A REPORT TO THE
DELAWARE RIVER AND BAY AUTHORITY

BY THE
UNIVERSITY OF DELAWARE
COLLEGE OF MARINE STUDIES
AND NEW JERSEY
MARINE SCIENCES CONSORTIUM

THE DELAWARE ESTUARY

RESEARCH AS BACKGROUND FOR ESTUARINE MANAGEMENT AND DEVELOPMENT

JULY 1983

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A Report to the Delaware River and Bay Authority

Edited by

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and
New Jersey Marine Sciences Consortium

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EXECUTIVE SUMMARY

BACKGROUND

The estuary of the Delaware River is a body of water stretching in length about 115 nautical miles, of which about 65 miles is saline. The heavily-populated upper end of the estuary contributes large amounts of municipal wastes (from about 5% of the United States population) and some industrial wastes. The broad, shallow lower estuary, surrounded by extensive salt marshes, supports healthy commercial and sport fishing as well as other recreational activities. The estuary, with a 55-foot natural channel 12 miles in from the mouth and a 40-foot dredged channel 90 miles from the mouth to Philadelphia, is a major transportation corridor and one of the largest ports in the United States. That the Delaware Estuary functions as a major waste receptacle, a fishing ground, a recreational resource, and a transportation corridor is due to a quirk of nature in the way that the estuary works. For it to continue successfully to support such diverse activities requires both understanding the natural mechanisms of the estuary and responsible stewardship. The Delaware Estuary has potential for growth and development in increased port facilities and expanded fisheries potential. Stewardship is required in such development to assure continued multiple use of the estuary.

The Delaware River and Bay Authority (DRBA) issued a contract in 1982 to the College of Marine Studies of the University of Delaware and the New Jersey Marine Sciences Consortium in response to a proposal to conduct research on the Delaware Estuary. As a result of the DRBA support and prior support from the Office of Sea Grant of the National Oceanic and Atmospheric Administration (NOAA), the bistate Delaware Estuary Project was begun. In addition to its association with the funding agencies, the Delaware Estuary Project has become informally associated with research and monitoring efforts of the Delaware Department of Natural Resources and Environmental Control, the New Jersey Department of Environmental Protection, the four-state Delaware River Basin Commission, and the NOAA National Ocean Service. The result is an understanding greater than that which the Delaware Estuary Project or any one agency alone could achieve. Every effort has been made to place the Delaware Estuary Project in the pivotal position for research and information coordination on the lower Delaware Estuary.

This is a report on the results of scientific inquiry and management issues specified in the contract by the DRBA. The objective of the original proposal, more fully developed as the major goal of the present Delaware Estuary Project, is that a thorough understanding of the Delaware Estuary is essential for rational estuarine management. In addition, this report addresses potential roles of the DRBA in improving the sound management and development of the estuary. The report consists of one part on the scientific investigations and a second part on management aspects. The first part presents the research supported by DRBA and Sea Grant, as well as historical information. It is a preliminary assessment of our present knowledge on the state of the estuary. The second part specifically addresses areas in which the DRBA might appropriately become involved to improve management of the lower Delaware Estuary.

THE STATE OF THE DELAWARE ESTUARY

To improve the management or to maintain the present condition, it is mandatory to first know the state of the estuary. There is a misconception that the Delaware Estuary is hopelessly polluted, leading some to suggest it be written off for recreational purposes and considered an industrial estuary. This is not so, and, in fact, there is every reason to believe that this body of water can be maintained and improved as a multiple-use estuary. Heavy pressure from human activities has caused serious environmental degradation in the region directly adjacent to areas of municipal build-up. However, the lower estuary apparently possesses some fairly effective natural cleansing abilities. During the past decade, marked improvement in the water quality of the upper estuary has been documented.

The shellfish and finfish yields from the Delaware Estuary were greater 75 years ago than they are today. Analysis of the fisheries with historical perspective suggests that prior poor fisheries management (coupled with habitat destruction and pollution) was the major cause of decline. The Delaware Estuary certainly can serve as a viable biological system supporting fisheries and recreational activities. While this body of water cannot become a pristine clear stream, it can be considered to be a healthy aquatic environment. Much of its characteristic is determined more by natural phenomena than by human influences.

The major freshwater input to the estuary comes from the Delaware River with the Schuylkill River at Philadelphia making the only other major contribution (about 10% of total flow). Saltwater from the ocean enters the mouth of the estuary between Cape May and Cape Henlopen. The circulation of the estuary is driven by the tides; however, river flow will greatly influence the salinity of the estuary. With low river flow, the estuary becomes saltier; this can exert either adverse or positive effects on biological organisms within the estuary. Under high flow conditions, freshwater penetrates more deeply than normal into the estuary and causes sufficient layering of the water that may significantly increase biological primary production in the lower estuary.

The waters of the Delaware Estuary have normal dissolved oxygen concentrations north of the Philadelphia municipal build-up, a pronounced decline in the municipal region, and normal oxygen contents again throughout the lower estuary. The pronounced oxygen demand in the municipal region is due primarily to sewage-treatment-plant and industrial effluents. With these effluents there is also an increase in acidity of the water and a very large increase in nutrients, especially nitrogen. There is only a small increase of organic matter in the municipal region, indicating that the oxygen demand is largely from ammonium nitrogen. This is indicative of fairly effective primary-secondary sewage treatment.

A survey of the estuary for organic content of the water, suspended sediments, and bottom sediments does not show strong indication of man's influence. The Delaware Estuary is very turbid; that is, there is a very high loading of suspended material. The suspended material appears to come primarily from land erosion and resuspension of bottom sediments. The abundance of suspended material is probably, in part, due to three centuries of agricultural land clearing in the watershed. The suspended material is primarily fine clay minerals with a relatively low organic content. In the lower estuary, where organic content of suspended material is higher, the nature of the material is indicative of an aquatic origin. Therefore, it appears that the majority of the organic matter within the estuary is produced there biologically, as opposed to coming into the estuary from effluents, land runoff, or marshes.

Trace metals in the estuarine waters are at moderate levels and show behavior and apparent inputs indicative of natural processes. There are sufficient build-ups of trace metals in bottom sediments to indicate slight industrial and municipal influences in the upper estuary and adjacent to lower estuary tributary mouths. While prior gross pollution is not obvious, these sensitive indicators suggest that there is some pollution potential.

Primary production by microscopic algae in the Delaware Estuary is similar to that of other productive estuaries. About 90% of the total production is in the broad, saline lower reaches of the estuary. In spite of exceptionally high levels of nutrients (nitrogen, phosphorus, silicon) in the upper estuary, excess algal production, or eutrophication, does not occur. This is probably due to a combination of rapid flushing and high turbidity. Production at other levels of the food chain and apparent transfer through the food chain appear to consume most of the algal production so that the overall biological production of the estuary is high. This is especially true in the lower estuary where the major fisheries are found.

The principal shellfish harvested from the lower Delaware Estuary are oysters and blue crabs. The oyster industry, which has yielded up to two million bushels annually, has returned to a seemingly stable harvest of about 200,000 bushels per year after a decline in the late 1950s to almost zero. There is potential for an increase of the oyster harvest to double the current level as is indicated in this report. The blue crab fishery is quite variable from year to year, but appears to be healthy and capable of continuing without danger of decline.

The principal finfish of importance today in the lower Delaware Estuary is the weakfish. Weakfish are the primary commercial harvest with annual yields in hundreds of metric tons; they are often the primary sport fish taken. Shad, which were once abundant and had declined to very low levels, are returning in importance in the estuarine catch. Other species provide commercial and sport fisheries of value. Many of the finfisheries in the Delaware Estuary are probably capable of increased sustained yields.

POTENTIAL ROLES IN MANAGEMENT OF THE ESTUARY

The Delaware River and Bay Authority created by the states of Delaware and New Jersey with the approval of the United States Congress, came about from the need to coordinate transportation facilities for crossing the Delaware Estuary. In writing the DRBA charter, the authors, representing both states, envisioned the eventual assignment of extensive responsibilities, subject to the approval of both states. These latent responsibilities include the economic development of the region, and the planning, development, and operations of transportation and terminal facilities. Other responsibilities may be assigned under the terms of the compact; however, their definition in the charter is less explicit.

