce a disease.

While it is often possible to correlate specific infectious diseases to particular factors or stressors, the demonstration of causation between environmental conditions and diseases is not often achieved, probably due, for the most part, to the high degree of understanding of a disease necessary for such a determination.

The diseases that I will deal with here are highlights of our knowledge of diseases of aquatic organisms in the Hudson-Raritan Bays complex. While it is clear that our knowledge of the interactions of factors that give rise to these diseases is most incomplete, in many cases the correlations are compelling enough to warrant further investigations into possible causation.

Lymphocystis

Lymphocystis is a viral disease which causes hypertrophy of fibroblast cells. The disease primarily affects the integument of the host fish. Additionally, it has been reported in the eyes, kidney, spleen, liver, heart, ovaries, and mesenteries of silver perch (Dukes and Lawler, 1975). It has been found in both marine and fresh water fish. In the N.Y. and N.J. bay complex, it has been found in winter flounder, and *Pseudopleuronectes americanus*, (personal observation and communication with J. Ziskowski). It has also been seen in striped bass over-wintering in the heated effluent of a Long Island generating station (Sindermann, 1979). Diagnosis can usually be made on gross observation alone (Fig. G-1); the presence of protruding spherical nodules is a field sign of this viral disease.

The virus responsible for this disease was demonstrated by electron microscopically (Walker, 1962; Walker and Wolf 1962) and by transmission of the disease with bacteria-free filtrates from the disease (Weissenberg, 1951; Wolf, 1962). In 1968, Midllige and Malsberger were able to demonstrate its morphology and development in fish tissue culture. The fibroblastic connective tissue cells can grow to enormous size, becoming easily visible to the naked eye. Severe cases may result in coverage of the majority of the body surface. Lymphocystis has been reported in 49 species of fish representing 20 families (Nigrelli and Ruggiari, Templeman 1965) suggested the possibility that the disease is enzootic in a population and may increase in intensity periodically. Other studies, however, have associated increased prevalence with environmental degradation (Christmas and Howse, 1970; Perkins et al., 1972; and Dethlefsen, 1978). Lymphocystis is an example of a disease in which an infectious agent definitely causes the lesion, but environmental degradation may be responsible for greater incidence.

Fin Erosion

Fin erosion is also know as "fin rot" since it is characterized by fin destruction. To quote Sindermann (1979): "Probably the best known but least understood disease of fish from polluted waters is a non-specific condition known as fin rot or fin erosion" (Figs. F-1 and F-2). The only thing researchers agree on is that it is found in degraded environments. Bacteria from the genera *Vibrio*, *Aeromonas*, and *Pseudomonas* have frequently been isolated from affected fish but not demonstrated as the etiological agent. Murchelano (1975) found no bacterial agents associated with lesions in winter flounder and additionally commented on the lack of a pronounced inflammatory reaction which should be presented if bacteria produced the lesion. In summer flounder (*Paralichthys dentatus*), he observed bacteria but still did not see a pronounced inflammatory response. He concluded that the necrotic process is probably due to a chemical irritant and is not microbial.

The disease occurs in both demersal and benthic fish in the N.Y. Bight and has been found in both. Mahoney et al. (1973) reported the occurrence of fin rot in 22 fish species in the N.Y. Bight. These included winter and summer flounder, bluefish, and weakfish. Ziskowski and Murchelano (1975) compared the incidence in winter flounder from different locations and found 14.1% from the inner Bight against only 1.9% from a more pristine environment (Great Bay, N.J.). The disease does not seem directly to cause mortality in fish. In severe cases, however, when the majority of fin tissue is no longer present, their swimming ability is impaired and, therefore, their ability to capture prey and avoid predators will be affected.

Although the disease does not have a demonstrated economic importance, researchers seem to agree that its occurrence signals degraded environmental quality and, consequently, it should be monitored.

Ulcer Disease

Ulcers are open hemorrhagic sores located anywhere on fish's body surface. This is considered the most common fish disease of polluted waters. Bacterial organisms have been frequently isolated from these lesions, usually Virbro anguillarum. Robohm and Brown (1977) experimentally infected summer flounder with a Virbrio isolated collected from an ulcer. They were able to reproduce the ulcerative lesion and recover the organism. Levin et al. (1972) achieved similar results with winter flounder. In the N.Y. Bight area, ulcerative lesions have been reported in red hake (Urophycis chuss), (Murchelano and Ziskowski, 1979).

Shell Disease

Shell disease, sometimes referred to as ulcers of anthropods, causes a progressive necrosis and lysis of the exoskeleton of crustaceans. This disease is caused by chitinoclastic (chitin-consuming) bacteria, Virbrio/Beneckea (Estrella 1984; Rosen, 1970, in Snieszko). These bacteria, in association with contaminant chemicals in polluted environments, combined to make shell disease a common phenomenon and a significant mortality factor in crustaceans inhabiting degraded environments (Sindermann, 1979). This disease is prevalent in highly polluted areas and has been suggested as a shellfish counterpart to fin erosion (Figs. S-1, 2, 3, 4, and 5).

Shell disease occurs in the N.Y. Bight in areas where dredge spoils, industrial wastes, and sewage sludge are present. A variety of crustaceans are affected including: crabs, Cancer irroratus; lobsters, Homarus americanus (Young and Pearce, 1975); shrimp (Gopalan and Young, 1975), and caridean shrimp, Cragnon septemspinosa (including one study, when 30% of over eight-hundred were infected) (Murchelano 1983).

Experimentally, this disease has been induced in Alaskan King crab exposed to bacteria (Bright et al., 1960) and in crabs and lobsters exposed in aquaria for six weeks to sediment from sewage sludge dump sites. Additionally, there have been reports in the literature of forms of shell disease (in Eastern Europe) whose causes can be traced to fungal infection (Ramularia) (Mann and Pieplow, 1938).

It is believed that this disease kills crustaceans. Dead crabs and lobsters with this disease syndrome have been reported by divers in the N.Y. Bight apex (Pearce, 1972). This disease attacks the calcified chitin once the epicuticle is damaged (figures). Because the disease does not appear to penetrate to the soft tissue, some researchers believe that, if the animal can survive to the next molt, it can overcome the disease. Rosen (1970) has reported observing this phenomenon in blue crabs, and McLeese and Wilder (1964) observed it in lobsters. The general consensus is that the disease is contagious and will spread in crowded conditions.

This is an example of the variable effects of a microorganism whose pathogenicity is most evident under conditions of environmental stress.

Microsporidiosis

One of the diseases that flatfishes are susceptible to is microsporidiosis. Microsporidia are spore-forming intracellular obligate protozoan parasites, known to infect every major group of animals. Species of the microsporidian genus Glugea parasitize fish and produce large "cysts" or xenomas that range in size from microscopic to greater than 5mm in diameter. These xenomas are enormously hypertrophied host cells.

One species, Glugea stephani, parasitizes several genera of economically important flatfishes throughout the world. In the United States, at least five flatfish species have been identified as its hosts. Although the American winter flounder, Pseudopleuronectes americanus, is a major component of the commercial and sport fishery, little attention had been given to the occurrence of this disease in it since 1901, when it was first described by Linton. The microsporidian was reported to infect winter flounder from Massachusetts to Canada, but recent investigations with Parophrys vetulus (English sole) demonstrated the preference of the parasite for warmer water, >15 C for both initiation and development of parasite infections (Olsen, 1976). A combination of the above two facts led us to believe that G. stephani would be present in winter flounder from the N.Y. and N.J. Lower Bay complex. Subsequent studies of winter flounder collected in this area validated the hypothesis (Takvorian and Cali, 1981) (Fig. G-1).

To determine the incidence of G. stephani in local flounder, we have monitored the disease prevalence continuously since 1978 and were able to demonstrate that G. stephani is present in local stocks on a year-round basis. Additionally, the incidence appears to be seasonal, fluctuating with water temperature (Takvorian and Cali, 1984). Monthly infection prevalences as high as 28% have been observed in the N.Y. and N.J. bay area in late summer (Fig. G-2a and Fig. G-2b). These data include only infected fish that have survived beyond the yearling stage and developed macroscopic cysts. Consequently, the incidence numbers are conservative.

Collections of winter flounder along the Massachusetts coast provided data demonstrating site/incidence variation, rather than seasonal variation. The incidence of infection found was 52% in Mass. Bay, 38% in Cape Cod Bay, and only 12% at Nantucket Shoals. These collections were all made within a one week period, indicating environmental differences other than, or in addition to, temperature in the areas of the first two collection sites as compared to the third (Cali and Takvorian, 1983).

As a consequence of the findings in Massachusetts, we divided the N.Y. and N.J. Lower Bay complex into 5 collection areas (Fig. G-3, map 1). A comparison of Glugea site/incidence percentages indicates that there is a marked increase in infection in the western part of the bays were determined by a G-test significance ($p<0.02$). These data appear to coincide with the east/west heavy metal deposition in Raritan Bay recorded by Greig and McGrath (1977) (Fig. G-4, map 2).

Additionally, Graves End Bay is located at the SE end of the Narrows and water flow patterns indicate that Hudson River flow bypasses much of the lower bay complex. An interesting hypothesis could be that something or some combination of anthropogenic factors coming from that water source is greatly influencing the incidence of disease. The Graves End site has significantly higher disease incidence that any of the other locations and 3x the disease incidence of Sandy Hook Bay.

In an effort to determine unbiasedly the environmental parameters necessary to promote infection, we are collaborating with Dr. Carl Berman (NOAA). He has computerized environmental archival data (collected on many NOAA surveys) of the NE coast and designed a multivariant analysis system which, hopefully, will lead to a predictive model of the environmental factors that promote the disease in this area.

Studies of G. stephani pathology indicate that it invades connective tissue cells of the digestive tract. Infected cells may be found in any of the connective tissue areas from the mesentery to the lamina propria of the intestinal villar projections, producing massive host cell hypertrophy (xenomas) often exceeding 5mm in diameter. With the histological observations obtained during this portion of the project, it became increasingly obvious that the pathology must lead to the death of fish.

In 1986, Cali et al. experimentally infected winter flounder and demonstrated Glugea induced mortality. Since this had never been done before, the experiment was repeated. Among fishes in the experimentally exposed group, 49.1% were infected and 63.3% of them died from G. stephani (Cali et al., 1986).

The mortality data from experimental exposures documents a point that is difficult, if not impossible, to demonstrate in the field. We and others have observed field collected fishes that clearly appeared to be moribund. However, proving that a diseased animal will die soon is an illusive point to demonstrate (flatfishes that are moribund or dead are likely to be consumed by scavengers rather than captured). Stunkard, in his 1969 review of the sporozoan, stated in regard to field collected young-of-the-year winter flounder massively infected with G. stephani:

> All information shows that these fishes do not survive into their second year."

The historically observations on moribund and live fishes demonstrates that they may die from a low intensity of Glugea infection if the xenomas are located in the mucosa where their size causes rupture of the intestinal epithelial lining (Fig. G-5). A fish may die from a high intensity of Glugea if the massive infection results in occlusion of the intestinal lumen, disruption of the intestinal integrity (Fig. G-6), or emaciation (starvation) (Fig. G-7). Additionally, a fish with a relatively high intensity of infection may survive if the xenomas are located on the serosal side of the intestinal tract and do not deplete the nutritional needs of the host to a point of starvation and death. Thus, the importance of xenoma location as well as intensity is evident in the pathology of Glugea stephani disease.

Our experimental infections have demonstrated a greater than 50% mortality in infected fish, a fact that could not been seen in the field. The field data have demonstrated the need for further studies into localized environmental factors. A combination of pathology, in-laboratory infections, field observations, and environmental data is necessary to provide a more realistic perspective of a disease impact than any one of these factors can, by itself (Fig. G-8).

We are grateful to N.J. Sea Grant and the National Marine Fisheries Service for the funding and facilities that are making such research possible.

NONINFECTIOUS DISEASE

In a 1982 publication on the effect of pollutants on fishes, Sindermann et al. listed mercury, cadmium, silver, PCBs, DDT and its metabolites, and petroleum hydrocarbons as the contaminants of particular importance to fishes and shellfish (Sindermann et al. 1982). Dioxin should be added to this list, since the NJDEP has posted warnings against the sale or consumption of any fish or crabs from the waters of Newark Bay, tidal Hackensack River, Arthur Kill, and Kill Van Kull because of a concern for dioxin contamination (Belton et al. 1985).

Since some recent studies with dramatic findings have been made in regard to Atlantic tomcod liver tumors and contamination (possibly with PCBs) in the Hudson River, I will focus on this problem. That is not to say that others are not important, but only that this is possibly the most studied pollution-related problem (in regard to fish disease) in our area.

Before beginning a discussion on this disease problem, a quick review of liver function is in order. Most marine animals (including fish, crabs, lobsters, and other arthropod) have a major organ in their body that functions as a liver; in some it is called a hepatopancreas or digestive gland. The liver (or its analog) functions in a myriad of essential activities. Among its many functions are filtration, secretion, and storage. Filtration includes cleaning and de-toxifying body fluids by removing waste matter, chemicals, or cells that should not be in the circulating blood. Secretion includes such activities as manufacturing digestive enzymes that are delivered to the intestine, thus enabling the animal to break down food and absorb it into the body tissue. Storage includes the intracellular holding of such materials as glycogen until the body needs them. It is obvious that, regardless of body type (shellfish or flatfish), the hepatic or liver tissue is essential for life and is a defense against toxic substance that accost the body.

The liver employs different strategies to deal with the various materials it filters from the blood. Some materials, such as old or dying circulating cells, are filtered out and broken down. Some materials, such alcohol, are filtered out at the expense of liver cells, which may die from exposure. If this occurs, the fibrous tissue that replaces the cells can cause cirrhosis of the liver. Other materials, including some toxic chemicals, are fat-soluble, and in an effort to remove these materials from the circulation, the liver cells can become filled with lipids (and thus store toxic chemicals that are dissolved therein). This condition is acceptable if the exposure to these substances is short-term, but if the exposure to the toxin is continuous, the liver cells will be overrun with fatty acids and normal liver function impaired. Additionally, when the animal takes some of this fat out of storage for functions such as making eggs for the reproductive system, the toxic chemicals stored in the lipid deposits may again be free in the bloodstream and have a deleterious effect on the animal or potential off-spring. Additionally, if this animal happens to be eaten by another animal (or by humans), they will be given a dose of the toxic substance as the animal is digested. Humans do not normally eat the livers of finfish but we do normally eat the entire body of clams and soft-shell crabs, and many people eat the hepatopancreas of the lobster. This very problem is the reason that many N.Y. and N.J. River and Bay areas have been closed to fishing (Figs. P-1 and P-2).

One aspect of chemical toxicity of particular concern is compounds that are carcinogenic. Carcinogenic compounds cause cell transformation and uncontrolled multiplication. Some of the toxic chemicals concentrated in the liver are carcinogenic; one manifestation of the presence of these chemicals is the occurrence of hepatocellular carcinomas (liver tumors).

In 1979, Smith et al. were investigating the effects of power plants in the Hudson River estuary in New York on the biology of several fish species. Because liver tumors and other abnormalities were observed so frequently in Atlantic tomcod (*Microgadus tomcod*), they undertook a study to estimate the prevalence of hepatomas in the spawning population of this species (Smith et al., 1979). Histological examination of livers demonstrated the presence of excessive fat deposition, congestion, necrotic cells, and mild hemorrhage, in addition to tumors. The tumor nodules appeared to be invading the surrounding normal tissues. In advanced tumors, cystic spaces containing debris, extensive hemorrhage, some fibrous deposition, and necrosis of tumor cells were present.

There are, in the literature, relevant findings which implicate PCBs. Falkmer et al. (1977) studying neoplasms, including hepatomas, in the Atlantic hagfish in Sweden, found a dramatic decrease in the rate of hepatocellular carcinomas between 1972 (5.8%) and 1975 (0.6%). They correlated this to a decrease in PCBs in Sweden in 1971-72. They carried out an extensive chemical study of the liver of these fish and demonstrated a direct correlation between the levels of PCB in liver tissue and the incidence of hepatocellular carcinomas. Additionally, they histologically compared the hagfish tumors with those experimentally produced in rats fed PCBs and found they were "strikingly similar."

A more recent comparative study demonstrates even more convincing correlations between carcinogens and fish. In 1986, Cormier published her study of the Atlantic tomcod in the Hudson River for hepatocellular carcinomas and compared them to tomcod from a cleaner river on the border of Rhode Island and Connecticut (Pawtucket River) (Cormier, 1986). She conducted an extensive evaluation of the livers of these fish and found more than 45% of the one-year old and over 90% of the two-year old Hudson River fish had evidence of this disease. This _is_ an extremely alarming occurrence of cancers because they do not occur in tomcods from cleaner rivers. According to Dr. Harshbarger (Director, registry of tumors in lower animals), hepatocellular carcinoma naturally has a 0% incidence of occurrence in fish (personal communication). Cormier began her study with an open mind, suspecting viral, genetic, or environmental causes for this carcinogenesis, and concluded her study by stating:

> "We believe that chemical compounds that are known to be present in the Hudson River are the most likely cause of the tumors found in the Atlantic tomcod."

Whether PCBs, other chemical compounds, or a combination thereof is causing the problem is not clear; what is clear is that this carcinogenic result is due to localized environmental degradation.

While PCB in Atlantic tomcod may be considered a serious problem to concerned scientists, it is only part of a larger issue that is far more dramatic, and certainly of concern to us.

In a 1983 document from the NJDEP, Office of Science and Research (Belton et al.), the subject was "How to Reduce Exposure to PCB Contaminated Fish." They posted two signs. The first one read: "Advisory Area" Advisory in effect to limit consumption of Striped Bass, Bluefish, White Perch, White Catfish, and American Eel. The advisory includes the following waterways and tributaries: Hudson River, Upper New York Bay, Newark Bay, tidal Passaic River, tidal Hackensack River, Arthur Kill, Kill Van Kull, tidal Raritan River, Raritan Bay, Sandy Hook Bay, and Lower New York Bay (Fig. P-3). The second sign posted dealt with the sale of fish: "Closed Area: Sale of Striped Bass and American Eel taken from these waterways is prohibited. Closed areas include Hudson River, Upper New York Bay, Newark Bay, tidal Passaic River, tidal Hackensack River, Arthur Kill, and Kill Van Kull." In 1985, (Belton et al.), blue crabs were added to the above list and that was with or without consumption of the hepatopancreas (Fig. P-4).

These warnings and closings are in regard to demonstrated presence of PCB in the consumable tissues of the various fishery animals. The studies, unfortunately, have not been extended to determine the effects of the presence of these compounds on the well being of the fishery animals involved.

FIGURES

Fish with Lymphocystis

Fig. G-2A = The lesions produced by Lymphocystis disease appear as granular to warty protrusions of fins and skin. They are white to gray-white or pink in color and the individual protrusions are tremendously enlarged connective tissue cells.

Lymphocystis in European plaice (*Pleuronectes platessa*. Photo by P. van Banning. (Taken from Sindermann, 1979, Fishery Bull., 751 pp.

Fish with Fin Erosion

Fig. F-1 = Demersal fish
Fig. F-2 = Summer flounder
(Taken from Sindermann, 1979, Fishery Bull.

Blue Crab and Lobster with Shell Disease

(Figs. S-1, 2, 3, 4, and 5, taken from Snieszko, 1970)
Fig. S-1 = A specimen of the blue crab (*Callinectes sapidus*) at an early stage of disease.
Fig. S-2 = A specimen of the blue crab at a late stage of disease.
Fig. S-3 = A specimen of lobster (*Homarus americanus*) at an advanced stage of the disease.
Fig. S-4 = A transverse section of the thoracic sternum of a blue crab demonstrating intact carapace and an early stage of disease. EPI, epicuticle; EXO, exocuticle; C. END, calcified endocuticle; NC. END, noncalicified endocuticle.
Fig. S-5 = A late stage of the disease as seen in a transverse section of the thorasic sternum of the blue crab. For explanation of symbols, see Fig. 4.
(Taken from Snieszko, 1970)

Microsporidiosis

Fig. G-1- = Winter flounder (*Pseudopleuronectes americanus*) infected with *Glugea stephani*.

Top photograph = A 21 cm fish and with heavily infected intestine.

Middle photograph = An enlargement of the intestinal area (the cysts are the opaque white rounded structures located all over the intestine).

Bottom photograph = A histological section through one *Glugea* cyst (Taken from Cali and Takvorian, 1985).

Microsporidiosis (cont'd)

Fig. G-2a = Lymphocystis in European plaice (Pleuronectes platessa).
Fig. G-2b = Graphs of the percentage of G. stephani infection and water temperature at the time of catch in the New York-New Jersey area, 1981-1983.
(Taken from Cali and Takvorian, 1985).
Fig. G-3 = Map of New York-New Jersey Collection Sites. Glugea infection percentages/site is indicated.

7.4% = Sandy Hook Bay
10.3% = East Reach Channel
12.1% = Wards Point
14.5% = Great Kills Harbor
23.6% = Graves End Bay

Fig. G-4 = Map 2. Heavy metals distribution in the sediments of Raritan and New York Bay. Contour line depicting arithmetic mean metal values for sediments (Taken from Greig and McGrath, 1977).
Fig. G-5 = Histological section of a submucosal infection obtained from a fish that died from a low intensity infection.
Fig. G-6 = Histological section of a serosal infection. (Taken from Cali et al., 1986).
Fig. G-7 = Histological section of a massively infected flounder intestine. The lumen. (Taken from Cali et al., 1986).
Fig. G-8 = Massively infected young-of-the-year winter flounder that died as a result. (Taken from Cali et al., 1986).

PCB

Fig. P-1 = Map taken from Belton, 1985 (p.44)
Fig. P-2 = Map taken from Belton, 1985 (p.45)
Fig. P-3 = Sign posted from Belton, 1985
Fig. P-4 = Sign posted from Mayer, 1982 (See xerox for legend)

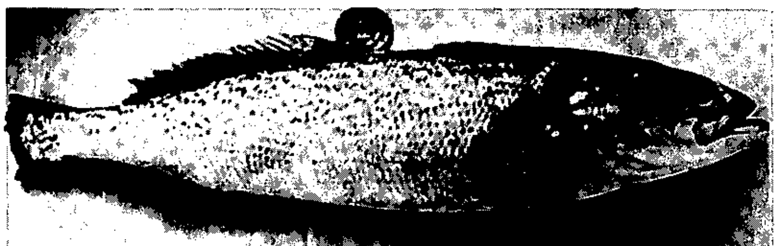


Figure F-1

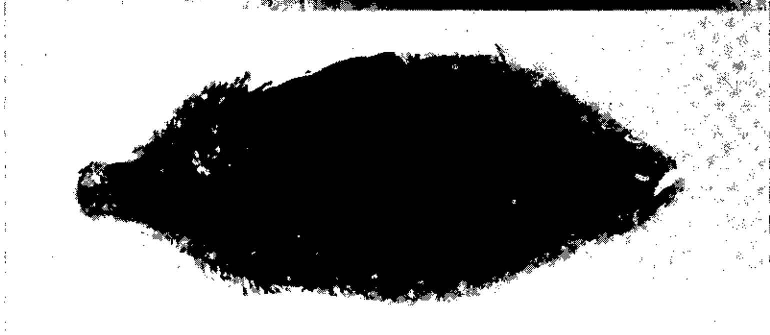


Figure F-2

Figure S-1

FIGURE 1. A specimen of the blue crab (*Callinectes sapidus*) at an early stage of the disease.

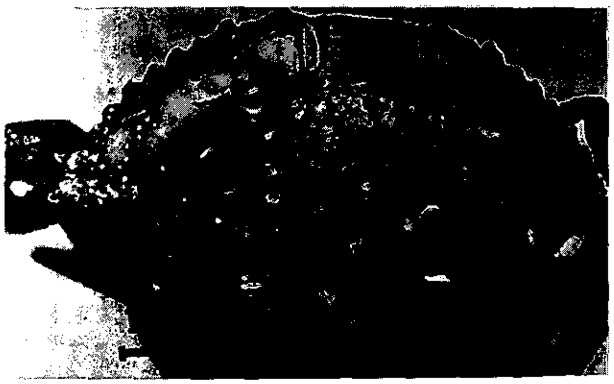


Figure S-2

FIGURE 2. A specimen of the blue crab at an advanced stage of the disease.

FIGURE 3. A specimen of lobster (*Homarus americanus*) at an advanced stage of the disease (Figure donated by Dr. McLeese.)

Figure S-3

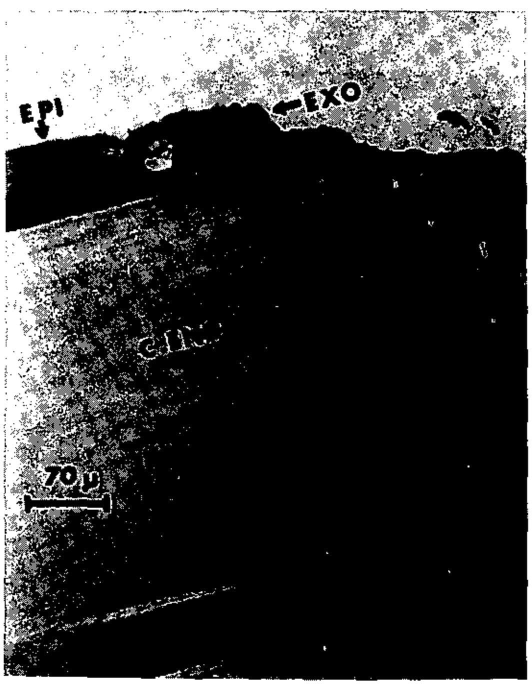


FIGURE 4. A transverse section of the thoracic sternum of a blue crab demonstrating intact carapace and an early stage of the disease. EPI, epicuticle; EXO, exocuticle; C. END, calcified endocuticle; NC. END, noncalcified endocuticle.

Figure S-4

FIGURE 5. A late stage of the disease as seen in a transverse section of the thoracic sternum of the blue crab. For explanation of symbols see

Figure S-5

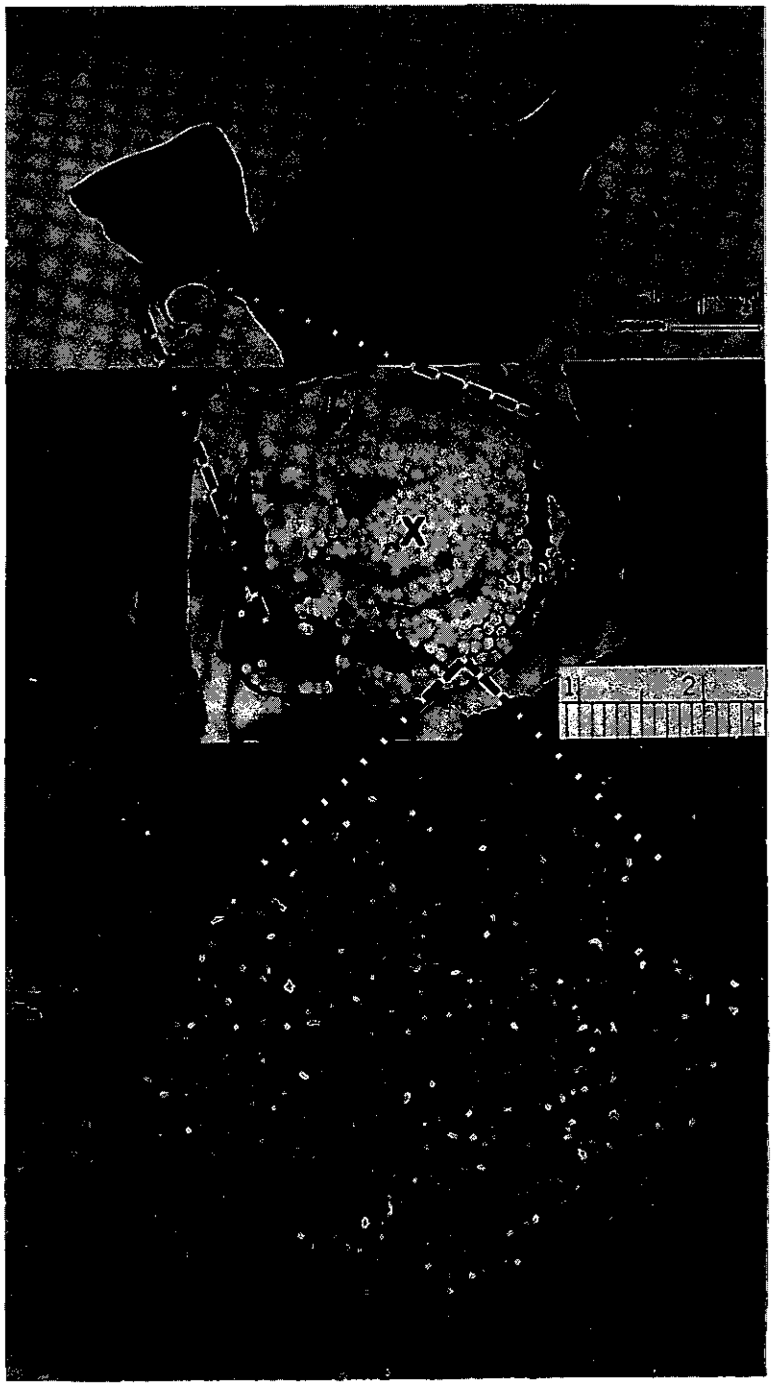


Figure G-1

E 5.—Lymphocystis in European plaice, *Pleuronectes platessa*. (Photograph courtesy of P. Van Banning, Rijkinstituut vo Visserijonderzoek, IJmuiden, Netherlands.)

Figure G-2a

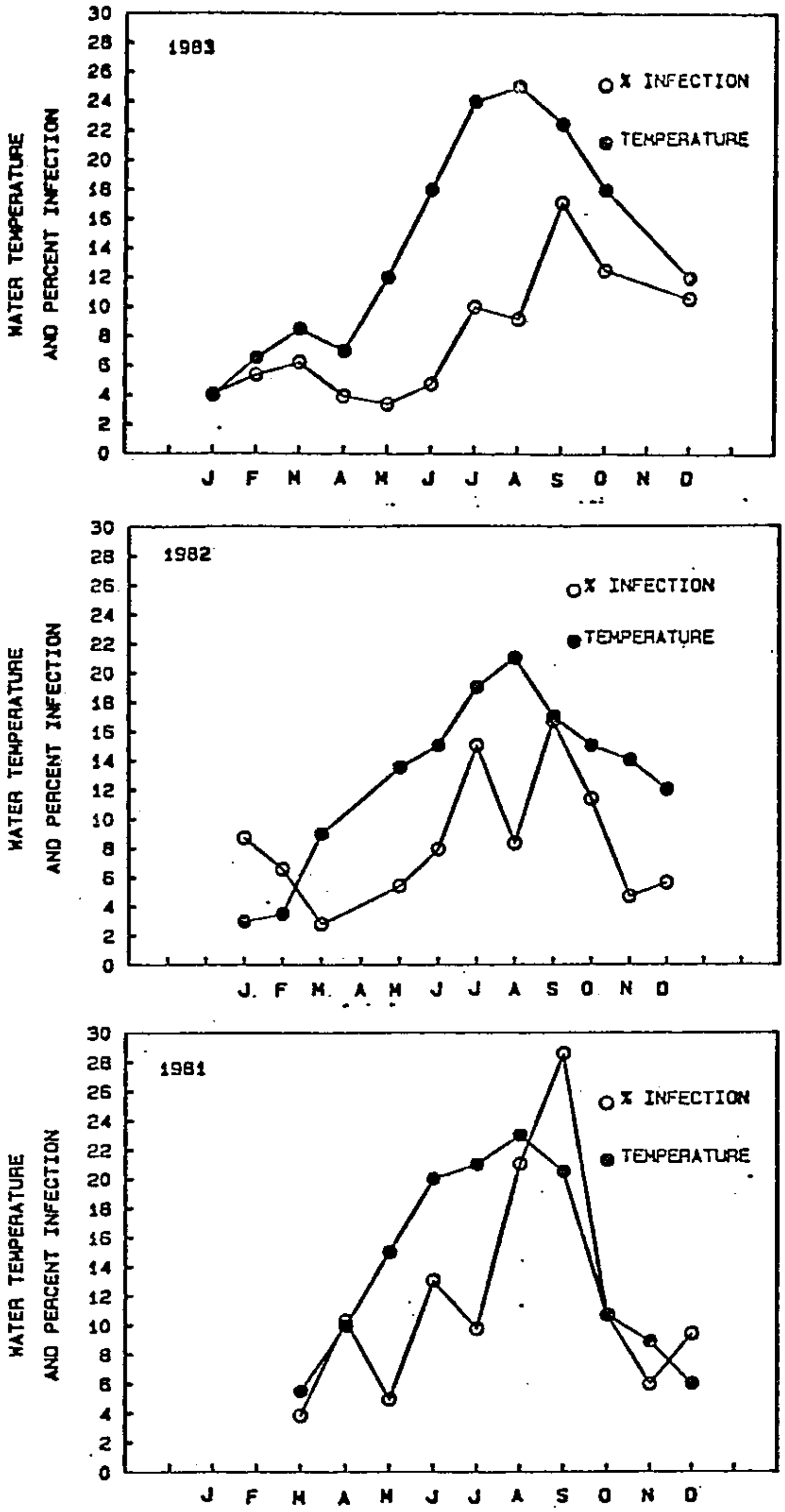


Figure G-2b

Relationship Between Percentage of <u>Glugea stephani</u> Infection and Water Temperature in the New York-New Jersey Area, 1981-1983.

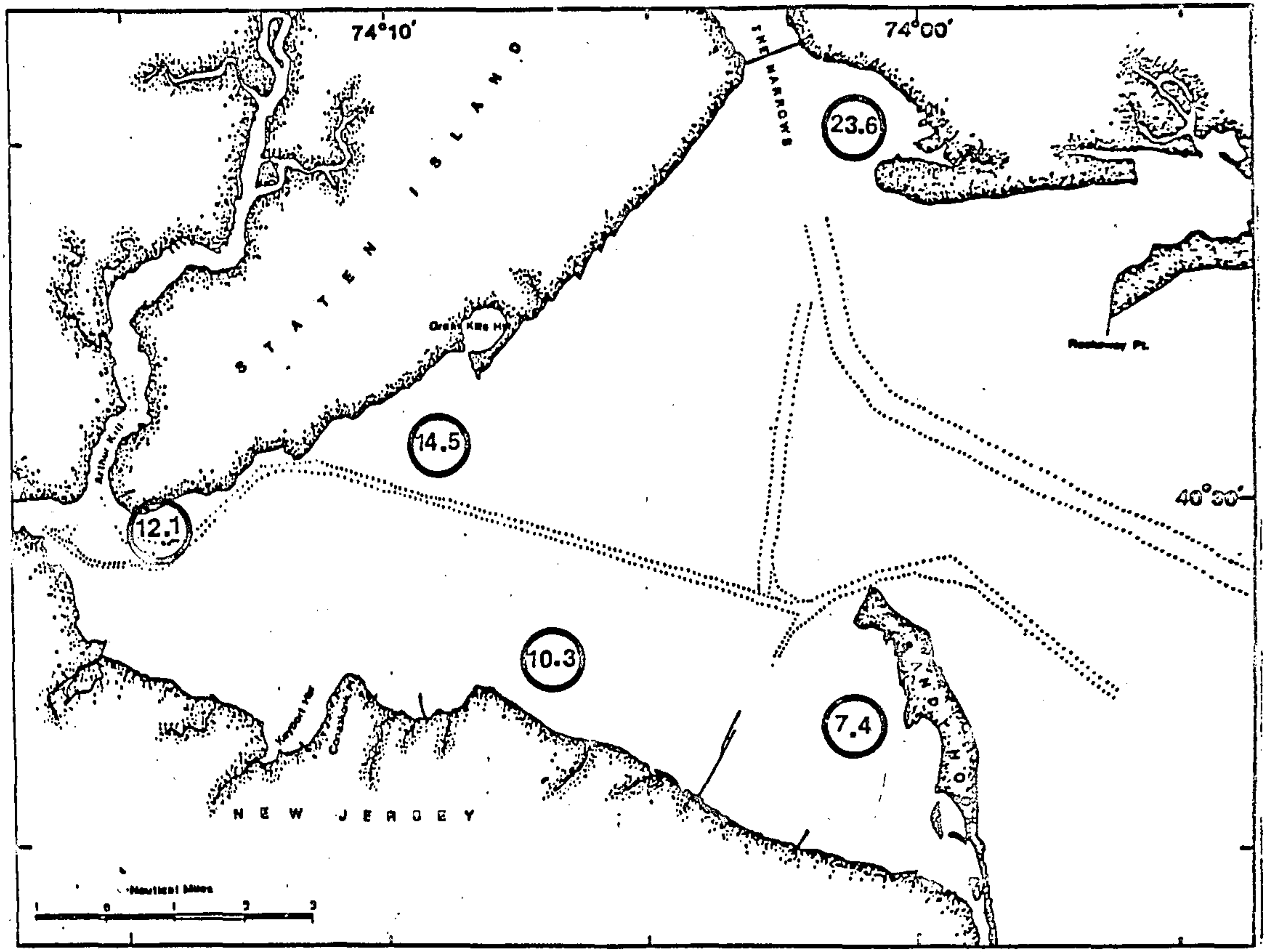


Figure G-3 New York - New Jersey Collection Sites. Glugea Infection percentage/Site Is Indicated.