In suggesting potential roles for the DRBA in the management of the estuary, it is important to appreciate the distinction between activities for which the DRBA has clearly specified responsibilities, either present or latent, and those activities in which the DRBA could play a significant role, but which have been delegated wholly or partially to other agencies, thus creating areas of clouded or overlapping jurisdiction. Based on the collective judgment of the authors in this report, the following are suggested roles for the DRBA, in descending order of priority, ranging from the roles where the DRBA has clearly specified responsibility to those where jurisdiction may be shared with other agencies.

(1) The most prominent and immediate area in which the DRBA would play a useful role in the management of the estuary is in coordinating the planning and acquisition of scientific information needed to insure long-term economic development of the region. Through funding of the Delaware Estuary Project, the DRBA has already made a significant commitment to the support of environmental research in the Delaware Estuary. The support of the Delaware Estuary Project was given as a feasibility study of possible future roles for the DRBA. Since several of the potential duties revolve around management and development of the lower estuary, further environmental research is a critical part of such planning. For the DRBA to be granted the enlarged role suggested in this report, it is important for the citizens of Delaware and New Jersey to feel that the DRBA has been instrumental in developing a thorough understanding of the physical, chemical, and biological characteristics of the estuary prior to further development.

(2) Also the DRBA should become the convening agency to address a series of highly significant regional problems that focus on the use of the estuary and its bordering areas. Examples of such issues include maritime planning to maximize efficiency of ports and terminals on the river and bay; examination of the disposal of dredged spoil generated by the harbor and channel maintenance; advocacy for better coordinated and compatible environmental regulations; and advisement in fisheries management and development. The DRBA may play a useful role in such issues as water-quality overview and the promotion and development of fisheries in the estuary. These, however, certainly are areas of overlapping jurisdiction. For water quality, the Delaware River Basin Commission and the states of New Jersey and Delaware have broad authority. Fishery regulation is clearly assigned to the states of New Jersey and

Delaware, both of which are presently active in this area. Some of these planning activities could be undertaken without further legislation and some would require legislation. All these activities should be approached carefully and systematically to insure both the broad participation by interested and affected organizations, the publication of results in interesting and comprehensive formats, and the determination of where further authority requires legislation. In this way the DRBA would become a central bistate planning and development agency.

(3) Present oil transfer and proposed coal transfer in the lower Delaware Estuary would benefit from overview of an agency with both a clear understanding of the environment and the economic well-being of the bistate region. The DRBA should seek authorization to become the permitting agency for these transfer activities, which are outside the purview of the two states. Regulatory authority would remain with the two states for their respective waters. This role for the DRBA would require concurrent legislation in the states of Delaware and New Jersey.

(4) The next most logical role for the DRBA in management of the estuary concerns the use of the naturally sheltered deep channel in the lower bay as well as the central location of the estuary on the east coast of the United States. The importance of a national deepwater port employing these natural assets in the long-term economic well-being of the region and the nation can hardly be overestimated. No other location on the Atlantic coast offers such attractive attributes to promote efficient and economical intermodal shipping for the eastern half of the United States well into the 21st century. Exploration of this concept will require time for careful studies to insure rational development plans. Time will also be required to present information to the public and for the public to assimilate the information and understand its long-term consequences. A feasibility study could be undertaken without further authorization; for the DRBA to undertake major or detailed planning of a port would require further legislation.

The DRBA has a central role to play in the future of the Delaware Estuary. The DRBA should continue to support and coordinate the scientific studies of the estuary, now well begun but far from complete, by the University of Delaware College of Marine Studies and the New Jersey Marine Science Consortium with established assistance from the National Sea Grant Program and expected assistance from the National Ocean Service of NOAA. The DRBA should establish itself as a central planning and development force in the lower Delaware Estuary, working in close cooperation with appropriate federal, regional, state, county, and municipal organizations. The DRBA should seek authority as a permitting agency for cargo transfer (oil and coal) in the lower estuary. The DRBA should encourage consideration of the concept and explore the technical feasibility of a national deepwater port with its necessary infrastructure.

PREFACE

This report is separated into two parts that are designated, out of convenience, as science and management. The first part consists of 13 chapters encompassing the hydrography, chemistry, and biology of the estuary; it begins with an introductory chapter. The second part of the report consists of 6 chapters addressing potential roles for the Delaware River and Bay Authority on management of the Delaware Estuary; it also is begins with an introductory chapter. A single combined reference list is given after Chapter 19 that lists all cited references from the report. A total of 31 authors have contributed to the writing of this report. Each chapter indicates the appropriate authors at its beginning. In the acknowledgments section at the end of the report, the authors' affiliations are identified. Other people who have contributed to the research and to this report are also recognized in the acknowledgments.

The Delaware River and Bay Authority has been the major supporter of the Delaware Estuary Project. Other sources of funding are also identified in the acknowledgments. In addition to this report, research in the Delaware Estuary Project will lead to publications in refereed literature and to technical reports. These outputs are just now beginning and will continue into the future; the delay between finishing research components and final publication is usually between nine months and two years.

A number of abbreviations are used for scientific units, especially in the first 13 chapters. Those most used are listed on the next page as an aid. A number of governmental agencies, commonly abbreviated as acronymns, are also listed here as guide.

Glossary of Scientific Terms

Distance

m = meter (1 m = 3.28 feet)
km = kilometer (1 km = 1000 m, also written as 10^3 m)
nmi = nautical mile (1 nmi = 1.15 statute miles = 1.85 kilometers)

Weight

g = gram: ug = microgram (10^{-6} g), mg = milligram (10^{-3} g), kg = kilogram (10^3 g)
t = metric ton (1 t = 1000 kg = 2205 pounds)

Current and River Flow

cm/s = centimeters per second
knot = nautical mile per hour
m^3/s = cubic meter per second
ft^3/s = cubic foot per second

Chemical Concentrations

°/oo = parts per thousand (1 part in 10^3)
ppm = parts per million (1 part in 10^6)
ppb = parts per billion (1 part in 10^9)
mg/L = milligrams per liter
ug/L = micrograms per liter
mg/m^3 = millograms per cubic meter
uM = micromolar (1 uM = 10^{-6} molar = 1 microgram-atom per liter)
nM = nannomolar (1 nM = 10^{-9} molar)

Glossary of Government Agencies and Terms

CAFRA = Coastal Area Facility Review Act (New Jersey)
CZA = Coastal Zone Act (Delaware)
CZMA = Coastal Zone Management Act (Federal)
CZMP = Coastal Zone Management Program (Delaware, New Jersey)
DDO = Delaware Development Office (Delaware)
DEP = Department of Environmental Protection (New Jersey)
DNREC = Department of Natural Resources and Environmental Control (Delaware)
DRBA = Delaware River and Bay Authority (Regional)
DRBC = Delaware River Basin Commission (Regional)
DRPA = Delaware River Port Authority (Regional)
DVRPC = Delaware Valley Regional Planning Commission (Regional)
EIS = Environmental Impact Statement (Federal, State)
EPA = Environmental Protection Agency (Federal)
FCMA = Fishery Conservation and Management Act (Federal)
FWPCA = Federal Water Pollution Control Act (Federal)
FWS = Fish and Wildlife Service (Federal)

NEPA = National Environmental Policy Act (Federal)
NMFS = National Marine Fisheries Service (Federal)
NOAA = National Oceanic and Atmospheric Administration (Federal)
NOS = National Ocean Service (Federal)
NPDES = National Pollution Discharge Elimination System (Federal, State)
OCZM = Office of Coastal Zone Management (Federal)
OMBP = Office of Management of Budget and Planning (Delaware)
PPC = Philadelphia Port Corporation (Pennsylvania)
RCRA = Resource Conservation and Recovery Act (Federal
SJPC = South Jersey Port Corporation (New Jersey)
USACE = U.S. Army Corps of Engineers (Federal)
USCG = U.S. Coast Guard (Federal)
USGS = U.S. Geological Survey (Federal)
Wilmapco = Wilmington Metropolitan Area Planning Coordination Council (Regional)

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SCIENCE SECTION

INTRODUCTION TO SCIENCE CHAPTERS

J.H. Sharp

THE DELAWARE ESTUARY PROJECT

This report is the culmination of a study of the Delaware Estuary by researchers from the University of Delaware College of Marine Studies and the New Jersey Marine Sciences Consortium (specifically Princeton University, Rutgers University, Stevens Institute of Technology, and Lehigh University). The study has been called the bistate Delaware Estuary Project. It was initially funded by the Office of Sea Grant of the National Oceanic and Atmospheric Administration (NOAA); later, major support came from the Delaware River and Bay Authority (DRBA).

The proposal soliciting the funding was titled "Water quality, biological production, and management strategies for the Delaware Estuary." The major tenet of that proposal and the ensuing research is that the best stance for estuarine management decisions is sound scientific understanding of the specific estuary in question. To that end, our effort has addressed the question of "How does the Delaware Estuary work?"

Table 1-1 lists the original individual research components and principal investigators for the Delaware Estuary Project from September 1980 through April 1983 as specified in the contract (DRBA 1982). A portion of the project (University of Delaware chemical study, item F in Table 1-1) began as a

Table 1-1. Original components of Delaware Estuary Project.

SUBJECT	PRINCIPAL INVESTIGATORS	PERIOD
A. Oyster quality	Harold H. Haskin (Rutgers University)	1982-83
B. Meroplankton grazing	Richard A. Lutz (Rutgers University)	1982-83
C. Physical oceanography	George L. Mellor (Princeton University) Richard I. Hires (Stevens Institute of Technology)	1982-83
D. Macrozooplankton and mysids	Sidney S. Herman Bruce R. Hargreaves (Lehigh University)	1982-83
E. Mercury transformations	Richard Bartha (Rutgers University)	1982-83
F. Water quality and biological production	Jonathan H. Sharp Robert B. Biggs Thomas M. Church Charles H. Culberson (University of Delaware)	1980-83

preliminary study in 1978 and became a formal program with Sea Grant funding in 1980. The rest of the project began in 1982 with DRBA funding. Considerable work on oysters and environmental conditions in the Delaware Bay (Haskin's Rutgers oyster study) has gone on for several decades prior to formally becoming part of this project in 1982 (item A in Table 1-1). Continuation and expansion of some of the original components plus some new components are presently underway with Sea Grant funding. These new components include a study of dispersal and recruitment of blue crab larvae by C.E. Epifanio and R.W. Garvine of Delaware, a study of sport fishing economics by L.G. Anderson of Delaware, and proposed studies on larval and juvenile weakfish feeding and survival by C.E. Epifanio of Delaware and C.B. Grimes of Rutgers. The report gives results from the original research project and discusses some potential research necessary for a fuller understanding of the Delaware Estuary.

This part of the report addresses the "basic relationships between hydrography, chemistry, and biology in the Delaware Estuary so that major natural and man-induced changes can be anticipated and adverse effects minimized" (DRBA 1982). It contains twelve chapters in adition to this introduction, each on a major scientific research area of the Delaware Estuary, but stressing those more basic areas pursued in this original project. Thus, emphasis is on the hydrography and chemistry of the estuary with less information on the biology. Clearly, future research must put more emphasis on biological considerations. The chapters are not all uniform in size and do not necessarily represent equal levels of research effort. Some, where information was available, are based primarily upon historical information, others are based almost exclusively upon our research of the past several years, and still others principally discuss future research needs. In all cases, data and illustrations presented are from our research project unless otherwise indicated. Before presenting the findings of the scientific investigations, it is helpful to describe the Delaware Estuary.

THE DELAWARE ESTUARY

The Delaware Bay was discovered by western man in 1609 when Henry Hudson sailed into the mouth and found the bay too shallow to navigate. Prior to 1640, permanent colonies were established at the mouth and the head of the estuary (Eckman et al. 1938). In the ensuing three and one-half centuries, major industrial and municipal activities have become established along the upper estuary and agricultural development dominates the drainage basin of the entire estuary. Today the Delaware Estuary serves as the second largest port in tonnage in the United States (GTF 1972) and its drainage basin serves about 5% of the population of the country. The Delaware Estuary is heavily urbanized at its head (Philadelphia, Camden, Trenton, and Wilmington), yet supports important wetlands and fisheries at its terminus. Much of the demographic description and history are given in a previous report supported by the DRBA (URS 1980).

Figure 1-1 shows the Delaware Estuary relative to the east coast of the United States. The drainage basin of the Delaware River is indicated on the insert. The tidal region of the estuary runs from the fall line near Trenton, New Jersey, to the mouth of the Delaware Bay. This entire stretch of about 115 nautical miles (nmi) will be referred to as the estuary. The saline reach of the estuary runs about 65 nmi from a point south of Philadelphia, indicated by point 1 on the figure, to the mouth of the bay. The stretch from point 1 to Trenton will be referred to as the freshwater portion of the estuary. The lower estuary, or Delaware Bay, generally refers to the wide region, below Port Mahon at point 2 on the figure; a length down the center of about 30 nmi.

The Delaware Bay is the drowned river valley of the Delaware River and during mean flow conditions is essentially a vertically homogeneous estuary (Biggs 1978). The Delaware River at Trenton, New Jersey, has a mean flow of 320 cubic meters per second (m^3/s); the only major subtributary, the Schuylkill River contributes about 80 m^3/s; and all other gauged flows have a total input of under 40 m^3/s (Polis and Kupferman 1973). The total mean freshwater inflow to the estuary is estimated to be about 550 m^3/sec. A significant volume of the Delaware Estuary exchanges with the fresh- and saltwater marshes along its periphery. Ketchum (1952) has calculated that the cumulative flushing time for the Delaware Estuary is about 80 days. The estuary is rather simple; it has a single major source, the Delaware River, which receives urban and agricultural inputs and a single bay within which these inputs and saltwater mix.

The Delaware River Basin Commission (DRBC) has broad authority in the Delaware Estuary and has been involved extensively in maintenance of water quality in the freshwater portion of the estuary as well as the Delaware River above the fall line. A great deal of research has been done pertaining to river flow, salinity intrusion, and water quality in the upper estuary (e.g. see DECS 1966, Kneese and Bower 1968, and Albert 1982). While the DRBC has been very active in the upper Delaware Estuary, priorities and limited resources have restricted their activities in the Delaware Bay. As a result, much less is known about the Delaware Bay than about the freshwater portion of the upper estuary.