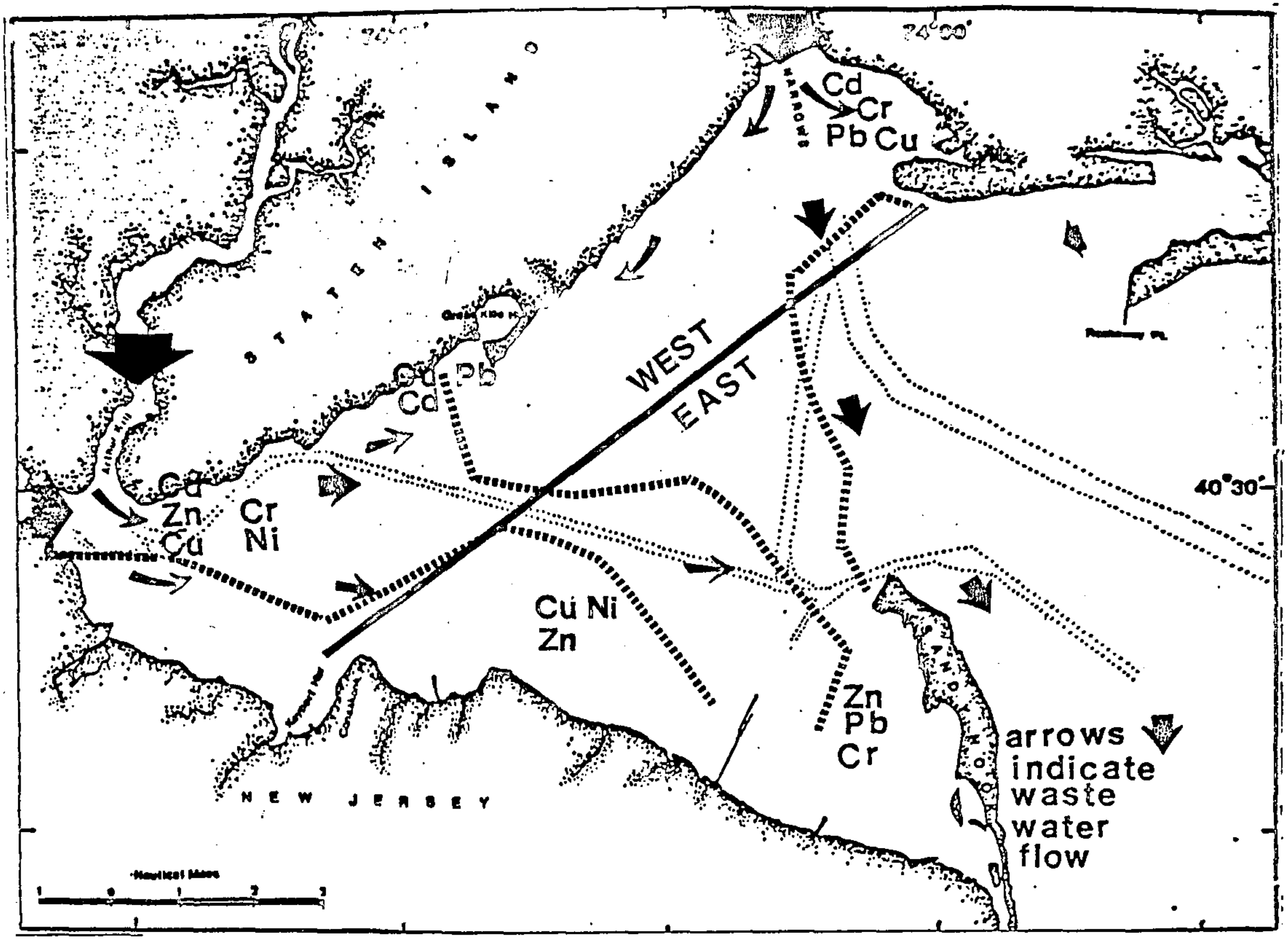


Figure G-4 Heavy Metals Distribution In The Sediments Of Raritan And New York Bay. Contour Lines Depicting Arithmetic Mean Metals Values For Sediments Are Indicated. Arrows Indicate Waste Water Flow. (Map änd metal distribution addapted from Greig & McGrath, Marine Poll.)

Figure G-5

Figure G-6

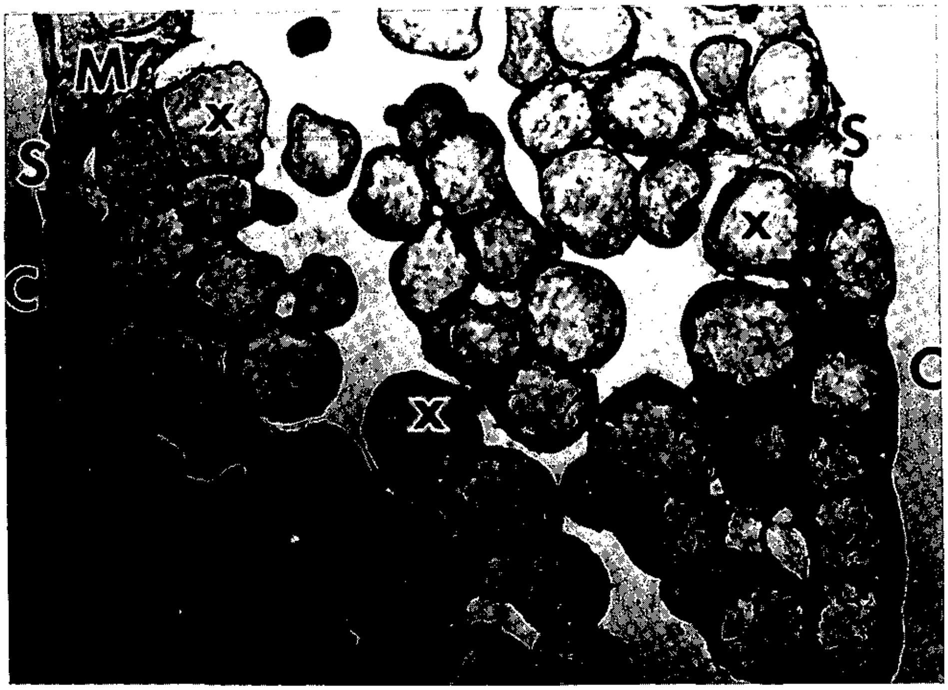


Figure G-7

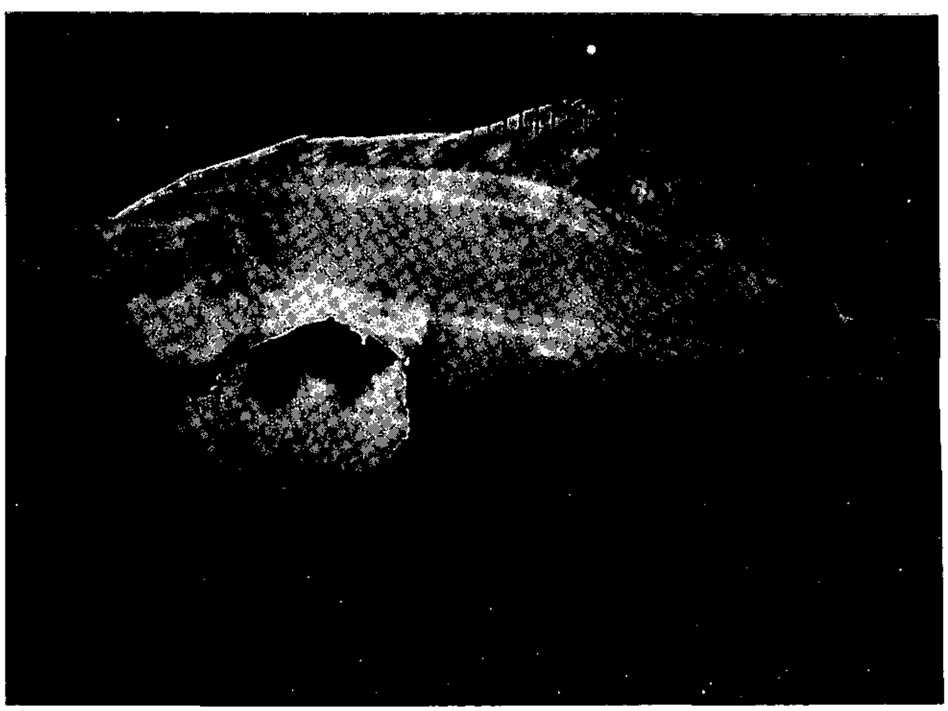
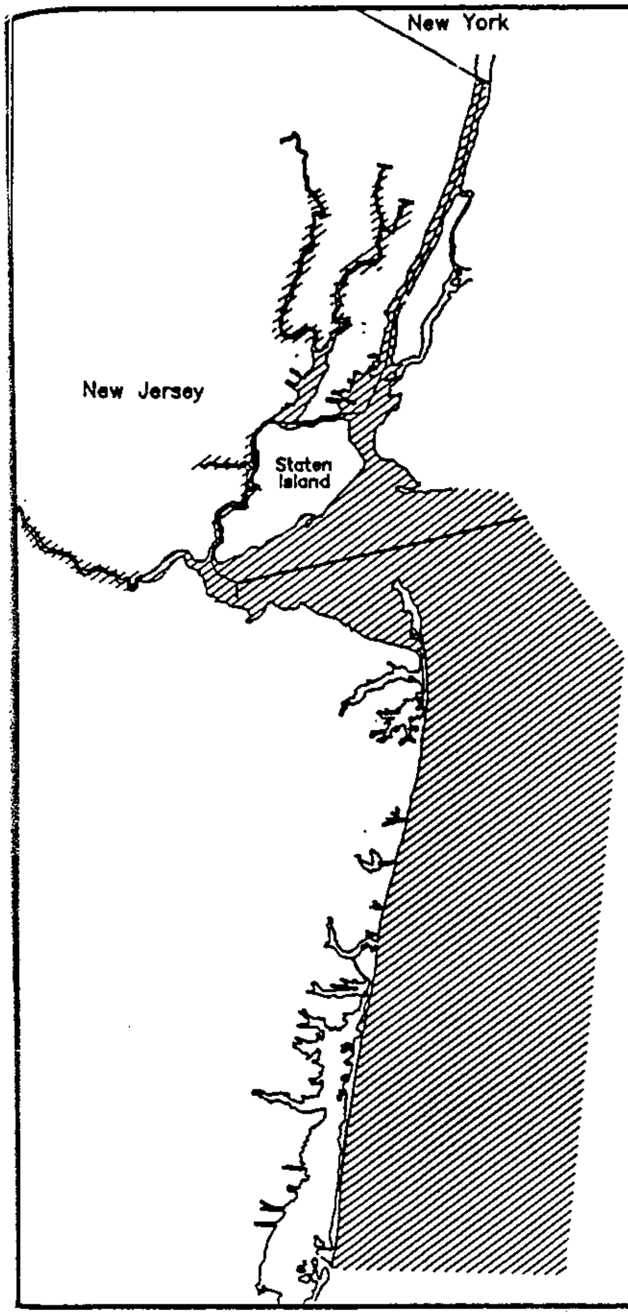


Figure G-8



FISHING ADVISORY AREA DUE TO PCBs IN FISH TISSUE

ADVISORY AREA

Advisory in effect to limit consumption of STRIPED BASS, BLUEFISH, WHITE PERCH, WHITE CATFISH, and AMERICAN EEL.

Advisory area includes the following waterways and tributaries:

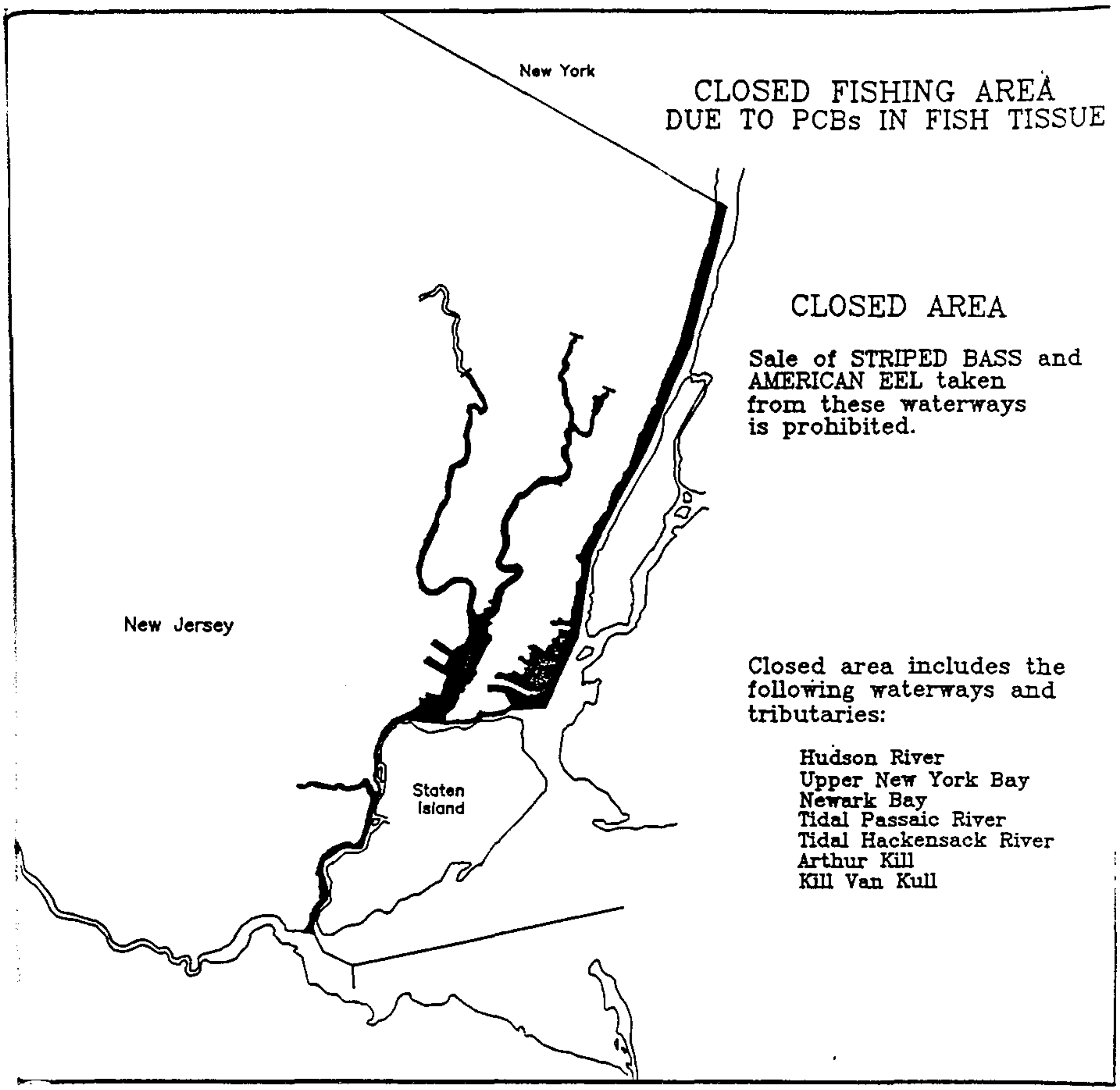
- **Hudson River**
- **Upper New York Bay**
- **Newark Bay**
- **Tidal Passaic River**
- **Tidal Hackensack River**
- **Arthur Kill**
- **Kill Van Kull**
- **Tidal Raritan River**
- **Raritan Bay**
- **Sandy Hook Bay**
- **Lower New York Bay**

STRIPED BASS and BLUEFISH advisory includes Offshore Waters for Northern Coastal Area.

AMERICAN EEL advisory includes all waterways statewide.

MAP 2

Figure P-1



MAP 3

Figure P-2


DO NOT EAT ANY
STRIPED BASS OR CRABS
FROM THESE WATERS
NO COMAN NINGUN LOBINA
NI CANGREJO DE ESTE AGUA

Figure P-3

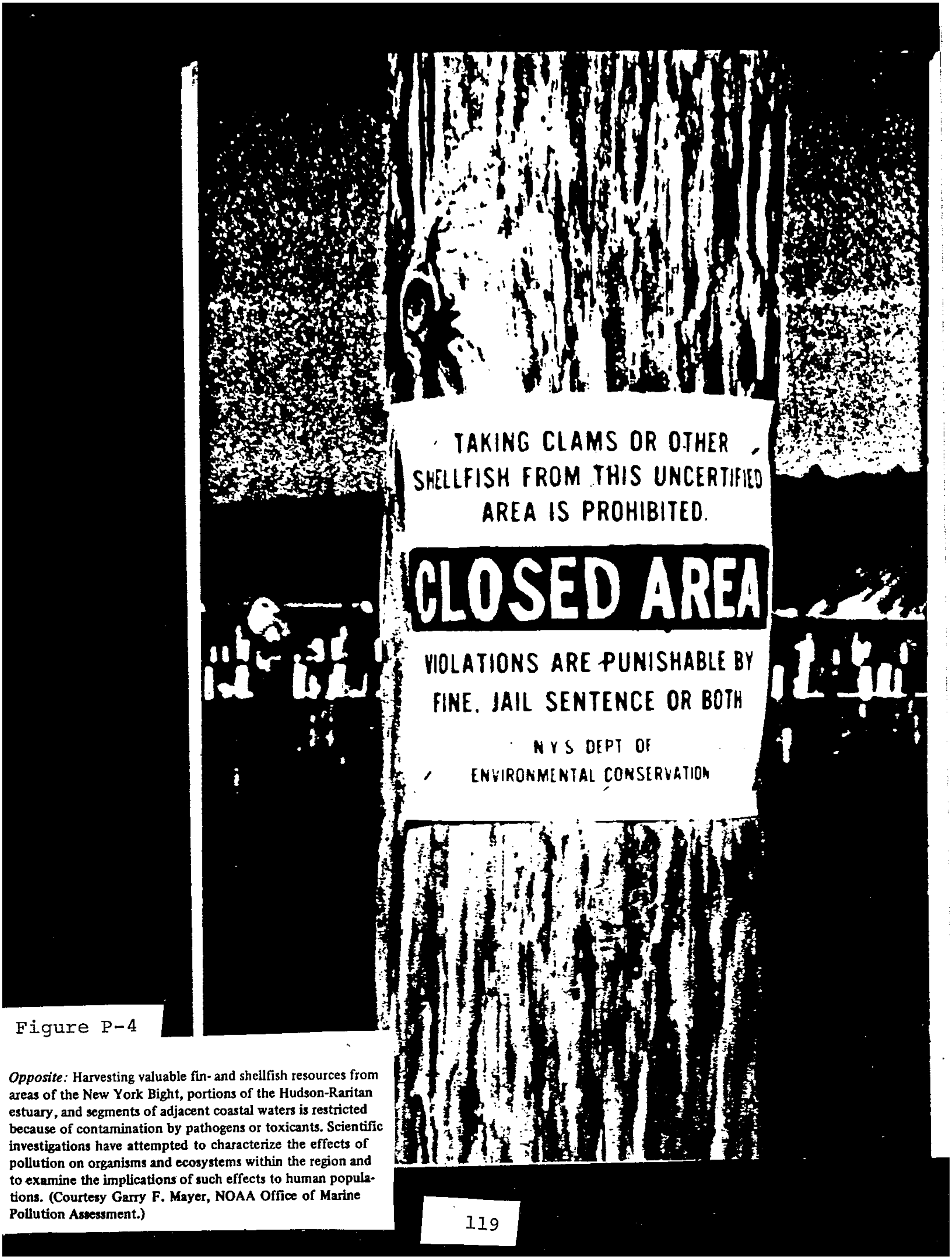


Figure P-4

Opposite: Harvesting valuable fin- and shellfish resources from areas of the New York Bight, portions of the Hudson-Raritan estuary, and segments of adjacent coastal waters is restricted because of contamination by pathogens or toxicants. Scientific investigations have attempted to characterize the effects of pollution on organisms and ecosystems within the region and to examine the implications of such effects to human populations. (Courtesy Garry F. Mayer, NOAA Office of Marine Pollution Assessment.)

REFERENCES

Belton, T.J., B.E. Ruppel, and K. Lockwood. 1982. PCBs (Aroclor 1254) in Fish Tissues Throughout the State of New Jersey: A Comprehensive Survey. New Jersey Documents 974.90, F537, 36pp.

Belton, T.J., B.E. Ruppel, and K. Lockwood. 1983. PCBs in Selected Finfish Caught Within New Jersey Waters 1981-82 (With Limited Chlordane Data). New Jersey Documents 974.90, F537, 36 pp.

Belton, M.A., B. Ruppel, et al. 1985. A Study of Toxic Hazards to Urban Recreational Fishermen and Crabbers. New Jersey Department of Environmental Protection, 45 pp.

Belton, M.A., R. Hazen, B. Ruppel, et al. 1985. A Study Dixon in Aquatic Animals and Sediments. New Jersey Department of Environmental Protection, 101 pp.

Bright, D.B., F.E. Durham, and J.W. Knudsen. 1960. King Crab Investigations of Cook Inlet, Alaska. Unpublished Report Cited in Sindermann and Rosenfield, 1967.

Cali, A. and P.M. Takvorian. October 1983. Environmental Variability as Reflected in Glugea stephani Incidence in Winter Flounder (Pseudopleuronectes americanus). International Council for the Exploration of the Sea Proceedings #64, 13 pages.

Cali, A. and P.M. Takvorian. 1985. New Jersey Sea Grant Annual Report 1983-1984, 14-16 pps.

Cali, A. and P.M. Takvorian. 1986. New Jersey Sea Grant Annual Report 1984-1985, 6-7 pps.

Cali, A. and P.M. Takvorian, J. Ziskowski, and T. Sawyer. 1986. Experimental Infection of American Winter Flounder (Pseudopleuronectes americanus) With (Glugea stephani) (Microsporidia). J. Fish. Biol., 28:199-206.

Christmas and Howse. 1970. The Occurrence of Lymphocystis in Micropogon undulatus and Cynoscion arenarius from Mississippi Estuaries. Gulf Res. 3, 131-154 pps.

Cormier, S.M. 1986. Fine Structure of Hepatocytes and Hepatocellular Carcinoma of the Atlantic tomcod, (Microgadus tomcod). (Walbaum), J. of Fish Disease, 9:179-194.

Dethlefsen, V. 1978. Occurrence and Abundance of Some Skeletal Deformities, Diseases, and Parasites of Major Fish Species in Dumping Areas off the German Coast. Int. Counc. Explor. Sea, C.M. E:8, 17 pp.

Dukes, T.W. and A.R. Lawler. 1975. The Ocular Lesions of Naturally Occurring Lymphocystis in Fish. Can. J. Comp. Med., 39:406-410.

Estrella, B.T. 1984. Black Gill and Shell Disease in American Lobster (Homarus americanus) as Indicators of Pollution in Massachusetts Bay and Buzzards Bay, Massachusetts. Department of Fisheries, Wildlife, and Recreational Vehicles, Division of Marine Fisheries, 17 pp.

Falkmer, S., S. Marklund, P.E. Mattsson, and C. Rappe. 1977. Hepatomas and Other Neoplasms in the Atlantic Hagfish (Myxine glutinosa: A Histopathologic and Chemical Study. Ann. N.Y. Acad. Sci., 298:342-355.

Gopalan U.K. and J.S. Young. 1975. Incidence of Shell Disease in Shrimp in the New York Bight. Marine Pollution Bulletin, 6(10):149-153.

Greig, R.A. and R.A. McGrath. 1977. Trace Metals in Sediments of Raritan Bay. Mar. Pollut. Bull., 8:188-192.

Levin, M.A. R.E. Wolke, and V.J. Cabelli. 1972. Vibrio angullarum as a Cause of Disease in Winter Flounder (Pseudopleuronectes americanus). Can. J. Microbiol., 18:1585-1592.

Linton, E. 1901. Fish Parasites Collected at Woods Hole in 1898. Bull. U.S. Fish. Comm., 19:267-304.

Mahoney, J.B., F.H. Midlige, and D.G. Deuel. 1973. A Fin Rot Disease of Marine and Euryhaline Fishes in the New York Bight. Transactions of the American Fisheries Society, 102(3):596-605.

Mann, H. and U. Pipeplow. 1938. Die Brandfleckenkrankheit Bei Krebsen und Ihre Erreger. Z. Fischerei, 36:225-240.

McVicar, A.H. 1975. Infection of Plaice (Pleuronectes platessa L. with Glugea (Nosema) stephani (Hagenmuller 1899) (Protozoa: Microsporidia) in a Fish Farm and Under Experimental Conditions. J. Fish. Biol., 7:611-619.

McLeese, D.W. and D.G. Wilder. 1964. Lobster Storage and Shipment. Fish. Res. Bd. Canada Bull., 147 pp.

McHugh, J.L. and A.D. Williams. 1976. Historical Statistics of the Fisheries of the New York Bight Area. New York Sea Grant Institute, 73 pp.

Midlige, F.H. and R.C. Malsberger. 1968. In Vitro Morphology and Maturation of Lymphocystis Virus. J. Virol., 2:830-835.

Murchelano, R.A. and J. Ziskowski. 1979. Some Observations on an Ulcer Disease of Red Hake (Urophycis chuss) from the New York Bight. Marine Environment Quality Committee, 7 pp.

Murchelano, R.A. and J. Ziskowski. 1979. Fin Rot Disease - A Sentinel of Environmental Stress? Marine Environment Quality Committee, 7 pp.

Needham, T. and R. Wootten. 1978. The Parasitology of Teleosts. In Fish Pathology edited by R.J. Roberts, Bailliere Tindall, London, 318 pp.

Nigrelli, R.F. and G.D. Ruggiari. 1965. Studies on Virus Diseases of Fishes. Spontaneous and Experimentally Induced Cellular Hypertrophy (Lymphocystis Disease) in Fishes of New York Aquarium, With a Report of New Cases and An Annotated Bibliography (1874-1965). Zoologica., 50:83-96.

Olsen, R.E. 1976. Laboratory and Field Studies on Glugea stephani (Hagenmuller), A Microsporidian Parasite of Pleuronectid Flatfish. J. Protozool., 23:158-164.

Pearce, J.B. 1972. The Effects of Solid Waste Disposal on Benthic Communities in the New York Bight. In M. Ruivo (editor), Marine Pollution and Sea Life, Marine Life, Fishing News (Books) Ltd., Lond., 404-411 pps.

Pearce, J.B. 1980. The Effects of Pollution and the Need for Long-Term Monitoring. Helgolander Meeresunters, 34:207-220.

Perkins, E.J., J.R.S. Gilchrist, and O.J. Abbott. 1972. Incidence of Epidermal Lesions in Fish on the North-East Irish Sea Area, 1971. Nature (Lond)., 238:101-103.

Post, G.W. 1983. "Textbook of Fish Health". TFH Publications, 256 pp.

Roberts, R.J. 1978. The Pathophysiology and Systematic Pathology of Teleosts. In Fish Pathology edited by R.J. Roberts, Bailliere Tindall, Division of Cassell Ltd., London, ISBN 0 7020 0674 2, 318 pp.

Robohm, R.A. and C. Brown. 1977. A New Bacterium (Presumptive Vibrio species) Causing Ulcers in Flatfish. Abstracts 2nd Annual Eastern Fish Health Wkshp., Easton, MD., Abstr. #3, 2 pp.

Rosen, B. 1970. Shell Disease of Aquatic Crustaceans. In S.F. Snieszko (editor), A Symposium on Diseases of Fishes and Shellfishes, Am. Fish. Soc. Spec. Pub. #5, 409-415 pps.

Rosen, B. 1967. Shell diseases of the Blue Crab (Callinectes sapidum). J. Invert. Path., 9:348-353.

Sindermann, C.J. and A. Rosenfield. 1967. Principal Diseases of Commercially Important Marine Bivalve Mullusca and Crustacea. U.S. Fish Bull., 66:335-385.

Sinderman, C.J., J.J. Ziskowski, and V.T. Anderson. 1978. A Guide for the Recognition of Some Disease Conditions and Abnormalities in Marine Fish. Sandy Hook Laboratory, Northeast Fisheries Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Highlands, New Jersey, 07732, Technical Series Report No. 14, 60 pp.

Sindermann, C.J. 1979. Pollution-Associated Diseases and Abnormalities of Fish and Shellfish: A Review. Fishery Bulletin, 76(4):717-749.

Sindermann, C.J., S.C. Esser, E. Gould, B.B. McCain, J.L. Hugh, R.P. Morgan, II, R.A. Murchelano, M.J. Sherwood, P.R. Spitzer. 1982. Effects of Pollutants on Fishes. In G.F. Mayer (editor) Ecological Stress and the New York Bight: Science and Management, Estuarine Research Federation, Columbia, South Carolina, Publishers, 23-38 pps.

Smith, C.E., T.H. Peck, R.J. Klaude, and J.B. McLaren. 1979. Hepatomas in Atlantic tomcod (Microgadus tomcod) (Walbaum) Collected in the Hudson River Estuary in New York. Journal of Fish Diseases, 2:313-319.

Snieszko. S.F. (ed.). 1970. A Symposium on Diseases of Fishes and Shellfishes. Symposium Committee, American Fisheries Society, Special Publication #5, 526 pp.

Stunkard, H.W. and F.E. Lux. 1965. A Microsporidian Infection of the Digestive Tract of the Winter Flounder (Pseudopleuronectes americanus). Biol. Bull., Mar. Biol. Lab., Woods Hole 129, 371-387 pps.

Takvorian, P.M. and A. Cali. 1981. The Occurrence of Glugea stephani (Hagenmuller 1899) in American Winter Flounder (Pseudopleuronectes americanus) (Walbaum) from the New York-New Jersey Lower Bay Complex. J. Fish. Biol. 18, 491-501 pps.

Takvorian, P.M. and A. Cali. 1984. Seasonal Prevalence of the Microsporidian (Glugea stephani) in Winter Flounder (Pseudopleuronectes americanus) from the New York-New Jersey Lower Bay Complex. J. Fish. Biol. 24, 655-663 pps.

Templeman, W. 1965. Lymphocystis Disease in American Plaice of the Eastern Grand Bank. J. Fish. Res. Board Canada, 22:1345-1356.

Walker, R. 1962. Fine Structure of Lymphocystis Virus in Fish. Virology, 18:503-508.

Walker, R. and K. Wolf. 1962. Virus Array in Lymphocystis Cells of Sunfish. Am. Zoologist. 2:566.

Wedemeyer, G. 1970. The Role of Stree in the Disease Resistance of Fishes. In A Symposium on Diseases of Fishes and Shellfishes. Symposium Committee, American Fisheries Society, Special Publication #5, 526 pp.

Weissenberg. 1951. Cancer Res. 11:608-613.

Weissenberg. 1965. Fifty Years of Research on the Lymphocystis Virus Disease of Fishes (1914-1964). Ann. N.Y. Acad. Sci., 126:362-374.

Wolf, K. 1962. Virology. 18:249-256.

Wolf, K. 1966. The Fish Viruses. Adv. Virus Research, 12:35-101.

Young and Pearce. 1975. Shell Disease in Crabs and Lobsters from New York Bight. Mar. Pollut. Bull. 6, 101-105 pps.

Ziskowski, J.J., V.T. Anderson, and R.B. Murchelano. 1980. A Bent Fin Ray Condition in Winter Flounder (Pseudopleuronectes americanus) from Sandy Hook and Raritan Bays, New Jersey, and Lower Bay New York, Copeia, 4:895-899.

Ziskowski, J., and R.A. Murchelano. 1975. Fin Erosion in Winter Flounder. Marine Pollution Bulletin, 6(21):26-29.

THE EFFECTS OF CONTAMINANTS ON THE FAUNA
IN THE HUDSON-RARITAN ESTUARY

Dr. Angela Cristini
Division of Science and Research
New Jersey Department of Environmental Protection
and School of Theoretical and Applied Science
Ramapo College of New Jersey

Introduction

Many estuarine ecosystems in the United States serve as a repository for toxic and non-toxic wastes from our society. Such chemicals and wastes enter the systems from sewage, industrial, and non-point sources. One of the most impacted areas in the country is the Hudson-Raritan estuarine system. The biota in this body of water are continuously exposed to varying concentrations of chemical mixtures. This paper will briefly summarize four studies that represent important research strategies used to approach the problem of the biological effects of chemical stressors in this system.

The most popular approach in attempting to understand the effects of degraded water quality on the aquatic biota is to measure the accumulation of chemicals in the tissues of various organisms. The published literature in the past 20-25 years is replete with levels of metals and organic contaminants in the tissues of organisms from plankton to fish, in many ecosystems, including the Hudson-Raritan estuary. The interpretation of these data, while difficult, is warranted for the evaluation of two major concerns in degraded systems such as the Hudson-Raritan estuary; (1) human health concerns: the necessity to measure levels of certain toxicants in fish and shellfish that are consumed by humans, and (2) environmental assessment: evaluating the health of aquatic organisms and ecosystems stability. The difficulty in data interpretations arises primarily because very little is known about the relationship between chemical bioaccumulation and either human health or ecological effects.

(1) Human Health Concerns

Pollution had affected man's use of resource species in the Hudson-Raritan Estuary long before any standards for permissible levels of contaminants in flesh had been established. The earliest record of contaminant problems is Goode's (1887) report that oysters and shad from Newark

Bay could not be sold by the time of the Civil War because they were tainted with coal oil. The Food and Drug Administration (FDA) has established action levels for nine compounds in edible fish (Table I).

Table I. FDA action levels Class A human health for chemical contaminants in edible fish[a] (modified from Connor et al. 1984)

Compound	Level (ppm, wet weight)
Mercury	1.0[b]
Cadminum	-[c]
Lead	-
PAH	-
PCB	2.0
DDT and metabolites	5.0
Chlordane	0.3
Dieldrin	0.3
Lindane	0.3[d]
Edrin	0.3
Heptachlor and heptachlorepoxide	0.3
Trans-nonachlor	-
Dioxin	2.5, 5.0 x 10

----

a Unless otherwise noted, information from U.S. Department of Health and Human Services (1982).

b Information from Armstrong and Sloan (1980).

c No level set.

d Information from Federal Register, De. 6 (1974).

e Two "levels of concerns" have been established. Above 50 parts per trillion, FDA recommends no consumption and below 25 pptr they place no limit on consumption. Between 25 and 50 pptr they recommend no more than one meal a week for infrequent consumers and 1-2 a month for frequent consumers (Belton et al. 1985).

The FDA action levels balance human health concerns against economic consequences. However, there are many uncertainties involved in establishing the action levels and the Environmental Protection Agency has, therefore, devised a more quantitative method of evaluating such compounds. "Carcinogenic potency factors" are calculated from responses of animals to various doses of the compound in question. This technique also relies on many unproven assumptions, including the validity of extrapolating from high-dose animal-feeding studies to low-dose human exposure (Connor et al. 1984). Still, it provides the best means available of evaluating risks from eating contaminated seafood. Carcinogenic potency for nine organic contaminants are listed in Table II, along with concentrations of the contaminants in individual fish of several species common to the Hudson-Raritan.

Concern over the PCB levels in fish and shellfish led the New Jersey D.E.P. (NJDEP) to issue fishing prohibitions and consumption advisories for selected species and waterways. These species include striped bass, American eel, large bluefish, white perch, and white catfish. The advisory refers to limiting consumption of those species identified and high risk groups including pregnant and nursing women, women of childbearing age and young children. In addition, the NJDEP prompted a 1984-86 Federal survey of PCB concentrations in flesh of bluefish collected along the entire U.S. east coast (National Marine Fisheries Service, 1987). No fish less than 20 inches long had levels above the FDA tolerance limit of 2 ppm. At least some of the larger fish from every site sampled clostridia exceeded that limit. A summary data for the large fish are given in Table III. Large bluefish from the New York Bight had some of the lowest percentages of concentrations exceeding the limit May/June and August 1985 (both 4.6%). However, the percentage of Bight samples with concentrations over 2 ppm in October/November 1985 (45.3%) was substantially above any other value food.

This temporal distribution indicates a movement of contaminated bluefish (large size) into the Bight region during the fall migration, and represents an increase in the human health risk to the consumers at that time. NOAA combined PCB levels with bluefish data on recreational catch and fishing pattern data to show that the mode of fishing, season and geographic location, all may affect

Table II.

Carcinogenic potency factor and wet weight concentrations of contaminants in individual fish or shellfish from the Hudson-Raritan Estuary[a]
From Connor et al. 1984.