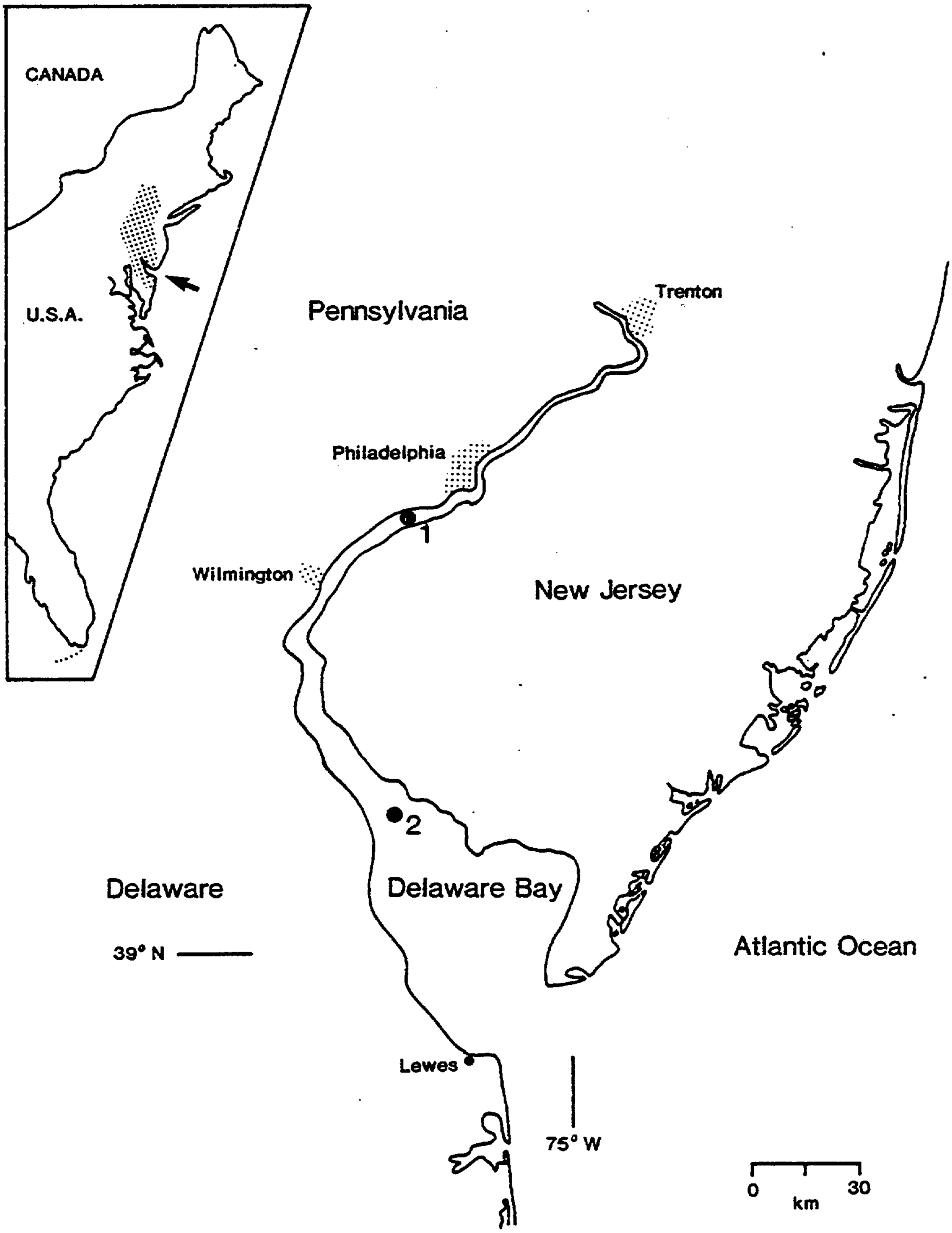


Figure 1-1. The Delaware Estuary, insert indicates location and shows the drainage basin (stippled area). The estuary extends from Trenton to the bay mouth, the saline portion runs from point 1 to mouth, and the Delaware Bay runs from point 2 to mouth.

The focus in the Delaware Estuary Project has been on the lower estuary, with major sampling efforts in either the entire saline portion (Figure 1-1, from point 1 to the bay mouth) or the bay (from point 2 to the bay mouth).

THE OCEANOGRAPHY OF THE DELAWARE ESTUARY

Technical aspects of water quality of the lower estuary are addressed in chapters 2 through 11 of this report. Lower estuary management must also address fisheries and thus technical background for fisheries is covered in chapters 10 through 13. A sound knowledge of how the estuary works is essential for management of transportation, waste disposal, or fisheries to occur with minimal environmental impact. Such knowledge is essential for the most efficient pursuit of planning and development activities suggested in the second part of the report. Thus, this first part of the report treats the various scientific aspects of the estuary that can be referred to holistically as the oceanography of the Delaware Estuary.

We have atempted to write these first 13 chapters so that they can be understood by a reader without much formal scientific background and also they can be informative to estuarine scientists. Obviously, some chapters are more descriptive and easily understood than others which treat more complex concepts. I note especially that chapters 2,4,7,12, and 13 may be on more familiar subject matter to the non-scientist reader and that chapter 3 treats a relatively complex subject.

Very little information was available on the oceanography (circulation, chemistry, and biology) of the lower Delaware Estuary prior to the Delaware Estuary Project. A great deal has been learned in a relatively short period of time. The project has completed the intended goals in the proposal submitted to the DRBA in January 1982. The information gathered in this project should be valuable to the DRBC as the present water quality manager of the upper estuary and to the Delaware Department of Natural Resources and Environmental

Control and the New Jersey Department of Environmental Protection as managers of both water quality and fisheries. It should also prove valuable to the DRBA in their present and potential roles in the Delaware Estuary.

Through accomplishing the proposed work, beginnings have been made on important future studies for the Delaware Estuary Project. Currently, some of these are partially funded by the Office of Sea Grant. As a result of the completed research, strong cooperation has been developed with major research agencies on the Delaware Estuary (divisions within the two states and the DRBC) and with the National Ocean Service of NOAA which has proposed circulation and bathymetric studies.

Our understanding of the Delaware Estuary has increased through the Delaware Estuary Project. Great potential exists for furthering our knowledge of the estuary that will guide better management and development of this very valuable resource.

Cited references for all chapters in this report are given in a composite reference list at the end of the report (after Chapter 13).

Chapter 2

RIVER FLOW AND SALINITY

J.T. Smullen, J.H. Sharp, R.W. Garvine, H.H. Haskin

INTRODUCTION

Salinity is an important environmental property that affects the distribution of fish, bottom-dwelling invertebrates, marsh, aquatic and marine plants, as well as some birds and mammals in and around the Delaware Estuary. Most of these organisms have a range of tolerance for salinity, or an optimum salinity. Some species of organisms can tolerate a wide range of salinities while others tolerate only a narrow range (Chezik 1981). When organisms are subjected to salinities near the limits of their natural tolerance, they undergo stresses that can adversely affect the rates and patterns of their growth, reproduction, and mortality.

The distribution of salinity in the Delaware Estuary has a direct effect on society through the salinity contamination of freshwater supplies for municipalities and industries. In 1979, 56 industrial and 5 municipal water supply systems in the Delaware Valley were withdrawing water either directly from tidal surface waters or from groundwater adjacent to the tidal system between Trenton and Artificial Island (WAPORA 1979). Large-scale pumping from groundwater supplies causes surface water to intrude into adjacent aquifers. This practice may increase the salinity of the aquifer if the recharge water is of higher salinity than the groundwater already stored there. For instance, at

Lewes, Delaware, saltwater contaminated the municipal well-field when the pumping rate was increased during World War II, forcing the town to seek a new supply (Marine and Rasmussen 1955).

The salinity of the upper Delaware Estuary is increasing steadily (Cohen and McCarthy 1962, Parker et al. 1964). This is probably due to a combination of the rise in sea level over time and the increasing consumptive losses caused by upstream withdrawals. The increase in salinity in the estuary caused the city of Chester, Pennsylvania, to abandon its local water supply in 1951 for a safer source (Parker et al. 1964).

This chapter describes the distribution of salinity in the Delaware Estuary and discusses the factors that affect salinity.

SALINITY DISTRIBUTION IN THE DELAWARE ESTUARY

Salinity is defined as the concentration in grams of the inorganic salts in 1000 grams of water. It is expressed as parts per thousand and written as $^{o}/oo$. Generally, it is assumed that chemically one can consider estuarine waters as dilute seawater. It has been recently demonstrated that this approach is indeed acceptable in the Delaware Estuary, where waters with salinity as low as $0.5^{o}/oo$ appear to be influenced very little by the chemistry of the river water (Sharp and Culberson 1982).

The salinity distribution in the tidal Delaware estuarine system is caused primarily by saltwater inflow from the adjacent Atlantic continental shelf and freshwater inflow from the upstream tributary drainage area.

The sea level of the ocean near Cape May and Cape Henlopen at the mouth of the bay is the main influence on the amount of saltwater entering the estuary. Salinity there is typically $30\text{-}31^{o}/oo$. Freshwater enters the system primarily from above the head of tide of the Delaware River (at Trenton, NJ) and from the Schuylkill River (at Philadelphia), and secondarily from smaller intermediate tributaries discharging to the tidal waters. Freshwater in the estuary dilutes the saltwater entering from the ocean. The concentration of salts in river waters is usually negligible relative to that in estuarine waters (Parker et al. 1964). Reported values for daily-averaged total dissolved salts in the estuary at Trenton, New Jersey, are less than 300 parts per million (0.3^{o}/oo).

The Delaware is generally considered a well mixed estuary and thus there is little sustained variation in salinity from surface to bottom. According to one classification system (Harleman and Ippen 1967) the degree of mixing in an estuary can be expressed by computing a functionally defined Estuary Number. Estuary Numbers greater than about 0.15 indicate a high degree of mixing. Under a typical freshwater inflow condition of about 572 m^3/sec (20,200 ft^3/sec) at the capes or 340m^3/sec (12,000 ft^3/sec) at Trenton, the Estuary Number for the Delaware is about 0.76 indicating that the estuary is well mixed most of the time (U.S. Army Corps of Engineers 1973).

Figure 2-1 shows typical differences in salinity variation for the upper, middle, and lower estuary. The upper most station near the Port of Wilmington exhibited salinities from 0 to 4^{o}/oo from May 1978 through March 1983. The most seaward point sampled at the capes also showed little variation; salinity there ranged from 28 to 31^{o}/oo. The middle estuary, represented here by data taken near Ship John Light, shows the greatest salinity variation over time with a range from 4 to 22^{o}/oo. Figure 2-2 shows this location as well as locations of several other geographic positions mentioned below.