		Wet weight concentrations (ppb) from muscle														
Compound	Carcinogenic potency factor	Raritan Bay winter flounder			Raritan Bay windowpane flounder			Hudson River striped bass			Raritan Bay lobster					Raritan Bay mussels
Chlordane	1.61	8.0	8.0	8.0	6.0	3.8	6.3	144	144	168	4.8	1.7	2.3	1.1	1.1	10.4
DDT and metabolites	8.42	16.0	10.0	9.0	22.0	13.1	18.9	792	1392	504	11.2	10.2	29.9	20.2	20.2	66.3
Dieldrin	30.40	0	4.0	4.0	0	3.8	4.2	0	0	0	6.4	3.1	0	2.2	2.3	0
Hexachlorobenzene	1.69	0	0	0.6	0	0.4	0.4	0	0	0	0.3	0.3	1.1	1.1	0.9	0
Heptachlor	3.37	0	0	0	0	0	0	0	0	0	0.8	0.7	0	0.2	0.1	0
Lindane	0.78	0	2.0	1.2	0	0	0.8	0	0	0	0	0	0	0	0.2	0
Nonachlor	0[b]	4.0	6.0	6.0	4.0	1.9	4.2	192	192	144	3.2	3.4	4.6	2.2	2.3	6.5
PAH[c]	0	6.0	8.0	10.0	12.0	14.4	13.4	10	5	0	12.8	25.5	77.7	6.6	36.8	250.9
PCB	4.34	100	80	80	160	76	126	12960	8880	3120	96	357	230	220	207	156

[a] Data from MacLeod et al. (1981).
[b] No experimental evidence of carcinogenicity.
[c] PAH included naphthalene, 1-methylnaphthalene, biphenyl, phenanthrene, fluoranthrene, pyrene, chrysene, and benz(a)anthracene. No experimental evidence has linked any of these compounds to cancer.

Table III. PCB Summary Table of >500 Millimeter Fork Length Five-Fish Composite Samples

Site (Date 1985)	No. of Five-Fish Composite Samples	PCB Level Median	PCB Level 90th Percentile	Percent of Samples >2 ppm
North Carolina (January/February)	65	1.35	2.16	10.6
North Carolina (March)	65	1.53	2.22	16.9
North Carolina (April)	65	1.70	2.45	23.1
New York Bight (May/June)	65	0.98	1.87	4.6
New England (June)	65	1.19	1.85	4.6
New York Bight (August)	65	0.77	1.51	4.6
New England (August)	65	1.37	14.16	27.7
New England (October)	65	1.02	1.63	3.1
New York Bight (October/November)	64	1.86	3.40	45.3

the risk to consumers. The highest risk identified is to fishermen on party or charter boats, fishing the Bight during the fall, where only four trips per season would result with a catch containing an elevated PCB dose. These data highlight the complexity of correlating PCB body burden data on specific migratory fish species and nearshore ocean water quality determinations.

In 1983, the NJDEP became concerned with dioxin contamination from point and non-point sources in the Passaic River, Newark Bay, Arthur Kill, and Raritan Bay. One of the main point sources identified was the Diamond Shamrock Chemical Company, manufacturers of herbicides in the 1960-1970's. Sediment core samples in the river and in Newark Bay and tissue samples from fish, crabs, and some lobsters have shown elevated levels of 2,3,7,8-TetrachlorodiBenzo-p-Dioxin), one of the most carcinogenic isomers of dioxin (Belton et al. 1985). These data have resulted in the closure of the fishery for blue crabs and striped bass in the inner estuary (Figure 1).

These two studies highlight the importance of monitoring bioaccumulation for human health concerns and the necessity to control the input of toxicants into the Hudson-Raritan systems.

(2) Health of Aquatic Organisms

There have been been many laboratory studies establishing the effects of toxicants such as heavy metals and organics on the physiology of fish and invertebrates. Unfortunately, there have been very few field verifications of the effects of chemical stressors on growth, disease occurrence, and reproductive success of organisms in a system such as the Hudson-Raritan. This is a very difficult and costly line of research. The variability in a system and within the species to be studied must be considered as well as the effects of the myriad of chemicals they are exposed to compounded by biotic factors such as competition and predation.

This paper will summarize two attempts to understand these parameters in populations of organisms living in the Hudson-Raritan region.

In any natural system, but particularly in an estuary, the levels of natural environmental stresses are important. Estuaries have a great deal of variation in abiotic factors such as salinity, temperature, and turbidity. Estuarine species often have a more plastic gene pool in order to ensure survival and reproduction in this changing environment. This could lead to the establishment of resistant populations of organisms, perhaps existing at the edge of their tolerance, in impacted systems such as the Hudson-Raritan.

Populations of the killifish (Fundulus heteroclidus) from Piles Creek, a small tributary to the Arthur Kill, in the highly industrialized Newark Bay area have been shown to produce eggs and embryos that are more resistant to methyl mercury than killifish from a cleaner area in Long Island (Weis et al. 1982A). The results from several laboratory experiments indicate that resistance has a genetic basis and that the Piles Creek animals are near their tolerance limit (Weis et al. 1982B).

An in situ study comparing soft shell clams (mya arenaria) native to Raritan Bay and clams from Long Island Sound caged in Raritan Bay also indicated the presence of a resistant population. The clams from Long Island had biochemical energy pools that were significantly lower than the clams native to Raritan Bay. These data indicate that Long Island clams were less able to accommodate to the long term stresses of living in this impacted system (Cristini, 1987).

The research approaches in these studies are valuable because they are measuring variations in organisms living in clean and impacted systems. The data generated will direct future work aimed at understanding the limits of variability, the stability of resistant populations, and the mechanisms of resistance. Closer coupling of in situ studies with bioaccumulation measurements will allow for better correlation between the levels of contamination and the health of important estuarine species. Future in situ work on organisms at different trophic levels will result in a greater understanding of the stability of estuary ecosystems stressed within the input of toxic chemicals.

Literature Cited

1. Belton, T.J., R. Hazen, B.E. Ruppel, K. Lockwood, R. Mueller, E. Stevenson, and J.J. Post (1985). A Study of Dioxin (2,3,7,8-TetrachlorodiBenzo-p-Dioxin) Contamination in Selected Finfish, Crustaceans, and Sediments of N.J. Waterways. NJDEP, Office of Science and Research Tech. Report. 101 pp.

2. Connor, M.S., C.E. Werme, and K.D. Rosenmann (1984). Chapter 6 In: Public Health Consequences of Chemical Contaminants in the Hudson-Raritan Estuary. R.J. Breteler (Ed). Chemical Pollution of the Hudson-Raritan Estuary NOAA Tech. Memo. NOS OMA7. 72 pp.

3. Cristini, A. (1987). An *In Situ* Study of Adenylate Energy Charge and Other Biochemical Parameters in the Bivalve *Mya arenaria* from Raritan Bay and Long Island Sound. In: Pollution Physiology of Estuarine Organisms. W.B. Verberg, A. Calabrese, F.P. Thurberg, and F.T. Verberg (Eds). University of South Carolina Press. 231-250 pps.

4. Good, G.B. (1887). Fisheries and Fishery Industries of the U.S. Section II. Geographic Region of the Fishery Industries and Fishing Communities for the Year 1880. U.S. Government Printing Office, Washington, D.C. 787 pp.

5. Weis, J.S., P. Weis, and M. Heba (1982A). Variation in response to methyl mercury in killifish (*Fundulus heteroclitus* embryos. In: Aquatic Toxicology and Hazard Assessment, Fifth Conference, ASTM STP 766. J.G. Pearson, R.B. Foster, and W.E. Bishop (Eds). American Soc. for Testing and Materials, Philadelphia. 109-111 pps.

6. Weis, J.S., P. Weis, M. Heber, and S. Vaidya (1982B). Investigations into Mechanisms of Heavy Metal Tolerance in Killifish (*Fundulus heteroclitus*) Embryos. In: Physiological Mechanisms of Marine Pollutant Toxicity. W.B. Verberg, A. Calabrese, F.P. Thurberg, and F.J. Verberg (Eds). Academic Press, N.Y. 311-330 pps.

ESTUARY AND PEOPLE: THOUGHTS ON THE CHALLENGES OF HUDSON-RARITAN MANAGEMENT

Baruch Boxer
Professor of Geography and Human Ecology
Department of Human Ecology
Cook College
Rutger University
New Brunswick, N.J. 08903

PROBLEM

When it comes to complex metropolitan estuaries or other densely populated sea-land interfaces, it is much easier to acknowledge that social and economic factors somehow influence management strategies and choices than to say anything new or significant about what is going on, or why. We seldom get beyond restatements of familiar positions on controversial issues affecting the health and productivity of the estuary and the people and ecosystems that depend upon it. Waste disposal, access to common property resources, research needs, and development policies are among the most prominent concerns. Legislators, publics, regulators, planners, and administrators, however, each have their own agendas and priorities. It becomes increasingly difficult for any single group to take the lead in facilitating better coordination of programs and activities in the public interest.

How can we deal with this dilemma? Are we forever bound by political whims and institutional inertia? The question is hardly academic in the case of the Hudson-Raritan estuary. Strong market forces place ever-greater pressure on federal, state, and county regulatory authority. Natural systems are increasingly stressed. Pressures for intensified riverine and coastal land and sea development pose a host of new problems for planners and policy makers. Admirable initiatives of the New York Academy of Sciences and the Coalition for the Bight seek to improve communication among users, scientists, and administrators, and to enhance public awareness. Yet little thought has been given to why we have difficulty relating what we know about the dynamics of regional economic growth and social change to the specific requirements of estuarine use and conservation.

I want to address these questions in the interest of helping to clarify the place of social and economic factors in estuarine planning and management. I see several basic elements that need to be considered. These, first, have to do with the nature of the issues: where do they come from; what are the obstacles to their resolution; and what makes them "social and economic"? My main point, however, is that effective management requires new ways of thinking about the land-sea interface: how can we better understand the interplay between the vast region drained by the Hudson-Raritan and lesser streams, and the estuary, bays, and Bight that receive the region's effluents while contributing in so many ways to its economic viability?

ISSUES

What do we mean by "social and economic" issues? It is easiest to assume that issues simply are statements of unresolved conflicts among estuary uses, users, and regulators regarding prerogatives, jurisdictions, responsibilities, and expectations. We know, for example, that marine transport, harbor and port maintenance and development, commercial and sport fishing, scientific and engineering research, littoral construction, beach and shore recreation, and waste disposal generate conflicting views on access, pollution, regulation, finance, and other concerns.

Is is enough to acknowledge that this potpourri of activities collectively define the issues that confront those concerned with the health and vitality of the estuary? Are the issues nothing more than expressed differences among coastal and ocean users on relative economic priorities of clean bathing waters, effective waste disposal, unobstructued waterways, space for development, or healthy fisheries? Can we get by with a paper consensus on policy guidelines in specific areas of disagreement? I think not. We need to think in larger terms.

First of all, upstream and coastal dimensions of estuarine studies need to be integrated more effectively. Coastal problems that command public and agency attention in the Hudson-Raritan region are seldom thought about in relation to basin-wide pollution, physical degradation, ecosystem destruction, and development encroachment.[1]. Discrete, local, politically charged matters such as solid waste on beaches, polluted or developmentdisplaced fisheries, and poor bathing water quality attract most attention. They are ultimately, however, nothing other than the end result of system-wide economic and social impacts.

---

[1] A notable exception to this is the imaginative attempt of Ayres and Rod to assess historical dimensions of Hudson-Raritan pollution. See Ayres, R.U. and Rod, S.R. 1986. Patterns of Pollution in the Hudson-Raritan Basin. <u>Environment</u>, 28(4): 14-20, 39-43.

The estuarine system, from upstream tributaries, through intertidal zones, to the sea, transmits social and economic impacts of use and abuse by transforming them, through natural processes, into the resource depletion, pollution, and landscape modification that arouses individuals, communities, and commercial interests in the coastal zone. Inland and coastal administrative jurisdictions, however, face too many obstacles in their attempts to coordinate limited, poorly defined and weakly supported regulatory authority. Users, administrators, and protectors of estuarine and coastal resources, alike, commonly talk past each other. More on this later.

We need to come up with imaginative ideas and programs that highlight the inseparability of coastal and inland economic and social contributions and costs, and the role of estuarine systems in making this connection. Few studies assume this perspective. A noted exception is the excellent recent volume on the The Hudson River Ecosystem by Limburg et al. But this reviews scientitic assessments of environmental impacts and regulatory response. It does not focus on estuarine roles in society-science communication[2].

Fragmented jurisdictions and programs also deter creative approaches to understanding how economic and natural forces interact within the land-sea contact zone. Passage of the Clean Water Act promises estuarine pollution management conferences and additional support for construction and regulatory programs. But disagreement among scientists and policy makers over the benefits of the precursor Chesapeake Bay project suggests that we have a long way to go before social, economic, and scientific perspectives on estuarine management can be mutually supportive.

Another problem in fostering a comprehensive view of estuarine management is that sea and land are indistinguishable in the vocabularies and methods of economic and social analysis. Calculations and projections of regional economic activity, for example, seldom focus comparatively on the wider implications of what is going on in marine or coastal domains. While it is common knowledge that coastal activities comprise New Jersey's second largest industry (total value approximately $11.5 billion), it is difficult to estimate the relative economic contributions of shore and nearshore commercial, recreational, and developmental components. Assessments of regional economic and demographic conditions, moreover, are based largely on analyses of macrolevel shifts among such variables as productivity, output, employment, labor force, or investment level[3].

---

[2] Limburg, K.E. et al. 1986. The Hudson River Ecosystem. New York: Springer-Verlag.

[3] Armstrong, R.B. 1985. Analysis of Regional Projections. New York: Regional Plan Association.

Derived patterns are then used to project social and economic trends, presumably to guide legislative and regulatory agendas. Political uncertainties and the limitations of economic models are acknowledged, but government agencies and private research groups rely mainly on loosely-defined trend data to support their regulatory, research, or advocacy missions. The crucial need to interpret region-wide developments in relation to the economic and social dynamics of what is going on in and around the land-sea estuarine interface is overlooked or ignored.

This deters creative thinking by public and private agencies in New York, New Jersey, and New York City about the necessity of linking inland and coastal estuarine reaches for planning purposes. One result is that well-intentioned constructive proposals, such as the "advanced identification procedure" recently advanced by EPA Region II for the Manhattan west side waterfront[4], may inadvertently encourage adversarial confrontations by focusing too narrowly on development vs. environmental protection tradeoffs. Concern for the larger picture will undoubtedly be subordinated to another "sorting-out-the-pieces" exercise. Establishment of a new agency to implement this proposal is also unlikely to improve decision making. Attention is diverted further from the main problem of understanding the mechanisms and implications of the symbiosis between sea and land in relation to wider social and economic choices.

Dynamic aspects of the estuarine littoral as a link between the sea and the regional economy and society have not been carefully explored. We still know very little about how to identify and describe specific social, cultural, and administrative dimensions of this relationship to regional developments, as well as to the natural processes that sustain and renew the estuary. With few exceptions, debates over appropriate balances between estuarine land and sea uses in face of natural constraints focus too narrowly on single issues. Prospects for more creative use and modification of existing legislative and regulatory tools are thereby undetermined.

Issues, then, are more than straightforward manifestations of controversies among users, regulators, and the public regarding economic priorities or social preferences in estuarine resource use. Commerce, science, and aesthetics drive debates to higher levels of intensity, their frames of reference become more complex, and grounds for compromise seem ever more elusive. Why is this so? Planning, policy, or advocacy positions on what is good, healthy, necessary, or possible for people and ecosystems

---

[4] Boorstin, R.O. U.S. Official Urges a Riverfront Development Plan. New York Times. January 16, 1987.

reflect varied perspectives on natural constraints and the ways society and economy should confront them. What are some of these perspectives? How and in what ways do they affect what people and institutions do and say about the Hudson-Raritan estuary?

PERSPECTIVES

Perspectives on what is socially or economically important about the estuary simultaneously influence and convey various points of view on questions pertaining to the use, protection, and management of land and sea resources. Diverse actions, political constituencies, and administrative jurisdictions interact at several levels. In each case, the form, content, and terms of debate reflect a particular perspective on rights and responsibilities attendant upon human use of the estuary.

Commercial users, municipalities, and the concerned public, for example, differ in their views on the relative weight of direct impacts (e.g., fishing, transportation, dumping, floating litter), in contrast to indirect, less immediately visible effects (e.g., urban runoff and outfall waste discharge, shoreline reclamation and extension, burrow pit capping). Regulatory, policymaking, and administrative bodies also have distinctive views on the importance of their contributions. So much of what users and developers want, what regulators do, and what the public protest, therefore, seems at cross purposes.

Policy controversies among private or public groups none-the-less seem to express several consistent themes. These reflect: 1) contradictions between the inherent advantages of economic cooperation and cohension at the regional level, and the inefficiences of competition among the two states and New York City; 2) differing interpretations at all levels of what is economically important or socially meaningful; and 3) competing interests' struggles to overcome bureaucratic obstacles to improved communication among themselves and the agencies with which they deal. This latter dimension, in particular, constrains New Jersey county and state efforts to integrate local and state level estuarine management efforts.

Problems of boundaries and jurisdictions are compounded by confusion over power, authority, and mission. A host of official, quasi-official, and self-styled user and public representational groups have the benefit of varying degrees of statutory legitimacy and guidance. They are subject as well to shifts in legislative directions and public attitudes. Resulting uncertainties and misperceptions perpetuate internal and internecine conflicts in and among New Jersey, New York, and New York City over estuarine conservation and use questions. They also generate disparate views on the economics of resource use as well as on perceptions of resource values.

We know very little, for example, about how to assess the preservation, in contrast to the use value, of living and non-living estuarine resources. With the furious pace of uncoordinated, late-1980's development, it is virtually impossible to apply project-specific benefit-cost analysis that might better weigh short- and long-term implications of technologically more sophisticated and larger scale human interventions along the shoreline. Especially in such focal areas as the Hudson River waterfront. Physical changes to shoreline, tidal zone, and river and seabeds pose unknown risks to living marine resources. Yet the difficulties of resolving science and policy questions for even a small area are illustrated by the prolonged review of the Westway project.

The macroeconomic consequences of resource mismanagement and loss is also underplayed. Regional economic forecasts, as we have seen, fail to incorporate these concerns in their models, and conservation values are seldom discussed. This relates to an earlier point; it is difficult to conceptually or methodologically incorporate the economic contributions of the sea-land littoral as a unit into econometric models. The economic and social significance of littoral activities, in their own right, therefore eludes analysis.

Indicators of demographic shifts, changes in forms or levels of investment, or the quantity or value of marine resources remain unrelated to wider regional trends. This again highlights the dominance of intra- and inter-regional political competition as a key determinant of estuarine use and development. It precludes more objective, balanced attempts to guide development through judicious combined use of scientific and planning tools. Many unresolved scientific questions relating to the fate and effects of PCBs in the Hudson, for example, suggest how difficult it is to benefit from objective scientific analysis where science has to respond to politically-defined environmental assessment norms and goals[5].

GOALS AND REALITIES

Planners, involved citizens, politicians, commercial users and developers, and harried administrators are quick to support an abstract notion of common goals. Everyone in principle favors a viable structure that can assure continuing equitable distribution of the development "pie." Regulatory equity, environmental protection, adequate infrastructure, flexible

---

[5] Limburg et. al., note 2 above.

financial resources, and user access are to be found on everyone's agenda for the future. The problem, however, is that there is a wide gap between dreams of regional prosperity and the day-to-day realities of regional life.

The rivers, bays, harbors, and shores that form the Hudson-Raritan system focus economic activities on the littoral, but we don't seem to be able to find the formula for managing the connection between shore and sea to support everyone's objectives. In an ideal world, planning, technology, politics, people, and economy should interact in the public interest, however that is defined. But social and economic challenges to living with and supporting an estuarine system illustrate what Edwared Wenk recently suggested is one of our greatest contemporary challenges: how to progress from a collective state of mind that focuses on problems of living <u>with</u> technology to one that confronts implications of the fact that we increasingly <u>live</u> technology[6]. The dilemmas of going about the business of managing Hudson-Raritan estuarine resources are truly illustrative.

Take, for example, the New Jersey situation. Several new initiatives are underway at the state level. Governor Kean's recently proposed Clean Ocean Authority is now being fleshed out in the Governor's Office of Policy and Planning. The aim is to improve coordination of state and local authority relating to coastal and shore protection, development, and use in the area under the jurisdiction of the state's coastal management program. Complementary efforts are underway in the State Legislature to provide enabling and operating legislation for the Authority. It is not clear, however, how the proposed Authority clear will incorporate well-conceived and effectively implemented existing programs of the Department of Environmental Protection's Division of Coastal Resources. The idea is to subsume eventually these activities under the new authority. In the meantime, politically-motivated, bureacratic experimentation deters more effective state-level response to coastal issues.

Parallel to this, the State Planning Office is busily preparing a State Master Plan for completion in the spring. The good intentions of the 1986 State Planning Act which directs this effort seem, again, to be out of touch with the overriding need for immediate improvement in state direction, and guidance of estuary and coast-related development. Contrasting needs of Middlesex and Hudson County waterfronts underline this.

---

6 Wenk, Edward Jr. 1986. <u>Tradeoffs, Imperatives of Choice in a High-Tech World</u>. Baltimore and London: The Johns Hopkins University Press, pp. 6-7.

Middlesex County is the crossroads of major transportation routes. It is also drained by the Raritan River. The mouth of the Raritan is the focus of several proposed Port Authority development and infrastructure improvement projects. How can the county best deal with the proliferating commercial development that increases pollution of the river, its tributaries, and estuary? County regulatory authority is limited by law to vaguely defined surface drainage control responsibilities. Efforts to improve and expand state-county coordination of water quality and other construction and maintenance programs is hampered by bureaucratic inertia and administrative overlap. Middlesex County's problems are extensive: development pressures are ubiquitous, they are spurred by county-wide competition for rateables, and are fueled by access to transportation.

Further north, on the Hudson waterfront, there is pressure to accomodate multibillion dollar development schemes in a physically-constrained coastal zone, hemmed in by the Palisades, and governed by eleven municipalities and a powerful county administration. Here, in contrast to the Middlesex scene, where county authority pales in the face of power of contending local baronies, the state has a strong and effective planning presence through its Office of Waterfront Development, an offshoot of the Governor's Office of Policy and Planning. The Division of Coastal Resources also applies the only coastal regulatory clout it can exert in this politically-charged environment, where technical questions still challenge interpretation of a vague statutory mandate. It has permit granting authority for waterfront development extending from the mean high waterline back 500 feet.

Despite the State's presence, however, planning and financial dimensions of waterfront modification and building seem strangely detached from coastal and estuarine issues elsewhere in the state and region. The driving force is the New York City relationship, one that bears on all manner of decisions relating to transportation, recreational access, housing, and a complex of infrastructure and financial issues. Here, it is as if littoral development in a Jersey frontline outpost takes on a momentum of its own as it confronts the behemoth across the river.

Issues in Middlesex and the riverfront reflect a common regional problem. At every level, county, state, and federal, statutory authority has evolved in response to narrowly conceived and loosely-defined goals. The problem not only is one of overlapping jurisdictions; agency roles are not responsive to the need to coordinate regulation and management of the sea-land interface. Each agency responds to shifting administrative, technical, and judicial interpretations of its mission. Even the Instate Sanitation Commission, with clear authority to enforce water quality discharge standards on a regional basis, is being challenged by state and municipal agencies with individual agendas that deter attainment of regional clean water goals.

CONCLUSIONS

Is everything so bad? We assume that we need to have a clearer idea of the nature and significance of economic and social issues to better confront future management challenges. But can we ever really grasp the interplay of factors that shape the economy and society in the vast Hudson-Raritan region? Maybe not, but we do need to pay more attention to the problem of understanding the natural dynamics of the sea-land contact zone in relation to the movement and redistribution of people, investment, jobs, and circulation patterns. To now, scientific and technical questions about pollution, physical changes, and ecosystem resilience have dominated discussion. It is time we thought more carefully about how to explore social, economic, and natural linkages more effectively. Parts of the study framework are largely in place. They need to be combined in new ways. Existing programs, under many agencies, deal with basic monitoring, assessment, and research needs. The challenge is to use our knowledge more effectively by overcoming institutional and bureaucratic barriers.

A final word on why we may be better off than we think. A recent New York Times article reports that Tokyo's quest for consideration as a "world class city" status involves construction of a "River City 21" commercial and residential complex for 7,500 people at the mouth of the Sumida River (sound familiar?). Since Tokyo has a regional metropolitan government, developers and government jointly plan and execute many inland, estuarine, reclamation, and artificial island projects in response to the tremendous demand for space (a square foot of property can sell for $22,500). Can there be much concern for human ecological impacts in the frenzied paving-over of land and sea, seen by many as the key to national economic salvation?[7] In the perspective of Tokyo's experience, perhaps we are not so badly off. Our institutional rivalries and vigorous scientific controversies at least stimulate healthy debate. We may never come up with perfect management solutions, but we can learn much trying.

---

[7] Haberman, C. Tokyo Aims to Reshape Itself as World Class City. New York Times. February 8, 1987.

ACKNOWLEDGEMENTS

A number of people in official positions and the private sector graciously shared insights and information concerning Hudson-Raritan problems and programs. I thank every one of them, but also assume full responsibility for any errors or misinterpretations. Research supported by the New Jersey Agricultural Experiment Station (Project Number 26409).

THE RARITAN-HUDSON ESTUARY
A REGIONAL PERSPECTIVE

Richard T. Dewling, Ph.D.
Commissioner
New Jersey Department of Environmental Protection

New Jersey Department of Environmental Protection

The area around the Raritan-Hudson Estuarine complex is undergoing a rapid revitalization. The Estuary has increasingly become a focus of development as builders rush to construct on the shorelines or convert old industrial buildings to new uses. Waterfront property or at least vistas of the harbor are becoming more and more desirable and, thus, more expensive.

John Weingart, Director of our Division of Coastal Resources tells me that there are proposals to put in place before the year 2000, 22,000 housing units, 3,000 hotel rooms, 2.5 million square feet of commercial space, and more than 13 million square feet of office space along the west bank of the Hudson alone, and that almost every available lot or developable space is already "spoken fore."

Our shorelines are crucial to the vitality of New Jersey and its citizens. Humans have always been attracted to shorelines and waterways. Rivers and waterbodies have played essential roles in cultural development, the rise of civilizations, and industry and technology, and they continue to provide a major focus for many of our essential human activities.

The Raritan-Hudson Estuary epitomizes this tendency to be a magnet for growth, both now and historically. By 1770, New York City's population of 33,000 exceeded that of Boston, and by 1810, with a population of 96,000, the City was larger than Philadelphia and had become the largest city in the nation.

Today, close to three-fourths of the population of New York State live in the Hudson River Basin, most in the Metropolitan area. New Jersey, the most densely populated state in the nation, averaging close to 1,000 people per square mile, is predicted to have more than 8.5 million population by the year 2000. Well over half of New Jersey citizens live close to the estuarine complex in the northeast part of the State.

Many of our citizens depend on the port facilities of the estuary for employment. Approximately, 570 overseas companies are located in New Jersey; there are more than 35,000 jobs directly dependent and 30,000 jobs indirectly dependent upon export trade. The export business depending on New York Harbor is a $3 billion per year industry, according to J.T. Grossi, NJ Department of Commerce and Economic Development.

Development around the estuary has brought with it numerous problems of pollution and adverse impacts on the ecosystem, as we've already heard today. We must not despair, however, or give up on this valuable resource at the nation's front door. I believe there is cause for optimism. Further improvement, though, will be arduous, time consuming, and will require continued massive investment in sewage treatment and industrial pollution prevention, as well as vigorous enforcement of the legal and regulatory tools at our disposal.

The uniqueness of coastal and estuarine water systems lies in their suitability for supporting a wide range of beneficial uses of ecological, economic, recreational, and aesthetic values which are dependent upon good water and sediment quality. The coastal water environment provides critical habitat for a wide range of ecologically and commercially valuable species of fish, shellfish, birds, and other aquatic and terrestrial wildlife. Economically, coastal waters are worth billions of dollars for the private and public sectors in uses which benefit from good coastal environmental quality, including commercial and recreational waterfront development and real estate, investment in port facilities for fisheries, and outdoor recreation. Millions of people each year enjoy estuarine and coastal environments for swimming, boating, fishing, hiking, bird watching, parks, refuges, and open space and associated aesthetics.

Degradation of coastal water environments has become a critical national problem. The cumulative impacts of a multitude of activities within the coastal drainage basins, in estuarine and coastal waters, and on the ocean are threatening daily the ecological, economic, recreational, and aesthetic integrity of coastal water systems throughout the United States. Furthermore, as growth in the coastal regions continues to accelerate, the ability of the near coastal water environment to sustain the conflicting uses common to the coastal zone will become increasingly stressed. Populations in coastal counties grew 69% from 1950 to 1980; by 1990, experts predict that 75% of the U.S. population will live within 50 miles of a coastline.

Our coastal waters are becoming more and more degraded despite existing federal, state, and local laws and regulations governing coastal and ocean pollution and land and water uses.

The environmental quality of coastal waters will continue to decline unless changes are made in the way land/water uses affecting them are managed.

What are the prospects for such changes in managing these environments? Are the billions of dollars we've already spent or the required billions more for combating pollution going to do the trick? As a regulator, I'm forced to ask how we can approach this problem more effectively. Do we need better ways to measure trends in the health of the estuarine ecosystem? What sort of timetable are we talking about?

As I said, there are grounds for hope. In a November 6th, 1986, a New York Times article headlined "Long-Abused Hudson Thrives Again," Sara Rimer quotes officials and environmentalists as saying -

"Though it still has serious contamination problems, New York's main waterway, the Hudson River, is cleaner and more inviting, its fisheries more productive, than has been the case in years.

"People are rediscovering the river that Henry Hudson first explored in 1609. They are swimming in it, fishing it, traveling it in boats, and finding new inspiration in its history, highlands and vistas. From Catskills to Yonkers, the river has recently been certified as safe for swimming.

"In the last two decades, the construction of municipal sewage treatment plants at such river towns as Ravena, Saugerties, and Poughkeepsie has eliminated most of the raw sewage that once turned that stretch of the river into an enormous spetic tank. Completion of a New York City treatment plant on the Hudson in 1988 should also bring tremendous relief to the lower part of the river.

Similarly, according to the "1986 Report on Water Quality in New Jersey" (the 305 b report), "The greatest water quality improvement in New Jersey between 1981 and 1985 has occurred in the Raritan River below Manville. A major industrial discharge to the river was eliminated and, as a result, water quality conditions have improved from poor to good." Earlier improvements to the Raritan River, with the coming on line of the Middlesex Sewage Treatment Plant in 1958, were the subject of a classic paper in pollution ecology by Dean and Haskin, describing repopulation of the river with species previously absent.

There was a major change in the pollution load on the western end of Raritan Bay between 1950 and 1960. The level of waste treatment increased but the total load applied also increased from the growing population and industry in the surrounding area.

The organic loading pattern of the Bay shifted when the Middlesex County Trunk Sewer (MCSA) was put into operation in the spring of 1958. Previous to the operation of MCSA the load was discharged from various outfalls and tributaries. After completion of MCSA, waste was discharged primarily from one point, the MCSA outfall which is located one-half mile off shore at South Amboy. In 1966 according to Charle Cole, the total load on Raritan Bay was 185,000 pounds of five-day BOD per day, of which 90 percent was from MCSA outfall.

Before 1958, the Raritan was so heavily loaded with industrial and domestic waste discharges that anaerobic conditions existed adjacent to New Brunswick. The MCSA trunk was put into operation in 1958 and accepted many of the community and industry flows that were formerly partially treated and discharged into the river.

The major sources of gross pollution entering the Raritan River and its tributaries were removed by MCSA and the Raritan River water quality was considerably improved. The DO at New Brunswick was zero in 1959, prior to the MCSA operation, and 80 percent of saturation in 1959. The BOD five miles upstream from New Brunswick was reduced from 105 mg/1 in 1958 to 6 mg/1 in 1959.

The Thames River and Estuary, London, England, has shown that dramatic improvement can occur following pollution abatement; reintroduction of more than one hundred species occurred and even salmon have come back to the Thames.

Thus, we must not yet write off the Raritan-Hudson Estuary. Some of the same kinds of effort that went into making tributary rivers, such as the Raritan and Hudson, cleaner could benefit the lower estuary.

The Interstate Sanitation Commission which has responsibility for measurement of the Hudson-Raritan Estuarine water quality recently reported:

"It has been two years since the last assessment of the waters was submitted for the 305(b) report. From the time of that report until now, the quality of the waters has remained essentially the same or may be slightly improved. The two year time period is not long enough to show dramatic changes, especially in light of the fact that no major improvements in treatment have been made during this time. However, it is encouraging that no backsliding in the water quality has taken place, and will be completed in the next few years, and with the advent of year-round disinfection starting July 1, 1986, it is expected that the water quality will show improvement."

Water quality in the Estuary would have to improve a great deal to return to conditions of a hundred years ago and to support a viable shellfishery. Franz, in a 1982 study, noted that numbers of species in Staten Island's shallow bay habitats in the late 1800's was similar to present species richness in areas which still have high water quality (e.g., Great South Bay, northeastern Long Island Sound). By the 1920's, many species had disappeared from Staten Island and species richness approached present levels. The major environmental deterioration was therefore considered to have occurred between 1890 and 1920. Franz noted a similar trend for oyster industry. Before 1900, oystering was conducted over much of the estuary, including Raritan Bay, Newark Bay, and Arthur Kill. By 1900, the industry was limited to waters south of the Narrows, and by 1920, it had largely disappeared from Lower New York Harbor. Sewagerelated pollution, leading to critically low summer oxygen levels, was thought to have a major role in the decline in oystering. Industrial pollution and harbor dredging probably also contributed. According to Hal Stanford, using data from the NOAA New York Bight MESA project, mass loading to the estuary of Biological Oxygen Demand amounted to approximately 1,000 metric tons per day in the early 1970's. An estimated 71% of this is from wastewater inputs directly to the estuary, 18% from urban runoff, and 10% from tributaries. Suspended solids of approximately 5,000 metric tons per day come 77% from the tributaries, 14% from wastewater, and 10% from urban runoff.

It is somewhat encouraging that comparisons of periods 1970 to 1974 and 1979-1980 show that BOD decreased from about 1,000 to 730 metric tons per day, and suspended solids from wastewater showed almost a 20% decrease.

Wastewater input into the estuary carries substantial amounts of toxic substances. Stanford's report gives the following mass loadings for some metals:

Arsenic	190-210kg/day
Cadmium	130-190kg/day
Copper	3,400kg/day
Lead	2800kg/day
Mercury	62-92kg/day

An example of organic contamination is contained in a recent report (CFM, Inc.), the Passaic Valley Sewage Authority, which shows loadings up to 11,600 pounds per day of 1,3-Dichloropropylene. Average daily loading for volatile oranic compounds varied between 4 pounds per day for 1,12-Trichloroethane to over 745 pounds per day for Toluene.

Recently, the Middlesex County Utilities Authority (MCUA) experienced a reduction in total flows, dropping from 95 MGD in 1978 to less than 80 MGD in 1983. During this same period, the MCUA effected a vast improvement in the water quality of its discharge to Raritan Bay. Loadings of BOD alone decreased from BOD reduction of 62% in 1978 to 92% in 1983.

The NJDEP's Office of Science and Research has performed extensive work in the Raritan River to study the fate and transport of toxic substances within the system. This work started with a sedimentological study in order to learn how sediment transport processes can predict where fine grain particles are accumulating (see 1982 305(b) report). Fine grain sediments can be useful in describing the sources and fates of pollutants that attach to them. For example, metals tend to bind to fine sediments by ion exchange. Organic compounds will also attach to these fine particles through sorption processes.

In May 1982 and 1983, sediment and water column samples were collected in the lower Raritan River. Most of these were collected in the main channel, but some were taken in tributary channels and tidal creeks. Water samples were analyzed for priority pollutants. Sediments were analyzed for priority pollutants as well as grain size.

The water analyses showed that the volatile organics were the most frequently occurring organic compounds. Chloroform, toluene, ethylbenzene, and 1,1,2,2-Tetrachloroethylene were found at levels up to 50 ug/1 in almost every sample. Copper, zinc, arsenic, and silver were the most frequently occurring metals.

Organic compounds were detected in the sediments infrequently. Metals were detected in every sample. Copper and zinc were detected at the highest levels, most likely due to their geological abundance. Lead was also detected at elevated levels. The amount of results on metals allowed further statistical analyses of this group. Positive correlations existed between fine grain sediments and the metal concentrations. Metals were also strongly intercorrelated, meaning that when one was high, others were also elevated. The study confirmed that fine grain sediments are sinks for metals and some organics and that the sediment transport system in the Lower Raritan experienced a net input of sediments from Raritan Bay and the Arthur Kill, possibly due to subtle rise in sea level.

The Hudson, Raritan, and Passaic are the three main contributors of freshwater into the Raritan-Hudson Estuary. The Hudson drains an area of abut 13,500 square miles, mostly in New York State.

The Raritan and Passaic basins, drained mainly by the Raritan and Passaic Rivers, each have areas of about 1,200 km2 (463 mi2), and are less important in the total supply of fresh water flowing into the Hudson-Raritan Estuary. The Raritan River, however, has a significant effect on the salinity of the upper Raritan Bay because it is the only substantial source of fresh water entering the western end of the bay.

The monthly mean discharges of the Hudson, Raritan, Passaic, and Hackensack Rivers are about 1,200 to 1,800 m3 (42,400 to 63,600 ft3/sec); highest flows occur during March, April, and May, and coincide with spring warming. Lowest total flows occur during August when evapotranspiration is the greatest.