The spatial variations of salinity in the estuary can be shown better by plotting the distribution of salinity in the estuary over a relatively short time. Figure 2-3 shows the longitudinal salinity distribution envelope for 20 individual periods sampled between May 1978 and March 1983. The envelopes are created by drawing two lines on the plot, one capturing the maxima of all values of the plot and a second plotted just below the minima of the plot. Also shown is the salinity distribution envelope for nine sampling periods between November 1951 and August 1954.

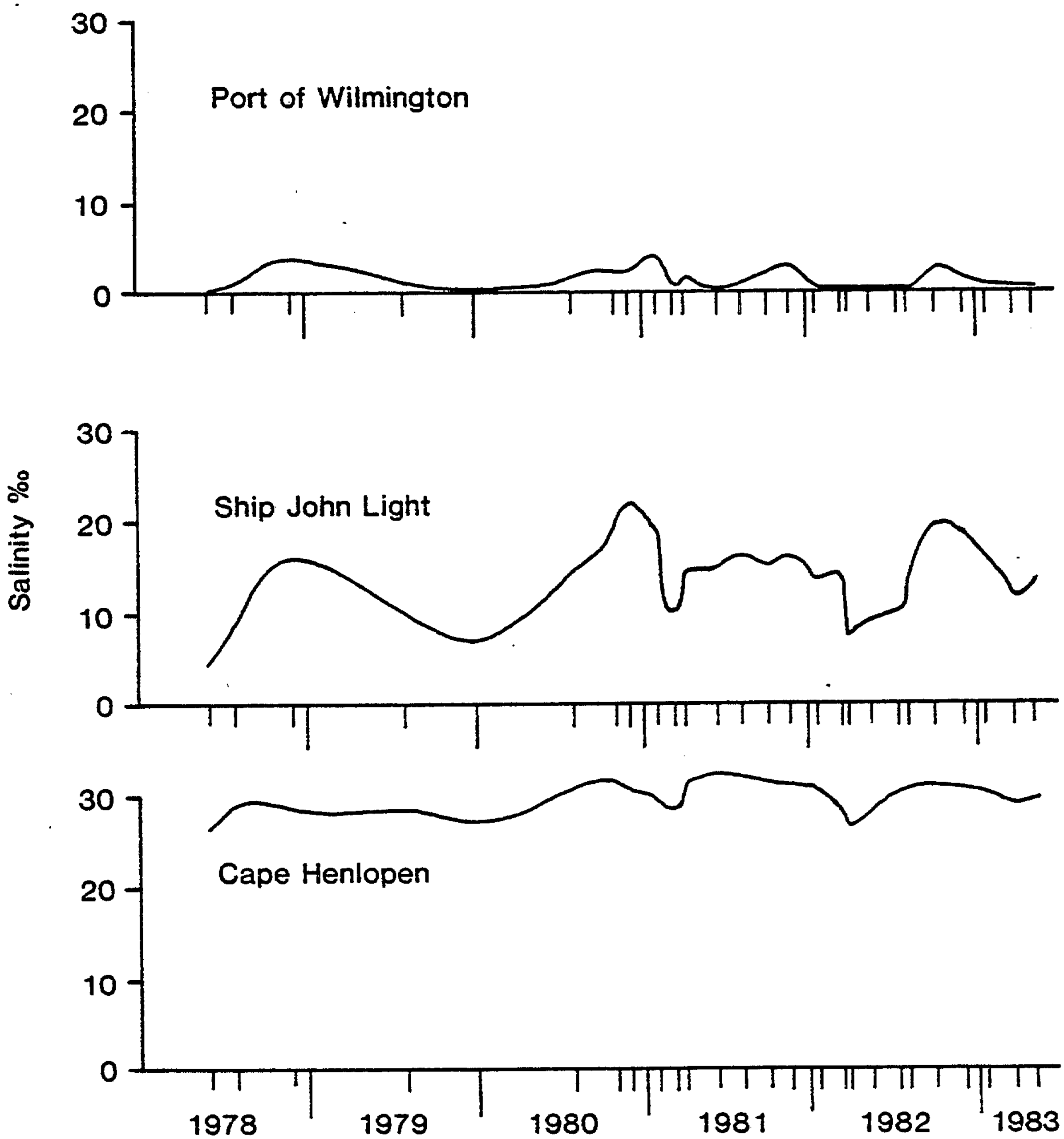


Figure 2-1. Typical differences in salinity variation over time for the upper (Port of Wilmington), middle (Ship John Light), and lower (Cape Henlopen) Delaware Estuary.

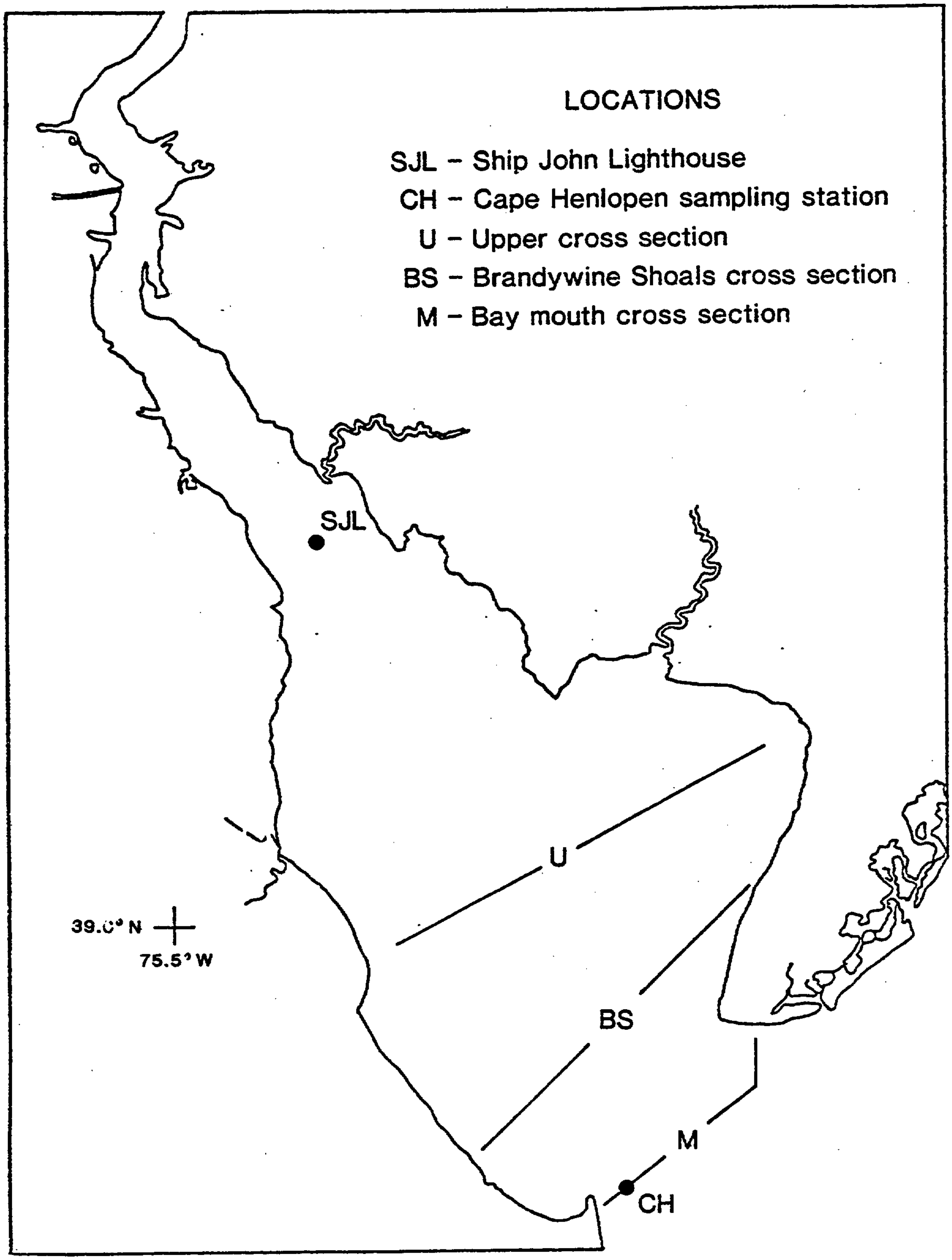


Figure 2-2. The lower Delaware Estuary showing locations indicated in other illustrations in this chapter.