The principal minimum mean discharge of the Raritan River occurs about one month after the minimum discharge of the Hudson and Passaic Rivers. The differences in the discharge of the Raritan may be explained by geography and differences in the relative amounts of snow received by the drainage basins

The Hudson-Raritan Complex also receives a considerable amount of fresh water volume from sewage effluent and city street runoff. Data from sewage treatment records indicate that about 60 m^3/sec (2,129 ft3/sec) of treated and untreated effluent are discharged into the local waters surrounding the estuary. Thus, sewage effluent is a major contributor of fresh water during periods of reduced riverine flows.

Sewage effluent from the New York metropolitan area is the principal source for the high concentration of nutrients observed in the bay complex. There is a net transport of nutrients and chlorophyll to the apex of the New York Bight. The nutrients originating from the bay complex and transported seaward have been implicated as an important factor leading to the decline of oxygen in bottom waters of the Bight during summer periods.

The impact of runoff from city streets during and immediately after a heavy rainfall is difficult to assess because of the combined sewer overflow system used in the New York metropolitan area. In this overflow system, untreated sewage, other wastes, and street runoffs are combined in the same sewer line. During heavy rainfall, the volume of these combined wastes exceeds the hydraulic capacity of the treatment plants. Under this condition, the combined load is intercepted at regular stations throughout the system. An Interstate Sanitation Commission study done in 1972 showed that within a short period after a heavy rainfall, there could be a ten-fold increase in the flow rate of wastes entering receiving waters and a 20-fold increase in the concentration of suspended solids. At one regulator, the quantity of total suspended solids discharged over a nine-hour period was 16% of the total suspended solids discharged for the entire month. Concentrations of other contaminants, such as oil and greases, were also measured by ISC and found to be greater in wet weather samples. The results demonstrated that the frequency, intensity, and duration of episodic rain storms have significant effects on the concentrations of pollutants entering the receiving waters.

In summary, although the principal sources of fresh water entering the estuary are from the rivers, we add an additional 2,442 million gallons a day from wastwater treatment plants, about 9 million gallons a day from storm water runoff (on average), and lesser quantities from groundwater flows, seepage, and other sources. All of these sources add pollutants to the estuarine waters. Some of the materials added are trapped in the estuary and become part of the sediments, others undergo significant physical, chemical, and biological transformations, and some move directly out of the estuary. Pollution is transferred to the Bight in the form of a plume of water flowing out over the bars to the Bight.

Based on available information, it has been estimated that something on the order of 2,660 metric tons of suspended particulate matter are carried out of the estuary to the Bight each day. But there is also about 2,630 metric tons coming into the estuary through circulation mechanisms from the Bight and elsewhere. The net exchange, which amounts to 30 metric tons of particulate matter each day, or 11,000 metric tons per year, is significant. The important difference, however, is that the outflow is significantly more contaminated than the inflow.

Anthropogenic nutrient inputs to estuaries have increased rapidly as sewage production, agricultural fertilization, and urbanization have increased. Nitrogen, the nutrient which most frequently limits phytoplankton production in coastal waters, may have increased by an order of magnitude over the past decade.

Inputs of nitrogen to the estuary come largely from wastewater effluents, most of which is discharged to the inner harbor regions. Dissolved inorganic nitrogen fluctuates around 60 ug-at/l.

Assimilation of dissolved inorganic nutrients by phytoplankton in the estuary is small compared to the sewage-nitrogen input, and most is thus transported out of the estuary with the coastal plume, supporting a large crop of phytoplankton in coastal waters.

According to Segar and Berberian, (1976) oxygen demand of particulate and dissolved organics in the estuarine discharge (Rockaway-Sandy Hook transect) may be as great as sewage sludge and dredge spoils together.

In viewing the Hudson-Raritan Estuary from a regional perspective, I see how important it is that New Jersey and New York work together, with Federal agencies, the private sector, and all concerned interest groups, to ensure that we address the totality of problems impacting on this complex system.

Local or regional proposals to address the problems within a single jurisdiction, with others hanging back, will not work.

Cooperation isn't always easy, nor has the region been necessarily noted historically for harmony as illustrated by a 1916 New York Harbor case, in which the Interstate Commerce Commission wrote:

"If we could overlook the fact that historically, geographically, and commercially New York and the industrial district in the northern part of the state of New Jersey constitute a single community; and if we were not persuaded that cooperation and initiative must eventually bring about the improvements and benefits which the complainants hope to attain through a change in the rate adjustment; then we might conclude that the present (rail) rates results in undue prejudice to the people and communities on whose behalf this complaint was filled. On the evidence now before us that conclusion cannot be reached."

Today, however, there are a number of initiatives to bring about a more holistic understanding of the Estuary and to encourage the research and planning, and the implementation of the tasks, to bring real improvement to the quality of the estuarine and coastal ecosystems. This symposium is such an effort.

The New York Academy of Sciences is currently conducting a fact-finding and mediation process involving all parties they could identify ("stakeholders" is the present buzzword) having an interest in New York Bight and Hudson-Raritan Estuarine issues. As a pilot project, for the next nine months, they have focused on the problems of PCB contaminant loading. Such joint efforts, with public involvement and active participation are vitally necessary to carry out the vision we speak of here today.

Bibliography

Cole, C.A. 1968. Water Quality Trends of Raritan Bay from 1950 to 1966. Masters Thesis, Rutgers University, April 1968.

Daggett, C.J. 1986. Testimony by Regional Administrator, Region II, EPA, submitted on November 13, 1986 to the New Jersey Clean Water Council on Ocean Water Quality.

Dudall, I.W., O'Connors, H.B., and Irwin, B. 1975. Fate of wastewater sludge in the New York Bight Apex.

Gross, M.G. 1976. Waste Disposal MESA New York Bight Atlas Monography 26. Albany, N.Y., New York Sea Grant Institute.

Interstate Sanitation Commission 1936, 1985, 1986 Reports.

Mueller, J. and Anderson, A. 1978. Industrial Wastes MESA New York Bight Atlas Monograph 30. Albany, N.Y., New York Sea Grant Institute.

Mueller, J.A., Jerris, J.S., Anderson, A.R., and Hughes, C.F. 1976. Contaminant Inputs to the New York Bight. NOAA Technical Memorandum ERL MESA-6 Boulder, Colo.

Mueller, J. and Werme, C.E. 1984. Contaminant Inputs to the Hudson-Raritan Estuary from: Breteler, R.J. (ed.) Chemical Pollution of the Hudson-Raritan Estuary. NOAA Technical Memorandum, NOS OMA #7, Dec. 1984.

New Jersey Department of Environmental Protection, 1986. Water Quality Inventory Report. NJDEP/Division of Water Resources.

Pacheco, A.L. (ed.) 1984. Raritan Bay. Its Multiple Uses and Abuses; Proceedings of the Walford Memorial Convocation. Sandy Hook Laboratory Technical Series Report, No. 30.

Passaic Valley Sewerage Commissioners, 1986. Investigation of Organic Priority Pollutants in the Influent to the Passaic Valley Sewage Commissioners Treatment Plant. Report by CFM Inc., Whippany, N.J.

Rimer, S. 1986. Long-Abused Hudson Thrives Again, N.Y. Times, Nov. 6, 1986.

Segar, D.A. and Berberian, G.A. 1976. Oxygen depletion in the New Bight Apex: Causes and Consequences Ann. Soc. Limuol. Oceanogr. Special Symposia Vol. 2, 1976.

Squires, D.F. 1983. The Ocean Dumping Quandry. State University of New York Press, Albany.

HAZARDOUS CHEMICALS IN THE HUDSON: AN EXAMINATION OF AVAILABLE WATER QUALITY AND NONPOINT SOURCE POLLUTION DATA

by Steven O. Rohmann, Ph.D.

The results of this eighteen-month study draw the first detailed picture of existing hazardous chemical pollution in an entire U.S. river. This report focuses on where and how much hazardous chemical pollution is present in the Hudson River's water. The goal of this study was to elucidate relationships among water quality, point source discharges and nonpoint source inputs to the river.

The Hudson River drainage basin covers 13,365 square miles and extends into parts of five states: Connecticut, Massachusetts, New Jersey, New York, and Vermont. Chemical pollution in the Hudson directly or indirectly affects many of the over 16 million people living along the river and its tributaries. Water drawn from the Hudson is treated and used for drinking by over 600,000 people, and many thousands use the Hudson for recreation. In addition, the Hudson supports over 130 species of fishes, plus hundreds of species of other aquatic organisms.

In this study, nearly 9,000 pieces of publicly-available data were studied for information pertaining to the concentrations of 26 specific hazardous chemicals in the Hudson's water over nine years (1970, 1975, and 1978 through 1984). This study also included information, obtained from the National Oceanic and Atmospheric Administration, on nonpoint sources of hazardous chemical pollution in the estuarine portion of the Hudson (essentially from the Battery of Manhattan Island upstream to Troy, New York)[1]. In a previous report, I identified and described 554 effluents of the 26 hazardous chemicals discharged to the Hudson by 183 industrial and sewage treatment plants, a shopping center, and a restaurant over a six year period (1978 through 1983)[2].

Since 1970, monitoring of the Hudson River's water for hazardous chemicals has been conducted primarily by five government agencies, and by five drinking water treatment plants that use the Hudson as a source of water. Undoubtedly, other agencies, organizations, and firms also monitor particular aspects of water pollution at various times. However, the data that are publicly available and most accessible are almost entirely those generated by these ten government agencies or water treatment plants.

METHOD

This study evaluated hazardous chemical pollution conditions in the 95% of the Hudson River basin located within New York State by examining water quality monitoring data provided in 40 official documents or computerized databases of these government agencies and drinking water treatment plants. These data equal the actual concentrations of the 26 chemicals found in water at 79 sampling locations along the Hudson and its tributaries. In order to assess water quality, the data were compared to the New York State Department of Environmental Conservation's ambient water quality standards promulgated in 1985[3]. These standards define at what concentrations the 26 chemicals in water may pose an unacceptable threat to either humans or aquatic organisms.

The 26 Hazardous Chemicals

The 26 chemicals studied were chosen as representative of chemicals of concern to both public health and the environment. Below are summarized the five categories that contributed to the selection of the 26 chemicals, and which chemicals fell into each category.

1. Cancer-related -- Some of the known and suspected carcinogens, according to the 1985 list of the U.S. Department of Health and Human Services (HHS)[4], including: arsenic, benzene, bis(2-ethylhexyl)-phthalate, cadmium, chloroform, chromium-hexavalent, and PCBs.

2. Widely found in drinking water supplies -- Six were chosen, including benzene, one of the seven carcinogens cited above, and dichlorobenzenes, 1,1-dichloroethylene, methylene chloride, tetrachloroethylene, and trichloroethylene[5].

3. Persistent in the environment -- Includes five of the carcinogens, plus lead, mercury, and eight pesticides: aldrin, chlordane, DDT (and its metabolites DDD and DDE), 2,4-D, dieldrin, endrin, heptachlor (and its metabolite heptachlor epoxide), and pentachlorophenol (PCP).

4. Widely used or discharged -- Includes four of the carcinogens, four of those found in drinking water, four that are persistent, and three others: cyanide, toluene, and oil & grease.

5. Widely present in runoff -- Includes several chemicals commonly found in runoff from city streets, such as lead and mercury, and six pesticides used, on a restricted basis, in agriculture.

Ambient Water Quality Standards

New York State surface waters are divided, section-by-section, into one of nine water-usage classifications, based on perceived usage. The definitions of the usages range from class A waters, which may be used as a source of drinking water after treatment and will support primary contact recreation (swimming), to class D waters, which should support fish survival and passage, but not reproduction, and where only limited secondary contact recreation (fishing) is allowed.

Ambient water quality standards have been developed in conjunction with these water-usage classifications. The standard for a particular chemical often changes from one class of water to another. For example, the aquatic organism ambient water quality standard for arsenic in class A, B and C waters is 190 micrograms per liter (ug/l); in class D waters, the standard is 360 ug/l; in class S(aline)A, SB and SC waters, the standard is 63 ug/l; and the standard in class SD waters is 120 ug/l. Because of the importance of class A waters, both a human water quality standard and an aquatic water quality standard may exist, and water quality data collected in these waters may be compared to either the human standard, the aquatic standard, or both. In all other water

TABLE 1. WATER QUALITY MONITORING — Number of Analyses of 26 Chemicals Performed Each Year.

Chemical	1970	1975	1978	1979	1980	1981	1982	1983	1984	Total
aldrin	2	14	155	176	4	1	44	43	36	475
arsenic	10	168	74	65	8	23	81	106	76	611
cadmium	6	155	112	76	18	30	97	110	84	688
chlordane	1	13	155	98	4	1	39			311
cyanide	7	55		5	23	19	37	1	1	148
DDT &/or metabolites	4	14	155	98	4	1	45	43	37	401
2,4-D	8	2	6	2	3	1	3	3	1	29
dieldrin	3	12	154	98	4	1	45	42	36	395
endrin	3	13	159	103	6	1	46	47	37	415
heptachlor &/or h. epoxide	2	12	155	101	4	1	45	43	36	399
lead	10	192	263	235	22	36	100	123	83	1064
mercury	11	165	90	62	13	31	96	118	84	670
PCBs or congeners	8	10	185	218	170	182	175	222	145	1315
benzene							60	74	65	199
bis(2-ethylhexyl)phthalate							42	43	36	121
chloroform			1	1			60	69	63	194
chromium-hexavalent	1							1		2
dichlorobenzenes						1	60	60	52	173
1,1-dichloroethylene							36	54	41	131
hexachlorobutadiene						1	42	42	12	97
methylene chloride							48	66	55	169
oil & grease	2	36	76	55	1	6	0	8	6	190
pentachlorophenol							48	48	42	138
tetrachloroethylene			1				67	72	62	202
toluene							57	70	65	192
trichloroethylene			10	1			67	74	62	214
TOTAL	78	861	1751	1394	284	336	1440	1582	1217	8943

TABLE 2. COMPARISON OF ACTUAL CHEMICAL CONCENTRATIONS TO WATER QUALITY STANDARDS.*

Chemical	Violations	No Violations	No Comparisons Due To Detection Limits	No Standards	Total**
aldrin	0	0	215	82	297
aldrin + dieldrin					393
arsenic	0	807	0	0	807
cadmium	130	411	349	0	890
chlordane	2	0	454	0	456
cyanide	37	65	128	0	230
DDT &/or metabolites	4	128	461	0	593
2,4-D	0	12	11	29	52
dieldrin	0	0	187	2	189
endrin	0	128	488	0	616
heptachlor &/or h. epoxide	0	0	586	0	586
lead	597	629	230	0	1456
mercury	99	514	263	0	876
PCBs or congeners	1241	12	526	0	1779
benzene	8	75	0	199	282
bis(2-ethyl-hexyl)phthalate	2	0	168	12	182
chloroform	2	0	84	194	280
chromium-hexavalent	0	2	0	2	4
dichlorobenzenes	0	239	0	0	239
1,1-dichloro-ethylene	0	0	54	131	185
hexachloro-butadiene	0	12	128	0	140
methylene chloride	0	74	0	169	243
oil & grease	0	0	0	245	245
pentachloro-phenol	0	0	198	0	198
tetrachloro-ethylene	1	0	80	202	282
toluene	0	86	0	192	278
trichloro-ethylene	0	93	0	214	307
TOTAL	2123	3286	5003	1673	12085

* - Total number of analyses (12085) reflects the aggregate of comparisons to aquatic and human water quality standards.

** - Aldrin and dieldrin have separate human water quality standards, but must be aggregated for comparison to the aldrin + dieldrin aquatic water quality standard. Total number of analyses (8550) reflects the aggregation of aldrin and dieldrin water quality data, whenever possible, to facilitate comparison to the aldrin + dieldrin aquatic water quality standard.

classes, only aquatic water quality standards may exist, and water quality data collected in these waters may be compared only to these standards.

In this study, the 1985 standards were compared to the water quality data available for all of the years studied so that a consistent up-to-date measure for evaluating the river's health could be made. Also, by using these standards, it was possible to discern whether water quality (in terms of violations of water quality standards) has improved or deteriorated over time.

The methods used to identify and quantify point source discharges and to estimate amounts of pollutants entering the Hudson from nonpoint sources and have been presented elsewhere[2,7].

FINDINGS AND DISCUSSION

Hazardous chemicals enter the Hudson through a variety of routes, including: surface runoff from land, and groundwater (nonpoint sources); discharges from industrial and sewage treatment plants (point sources); and direct spraying, direct dumping, dust, and direct rainfall.

Depending on the chemicals' characteristics, chemicals entering the river dissolved in water may remain dissolved in water, evaporate, be taken up by fish or other aquatic organisms, adhere to particles in the water, or degrade into another chemical form. Those chemicals entering the river associated with suspended sediment may remain attached to sediment, falling to the river bottom, may dissociate from the sediment and dissolve in the water, or may concentrate in the fish and other aquatic organisms.

The fate of chemicals in the the river also depends on certain properties of the water. These properties include the water's temperature, pH, and ionic species concentrations. The last two properties affect the forms and amounts of chemicals in solution. The presence of detrital materials, such as clays and organic matter, can remove, through adsorption, certain chemicals from solution in water.

Water Quality Data

A total of 8,943 analyses for the 26 hazardous chemicals in water during the years studied were evaluated (see Table 1). These 8,943 analyses yielded a total of 12,085 possible comparisons to standards: 3,535 comparisons to human (class A waters only) water quality standards; and 8,550 comparisons to aquatic water quality standards. Analyses for PCBs or its congeners in water yielded the largest number of possible comparisons (1,779), followed by lead (1,456), cadmium (890), and mercury (876; see Table 2). Of the 12,085 possible comparisons, 2,123 were found to exceed applicable ambient water quality standards. The pollutant found to be most frequently in violation of standards was PCBs or its congeners (1,241 violations). This indicates that, for every opportunity where a comparison of an actual PCB concentration in water could be made to a PCB standard, 69.8% of these comparisons exceeded the standard. Similarly, 41.0% (597) of the 1,456 lead comparisons possible exceeded the lead standards; 16.1% (37) of the 230 cyanide comparisons possible exceeded the cyanide standards; and 14.6% (130) of the 890 cadmium comparisons possible exceeded the cadmium standards.

A total of 3,286 of the 12,085 comparisons possible showed actual concentrations of the chemicals in water did not exceed applicable standards. For two of the 26 chemicals, arsenic and dichlorobenzenes, 100% of the actual concentrations found in water were not in excess of arsenic or dichlorobenzene standards. In the case of mercury, 58.8% (514) of the 876 comparisons possible did not exceed the mercury standards. For cadmium, 46.2% (411) of the 890 comparisons possible did not exceed the cadmium standards.

Of the 12,085 possible comparisons, 5,003 could not be made because both the standard for a particular chemical and its actual concentration in the water sample were below the detection limit established for that chemical. Detection limits are chemical concentrations below which it is difficult, based on analytical capability, in the judgment of a particular agency, or both, to measure concentrations of chemicals in samples.

For 1,673 of the 12,085 possible comparisons, evaluation of the relationship between actual chemical concentrations in water and applicable standards could not be made because standards for certain chemicals had not been established in some or all classes of water. There are important reasons, other than monitoring for violations of water quality standards, why sampling of Hudson River water is performed. Sampling is often conducted in sections of the river where no standards apply, for the purposes of monitoring discharges of pollutants in those sections of the river, or in order to establish baseline conditions against which to compare future samples.

Table 3 shows the number of violations of water quality standards for each of the 26 hazardous chemicals each year. The frequent occurence of high concentrations of four chemicals, PCBs, lead, cadmium, and mercury, accounted for 2,067 violations of water quality standards, or 97.4% of all (2,123) violations found. Excessive PCB concentrations accounted for 1,241 violations (58.5%), lead for 597 violations (28.1%), cadmium for 130 violations (6.1%), and mercury for 99 violations (4.7%). Fluctuations in the number of violations from year to year vary widely from one chemical to the next, and may reflect changes in the number of actual analyses performed for each chemical, as well as variability in chemical concentrations found. The actual concentrations of one chemical, mercury, appear to be present in excess of mercury standards more often in recent years (1982-1984) than in earlier years (1970, 1975, and 1978-1981). This is in contrast to the temporal trends in violations for the other chemicals which fluctuate widely or decrease in number in recent years. The reason for this increase in the frequency of mercury violations remains unexplained.

Of the 2,123 comparisons revealing violations of water quality standards, 345 were of comparisons to the human water quality standards (see Table 4). Of these 345 violations, PCBs accounted for 316, or 91.6%. Lead (12 violations) and benzene (8 violations) together accounted for another 5.8% of the 345 violations of human standards.

TABLE 3. VIOLATIONS OF WATER QUALITY STANDARDS -- For Each of the 26 Chemicals, by Year.*

Chemical	1970	1975	1978	1979	1980	1981	1982	1983	1984	Total Violations
aldrin	0	0	0	0	0	0	0	0	0	0
aldrin + dieldrin										
arsenic	0	0	0	0	0	0	0	0	0	0
cadmium	1	59	25	17	1	13	6	2	6	130
chlordane	0	2	0	0	0	0	0			2
cyanide	1	32		0	3	1	0	0	0	37
DDT &/or metabolites	2	2	0	0	0	0	0	0	0	4
2,4-D	0	0	0	0	0	0	0	0	0	0
dieldrin	0	0	0	0	0	0	0	0	0	0
endrin	0	0	0	0	0	0	0	0	0	0
heptachlor &/or h. epoxide	0	0	0	0	0	0	0	0	0	0
lead	4	151	198	138	20	30	19	22	15	597
mercury	0	5	11	11	6	18	15	16	17	99
PCBs or congeners	16	10	210	221	211	168	102	171	132	1241
benzene							3	4	1	8
bis(2-ethylhexyl)phthalate							2	0	0	2
chloroform			0	0			0	2	0	2
chromium-hexavalent	0							0		0
dichlorobenzenes						0	0	0	0	0
1,1-dichloroethylene							0	0	0	0
hexachlorobutadiene						0	0	0	0	0
methylene chloride							0	0	0	0
oil & grease	0	0	0	0	0	0	0	0	0	0
pentachlorophenol							0	0	0	0
tetrachloroethylene			0				1	0	0	1
toluene							0	0	0	0
trichloroethylene			0	0			0	0	0	0
TOTAL	24	261	444	387	241	230	148	217	171	2123

* - Total reflects the aggregation of violations of both aquatic and human standards.

TABLE 4. COMPARISONS MADE TO HUMAN AND AQUATIC WATER QUALITY STANDARDS -- Breakdown, by Chemical, Showing Number of Violations and No Violations.*

	HUMAN STANDARDS		AQUATIC STANDARDS	
Chemical	Violations	No Violations	Violations	No Violations
aldrin	0	0	0	0
aldrin + dieldrin			0	0
arsenic	0	196	0	611
cadmium	2	199	128	211
chlordane	1	0	1	0
cyanide	0	62	37	3
DDT &/or metabolites	2	128	2	0
2,4-D	0	12	0	0
dieldrin	0	0	0	0
endrin	0	128	0	0
heptachlor &/or h. epoxide	0	0	0	0
lead	12	380	585	249
mercury	1	205	98	309
PCBs or congeners	316	12	925	0
benzene	8	75	0	0
bis(2-ethyl-hexyl)phthalate	0	0	2	0
chloroform	2	0	0	0
chromium-hexavalent	0	0	0	2
dichlorobenzenes	0	66	0	173
1,1-dichloro-ethylene	0	0	0	0
hexachloro-butadiene	0	0	0	12
methylene chloride	0	74	0	0
oil & grease	0	0	0	0
pentachloro-phenol	0	0	0	0
tetrachloro-ethylene	1	0	0	0
toluene	0	86	0	0
trichloro-ethylene	0	93	0	0
TOTAL	345	1716	1778	1570

SUMMARY:	345	1716
	1778	1570
	2123	3286

* - Aldrin and dieldrin have separate human water quality standards, but must be aggregated for comparison to the aldrin + dieldrin aquatic water quality standard.

Of the 2,123 comparisons indicating violations of standards, 1,778 were violations of aquatic water quality standards. Of these 1,778 violations, PCBs, lead, cadmium, and mercury together accounted for 1,736, or 97.6%. PCBs alone accounted for 925, or 52.0%, of the 1,778 violations of aquatic standards. In comparing the frequency in which water quality standards were exceeded, 20.8% (1,778/8,550) of comparisons to aquatic standards revealed violations while 9.8% (345/3535) of comparisons to human standards revealed violations. This is due to the fact that aquatic water quality standards are generally set at lower concentrations than human water quality standards.

Point Source Discharges

Point source dischargers, such as industries and sewage treatment plants, have been perceived by the public as the major cause of hazardous chemcial pollution problems in the Hudson. In the case of PCB contamination, this perception appears to be accurate. However, until recently, no analysis was available that would allow enough quantitative comparisons of point sources to question this perception.

A recent report indicates that, during the years 1978 through 1983, dischargers of 26 haszardous chemicals released thousands of pounds of these chemicals into the Hudson each year[2]. Table 5 is a summary of the quantities of 14 chemicals released into the Hudson in 1982. One pollutant, oil & grease, accounted for 97.1% of the total amount of these chemicals dischgarged in 1982. Of the 22,876.1 pounds of 13 other chemicals discharged in 1982, 36.7% was of toluene. Only 0.7 pounds of PCBs were discharged by point sources in 1982.

Nonpoint Pollution Sources

Nonpoint source pollution is pollution that cannot be traced to a specific, identifiable source, such as an industrial plant or municipal sewage treatment plant. Nonpoint source pollution is diffuse, and typically occurs when rain or melting snow washes pesticides, car exhaust, oil & grease, sediment, and other pollutants off large land areas into nearby water bodies. Unfortunately, nonpoint source pollution is, in many situations, difficult to measure, and in certain situations, difficult to control[8].

Agricultural and urban runoff account for the largest amounts of nonpoint source pollution nationwide, according to an EPA Report to Congress in January 1984[9]. Other contributors to nonpoint source pollution include runoff from mining, timber harvesting, construction site activities, and waste disposal sites. The New York State Department of Environmental Conservation has indicated that pollution associated with agricultural and urban runoff adversely affects the water quality of more sections of the State's rivers than from all of the other categories of nonpoint source pollution combined[10]. Because of the significance of agricultural and urban runoff as contributors of pollution to rivers in New York, this study of nonpoint source pollution of the Hudson focused on these two types of nonpoint pollution sources.

Pollutants associated with agricultural runoff are typically car-

TABLE 5. QUANTITIES OF CHEMICALS DISCHARGED IN 1982 BY 47 DISCHARGERS*

Chemical	Amount Discharged (Lbs/Yr)
toluene	8,395.0
lead	4,555.2
cyanide	3,877.4
chloroform	3,034.2
chromium-hexavalent	1,805.3
cadmium	465.4
benzene	438.0
trichloroethylene	152.2
bis(2-ethylhexyl)-phthalate	59.5
arsenic	41.2
methylene chloride	40.1
mercury	2.9
PCBs	0.7
oil & grease	771,007.0
TOTAL	793,874.1

* - A discharger's effluent may contain more than one hazardous chemical. As a result, the 47 dischargers are responsible for a total of 85 chemical discharges.

TABLE 6. COMPARISON OF CIRCA 1982 NONPOINT SOURCE AND 1982 POINT SOURCE POLLUTION DISCHARGES TO THE HUDSON RIVER[1,2].

	LOWER HUDSON RIVER			
	Nonpoint Source Input			
	Urban Areas (NOAA est.)	Agricultural Areas (NOAA est.)	Point source inputs	Ratio nonpoint to point
Runoff (gals/yr)	120.5 billion	365.5 billion	NA	NA
Arsenic (lbs/yr)	5,320.9	18,860.8	27.7	873X
Cadmium (lbs/yr)	2,813.4	1,374.9	5.5	762X
Chromium* (lbs/yr)	26,284.6	152,124.5	83.6†	NA
Lead (lbs/yr)	148,496.0	33,822.2	239.4	762X
Mercury (lbs/yr)	535.7	0.5	0.7	766X
Oil** (lbs/yr)	9,262,620.0	NA	385,731.3††	NA
PCBs (lbs/yr)	2,502.9	NA	0.4	NA
CHPs*** (lbs/yr)	7,438.0	491.7	NA	NA

1 - Basta, et al., 1985.

2 - Rohmann, 1985.

NA - Data not available or insufficient data to allow for estimation.

* - Point sources refer to discharge of chromium-hexavalent, not chromium.

† - 3 of 16 dischargers could not be assessed.

** - Point sources refer to discharge of oil & grease, not oil only.

†† - 12 of 38 dischargers could not be assessed.

*** - Only one of NOAA's six chlorinated hydrocarbon pesticides investigated, endrin, was also investigated by INFORM.

ried off the land as eroded soil. Agricultural runoff almost always contains heavy metals and often contains pesticides, which, after application, tend to adhere to soil. If intense runoff occurs soon after pesticide application, high concentrations can appear in the runoff, causing localized problems, such as fish kills, when the runoff reaches the receiving water[11].

Pollutants associated with urban runoff typically reach the receiving water body through a municipal sewer system. Combined sewers carry both sewage and stormwater -- runoff from streets, parking lots, and other surfaces. Under normal conditions, combined sewers transmit the sewage and stormwater runoff to sewage treatment plants, where both go through treatment processes and then are discharged to an adjacent water body. When the combined volume of sewage and stormwater runoff exceeds the hydraulic capacity of the sewage treatment plant, the excess volume of combined sewage and stormwater is released, untreated, through "Combined Sewer Overflows," directly to the nearby water body[12].

Newer cities typically have two systems: 1) separate storm sewers, which carry only stormwater and do not connect to a sewage treatment plant; and 2) a sewer system, which carries domestic sewage and, in many cases, urban-area industrial discharges, to the sewage treatment plant. While allowing stormwater to go untreated under all situations, separate sewers prevent the severe overloading of sewage treatment plants during rainstorms and the release of raw sewage to nearby water bodies.

The characteristics of separate storm water runoff from 28 urban areas throughout the U.S. and the extent to which runoff contributes to water quality problems nationwide has been investigated[12]. In 86 samples of urban stormwater runoff from 18 of the 28 cities, lead was found to be present in 95% of the samples. Cadmium, as well as arsenic and chromium, were found to be present over 50% of the time. Further, because so much of city land is impervious to water, a much greater precentage of pollutants which are collected on surfaces will run off. For instance, from 85-95% of lead accumulated on city streets between storms is transported to nearby receiving waters during rainfall washout. Similarly, up to 100% of insecticides and herbicides used in urban areas may be transported during these rainfall events[13].

The National Oceanic and Atmospheric Administration (NOAA) has estimated the quantities of eight (of the 26) hazardous chemicals which enter the lower Hudson (between the Battery of Manhattan and Troy, New York) from urban and agricultural runoff[6,7]. Comparing these estimates to the amounts of these chemicals discharged in 1982 by point sources revealed the much greater contribution that nonpoint sources are making to total pollution in the lower Hudson. With regard to inorganic chemicals, hundreds of times more arsenic, cadmium, lead, and mercury are associated with urban and agricultural runoff than with point sources. Nearly 182,500 pounds of lead entered the lower Hudson in 1982 from nonpoint source runoff, compared to 239 pounds from point sources; 536 pounds of mercury came from nonpoint sources, compared to less than one pound from point sources; 4,188 pounds of cadmium came from nonpoint sources compared to some six pounds from point sources; and 24,182 pounds of arsenic came from nonpoint sources, while 28 pounds came from point sources. Table 6 shows these comparisons.

CONCLUSIONS

A clear picture of hazardous chemical pollution in Hudson River water, related to the 26 chemicals investigated, can be developed by evaluating available water quality monitoring data. Further, evaluating these data shows where problems, such as excessive discharges or gaps in sampling, may exist in the river or the monitoring efforts.

Hazardous chemical pollution problems in Hudson River water center around the presence of four chemicals: PCBs, lead, mercury, and cadmium. These four chemicals appear consistently in Hudson River water and in high concentrations (as defined by comparison of actual concentrations to ambient water quality standards). PCBs appear to be the most pervasive hazardous chemical pollution problem in the river. The PCB contamination affects not only Hudson River water, but also sediment and aquatic organisms[14]. The presence of lead, mercury, and cadmium appear, to a lesser extent, to be problems in water. However, it is not clear whether the lead, mercury, or cadmium found in Hudson water is also present in Hudson sediment, which may contain natural, as well as anthropogenic concentrations of these chemicals. Also, it was found that not all of the data available on water quality testing had been provided upon request, leading to data gaps in several sections of the river.

Based on available data, no relationships could be discerned between point source discharges identified and concentrations of the 26 hazardous chemicals in the river. Possible reasons for this include: 1) point source discharges are well controlled; 2) the frequency or location of sampling was such that any in-stream concentrations which might have been increased by point source discharges could not have been detected; and 3) high concentrations of chemicals found in the river unattributable to point sources may have been due to nonpoint and/or unknown point sources of these chemicals.

The water quality monitoring data appear to indicate a reduction in pollution levels of lead and cadmium since 1975, perhaps due to point source controls instituted between 1975 and 1980, and, in the case of lead, to the use of unleaded gasoline beginning in the mid-1970s. No trends since 1980 for these two chemicals are distinguishable. This may be because pollution from nonpoint sources, which may be masking the discharges coming from point sources. No trends were distinguishable for any of the other 26 hazardous chemicals studied. The inability to discern trends is also due, in part, to the inconsistent use of sampling locations, and testing of chemicals from on year to the next.

Agricultural and urban runoff inputs of hazardous chemicals to the Hudson appear to greatly exceed inputs originating from point sources. For each of eight chemicals, inputs from either urban areas, agricultural areas, or both exceed the inputs from all point sources in the same geographic area combined. The NOAA estimates also indicate that nonpoint sources can be the dominant contributors of these pollutants to a river located in a geographic area known to be highly industrialized. Regardless of the potential quantitative assumptions associated with these estimations, nonpoint sources of hazardous chemicals are a serious problem in the lower Hudson River. Further, other research has indicated that atmospheric deposition of hazardous chemicals in the Northeastern U.S., particularly arsenic and cadmium, may be the cause of increasing concentrations of these chemicals in water[15]. The impact of nonpoint pollution sources on Hudson River water quality can be assessed only by better characterization and monitoring of the major contributors to the problem. Without such efforts, any further improvements in water quality will be negligible in the foreseeable future.

REFERENCES

1. Basta, D.J., B.T. Bower, C.N. Ehler, F.D. Arnold, B.P. Chambers, D.R. Farrow. 1985. The National Coastal Pollutant Discharge Inventory. Proceedings of the Coastal Zone 85 Conference, July 30 - August 2, 1985.

2. Rohmann, S.O. 1985. Tracing a River's Toxic Pollution: A Case Study of the Hudson. 158 pp.

3. New York State Department of Environmental Conservation. 1985. Ambient water quality standards and guidance values, Amendments to 6 NYCRR Part 701-702, August 2, 1985.

4. U.S. Department of Health and Human Services, Public Health Service. 1985. Fourth Annual Report on Carcinogens, Summary 1985. NTP 85-002.

5. Brown, H.S., D.R. Bishop, and C.A. Rowan. 1984. The role of skin absorption as a route of exposure for volatile organic compounds (VOCs) in drinking water. American Journal of Public Health, 74: 479-482.

6. Dalton, Dalton, and Newport. Non-urban storm runoff methods document, National Coastal Pollutant Discharge Inventory, 1985. Prepared for: Ocean Assessments Division, National Oceanic and Atmospheric Administration, March 6, 1985

7. Dalton, Dalton, and Newport. Urban storm runoff methods document, National Coastal Pollutant Discharge Inventory, 1984. Prepared for: Ocean Assessments Division, National Oceanic and Atmospheric Administration, December 18, 1984.

8. Chesters, G. and L. Schierow. 1985. A primer on nonpoint pollution. Journal of Soil and Water Conservation, 40(1):9-13.

9. U.S. Environmental Protection Agency, Office of Water Program Operations 1984. Report to Congress: Nonpoint Source Pollution in the U.S.

10. Association of State and Interstate Water Pollution Control Administrators. 1985. America's clean water: the states' nonpoint source management experience.

11. Novotny, V., and G. Chesters. 1981. Handbook of Nonpoint Source Pollution: Sources and Management. Van Nostrand Reinhold, New York, N.Y. 555 pp.

12. U.S. Environmental Protection Agency. Results of the Nationwide Urban Runoff Program, Volume I - Final Report. 1983. Water Planning Division, U.S. Environmental Protection Agency. NTIS accession No. PV84-185552.

13. U.S. Environmental Protection Agency. 1982. Nonpoint source runoff: Information transfer system. EPA 430-9-83-009.

14. Brown, M.P., M.B. Werner, R.J. Sloan, and K.W. Simpson. 1985. Polychlorinated biphenyls in the Hudson River. Environmental Science and Technology, 19: 656-661.

15. Smith, R.A., R.B. Alexander, and M.G. Wolman. 1987. Water quality trends in the nation's rivers. Science, 235: 1607-1615.