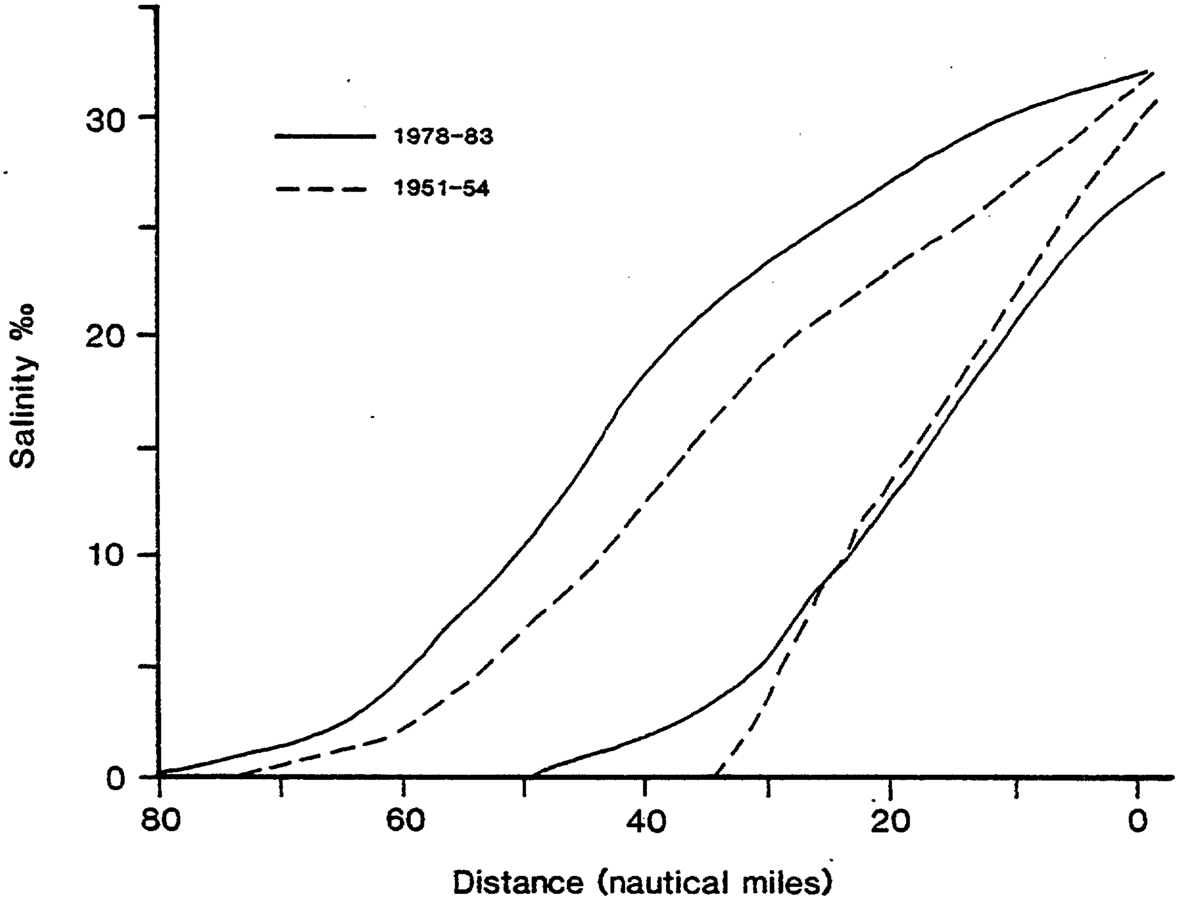


Figure 2-3. Longitudinal surface salinity distribution envelope for 20 periods between May 1978 and March 1983 and for 9 periods between November 1951 and August 1954. Distance measured from mouth of bay along central axis of the estuary.

It can be seen by examining Figure 2-3 that not only is there great variability in salinity as one moves up or down the estuary but also there is almost as much variability in the middle estuary at one place over a short period of time. However, over a 30-year period there is no obvious change in the overall salinity distribution.

Figure 2-4 shows the distribution of salinity vertically and laterally in a cross-section through Brandywine Shoal. Sampling was done in 1952 over the period of one month. Sections shown are composite pictures from samples taken near low tide. Figure 2-4A shows salinity distribution at a time of low river flow; the average flow at Trenton for the month preceding the sampling was 113 m^3/sec (4000 ft^3/sec). Figure 2-4B shows the distribution at a time of high

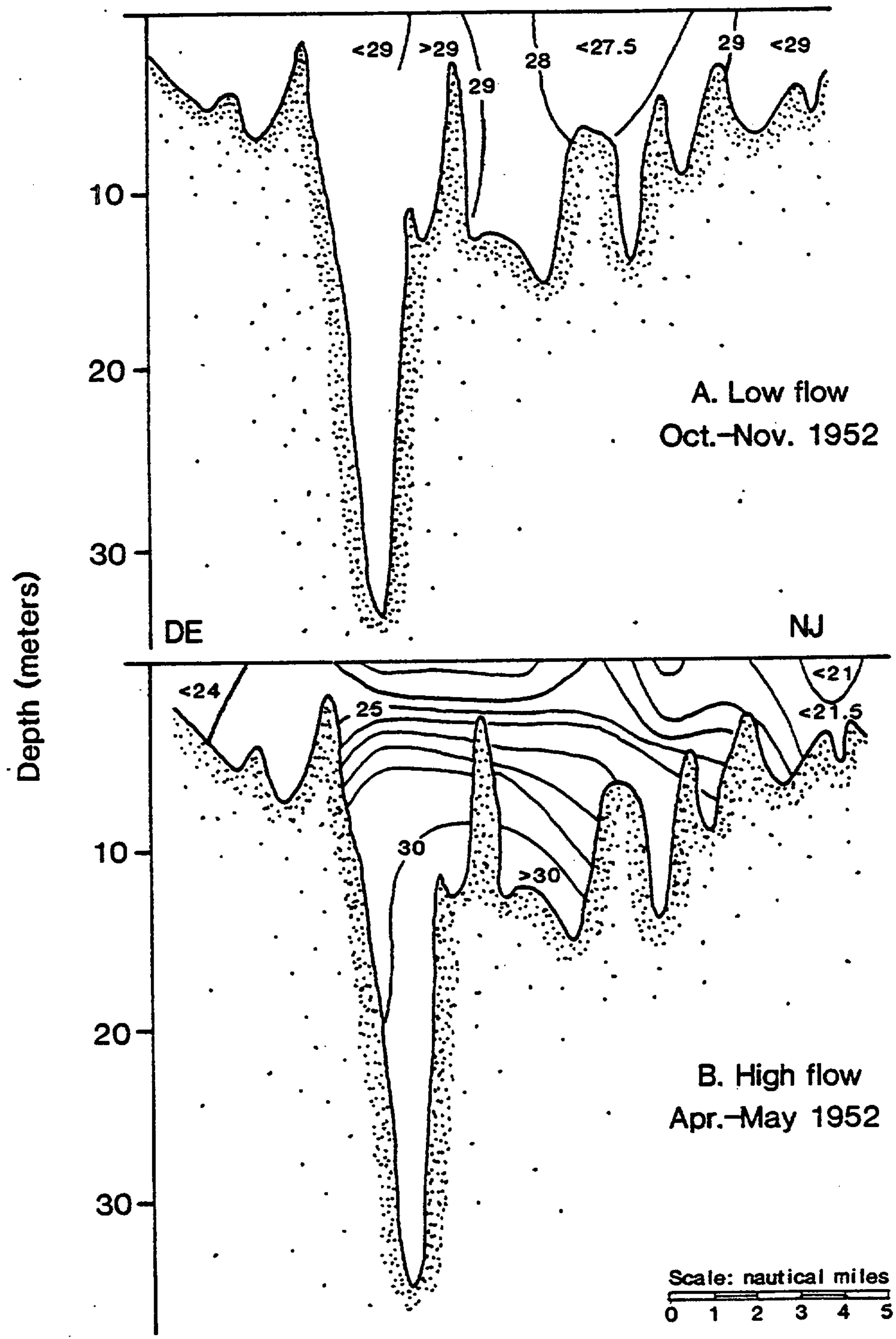


Figure 2-4. Cross sections of Delaware Bay looking upstream through Brandywine Shoal from composite of sampling at low water, isopleths of salinity (°/oo) shown. Data from Haskin, unpublished. Location indicated in Figure 2-2.

river flow (680 m^3/sec = 24,000 ft^3/sec). Note the very strong stratification under high-flow conditions and lack of stratification under low-flow conditions.

Recently electronic equipment has enabled us to gather data for such a section quickly. Figure 2-5 shows sections done in July 1982 and March 1983 at which time all the sampling was done in about eight hours. These sections are farther upbay from those in Figure 2-4. Figure 2-5A is from a moderate flow condition of 403 m^3/sec (14,200 ft^3/sec) averaged at Trenton 30 days prior and 2-5B is from a low-flow condition of 131 m^3/sec (4600 ft^3/sec). Again, significant stratification is obvious under high-flow conditions. The sections in Figure 2-5 depended on sampling done independent of the tidal cycle. Figure 2-6 shows salinity variations over one tidal cycle at the bay mouth during high-flow conditions. Considerable stratification sets up and then lessens with the alteration of tidal flow. Figure 2-7 is a cross-section across the mouth of the bay showing the salinity during both ebbing and flooding tidal stages.

Considerable variability is present with more saline waters near the New Jersey shore on flooding tide. This is common for estuaries on the east coast of the United States where higher salinity waters, which are more dense than freshwater, tend to be offset to the northerly shores. This is thought to occur because of forces exerted by the rotation of the earth. Other explanations for this phenomenon are possible, such as the longshore current pattern along the ocean coast (see Chapter 3). Ketchum (1952) observed that at certain times in the tidal cycle, salinities were higher on both sides of the lower bay spanning the deep channel than in the channel itself. Various investigators (Cohen 1957, Cohen and McCarthy 1962, Parker et al. 1964) have reported that salinity in the upper estuary above Reedy Point is, for the most part, laterally homogeneous.

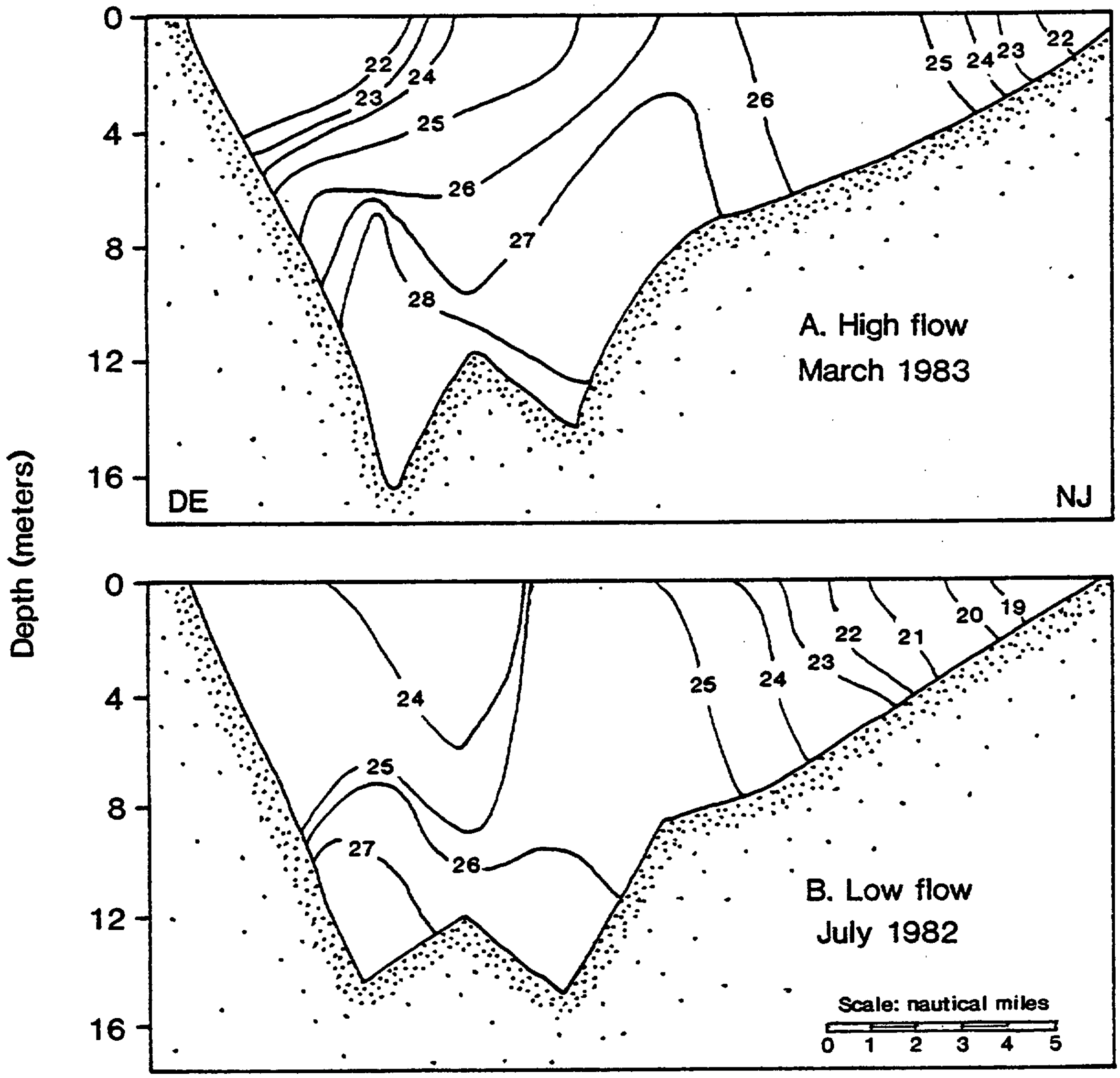


Figure 2-5. Cross sections of lower Delaware Bay looking upstream between Miah Maull and Brandywine Shoals, isopleths of salinity ($^{o}/oo$) shown. Location indicated in Figure 2-2.

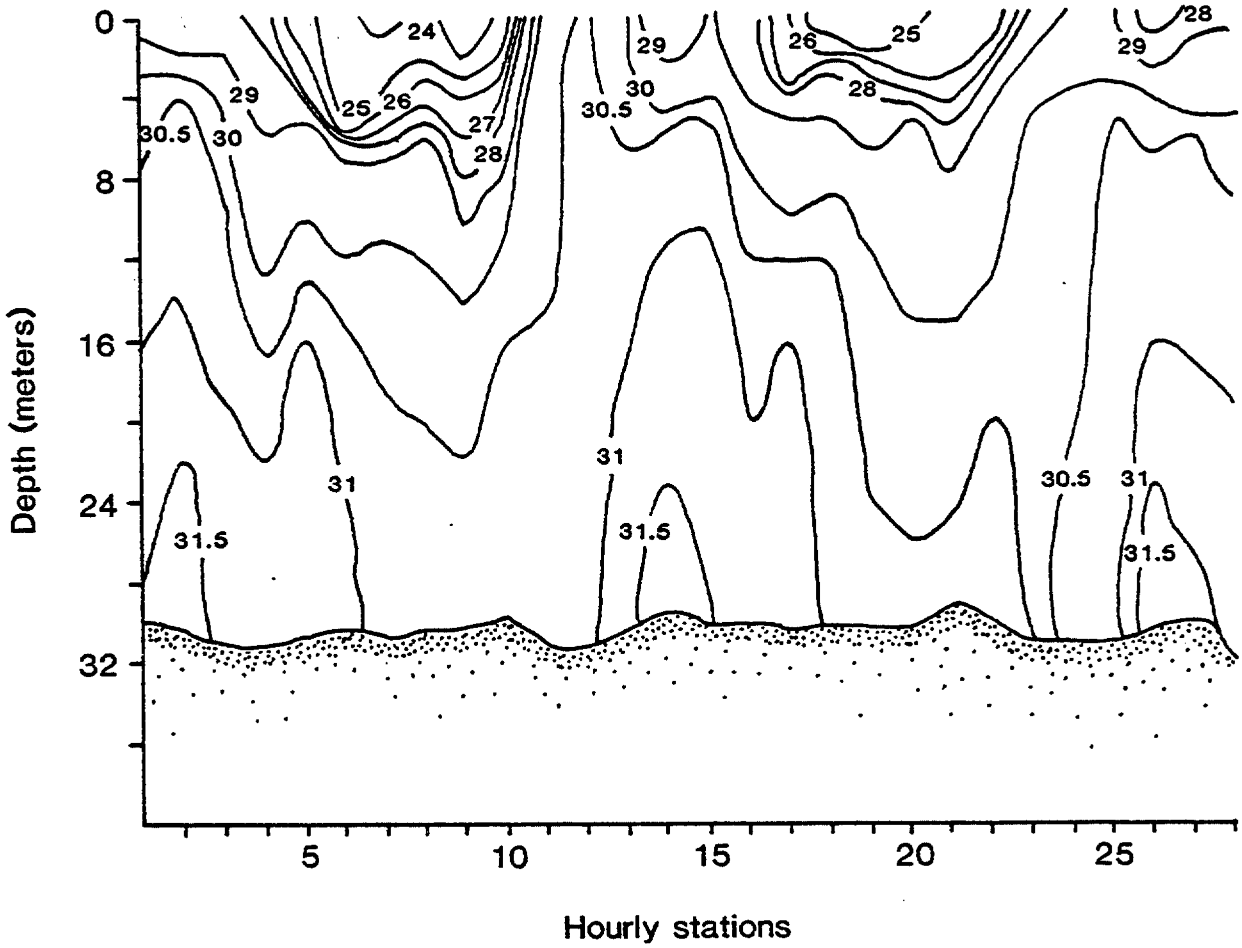


Figure 2-6. Salinity variations at the bay mouth over two tidal cycles during high flow conditions. (May 1982). Isopleths of salinity ($^{o}/oo$). Location is shown in Figure 2-2.

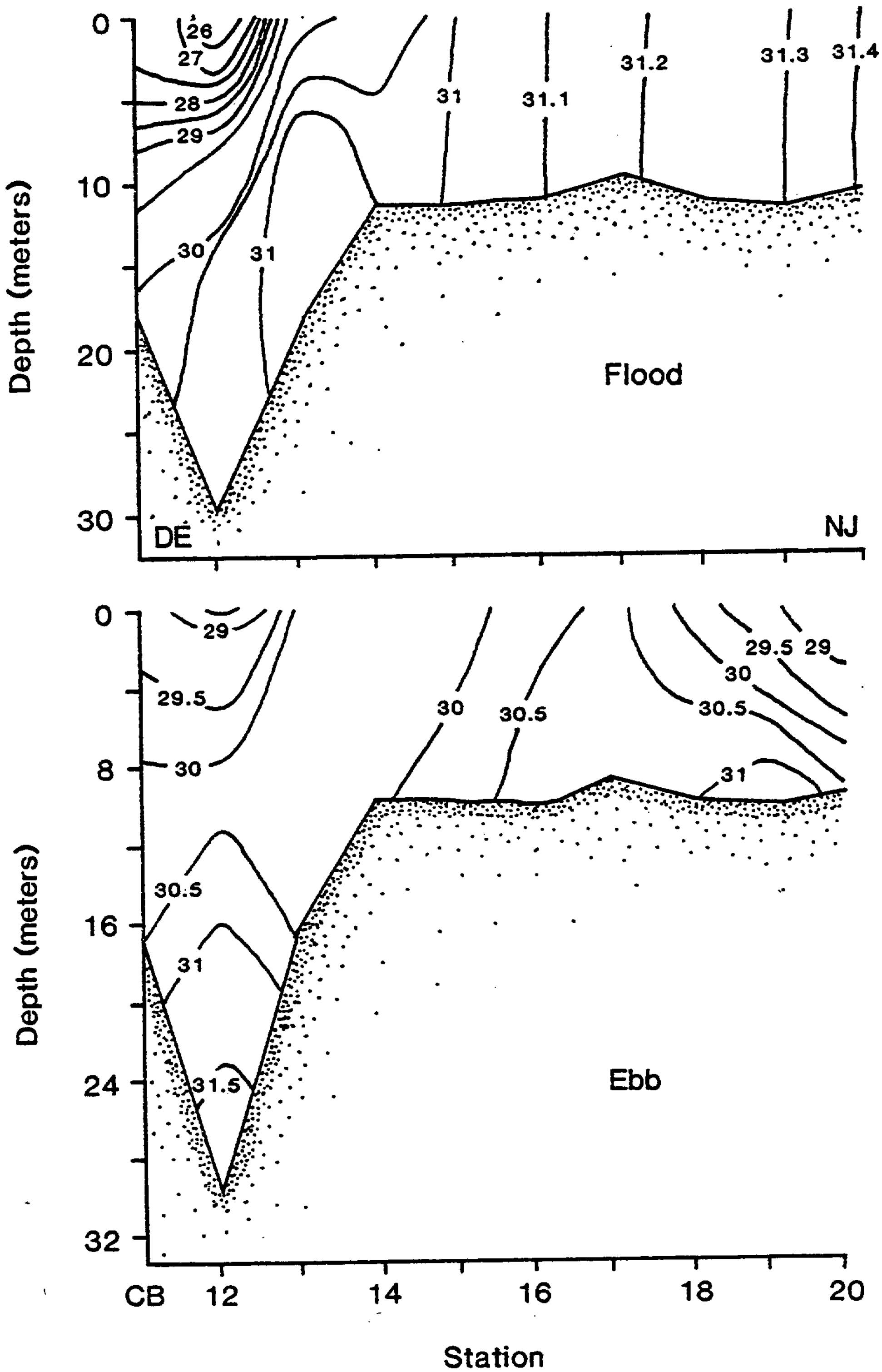


Figure 2-7. Cross section at mouth of the Delaware Bay during high flow conditions (May 1982) showing salinity (°/oo). Location is shown in Figure 2-2.

Table 2-1. Water inputs to the Delaware Estuary shown with distance as nautical miles upstream from the mouth of the Delaware Bay. Data from USACE (1973) except Delaware River (personal communication from R. Shop, USGS, Trenton, NJ).

Source	Distance	Drainage Area (km^2)	Average Annual Flow (m^3/s) (ft^3/s)
Delaware River at Trenton	115	17,560	319 (11,280)
Intermediate small tributaries	-	3,367	51 (1,800)
Schuylkill River at Philadelphia	81	4,944	78 (2,750)
Intermediate small tributaries	-	1,202	18 (650)
Christina-Brandywine near Wilmington	61	1,475	21 (750)
Intermediate small tributaries	-	4,514	63 (2,240)
Total at mouth	0	33,062	550 (19,470)

FACTORS THAT AFFECT SALINITY DISTRIBUTION

As previously mentioned, one of the most important factors that affects salinity is the freshwater inflow regime. The sources of freshwater inflow to the Delaware Estuary are primarily from drainage of the main stem of the Delaware River above Trenton and from the Schuylkill river at Philadelphia. Together, these rivers drain about 68% of the total 41,750 sq km (12,765 sq mi) terrestrial drainage of the estuary and carry about 73% of the total freshwater flow. Most of this drainage area lies in five physiographic provinces: the Appalachian Plateau, the Valley and Ridge, the Great Valley, the New England Upland, and the Piedmont. Other tributaries drain mostly Coastal Plain provinces. Table 2-1 shows drainage areas and average annual discharge for the major and small intermediate tributaries.

Table 2-2. Delaware River discharge at Trenton given as averages based upon the record from 1954-81. Data from R. Shop, USGS (Trenton, NJ).

Monthly Averages (m^3/s)			
Jan.	338	July	172
Feb.	366	Aug.	177
March	545	Sept.	162
April	603	Oct.	219
May	381	Nov.	282
June	246	Dec.	352

Seasonal Averages (m^3/s)	
Winter (Nov-Feb)	334
Spring (Mar-May)	510
Summer (June-Oct)	195

Annual Average (m^3/s)	
Oct-Sept	320

In general, large freshwater inflows push saline waters seaward, while low flow rates allow landward intrusion of salinity. Discharge of freshwater varies with season, typically greatest in spring because of the thawing of frozen surface water and near-surface groundwater and higher rainfall in spring, and decreasing through the growing season as soil moisture is taken up by plant evapotranspiration. The mean monthly discharges of freshwater for the Delaware River at Trenton are shown in Table 2-2. In addition to the mean monthly mean values, averages are given for three seasons; these are the three seasons used for analyses in chapters 5,6, and 10.

The distribution of salinity with distance up the estuary for extreme flow regimes was indicated by the salinity envelope in Figure 2-2. Figure 2-8 shows isohalines (lines of equal salinity) for an extreme flood and an extreme drought documented in the 1930s. Examination of Figures 2-3 and 2-8 clearly shows the longitudinal variability of salinity that occurs with freshwater fluxes.

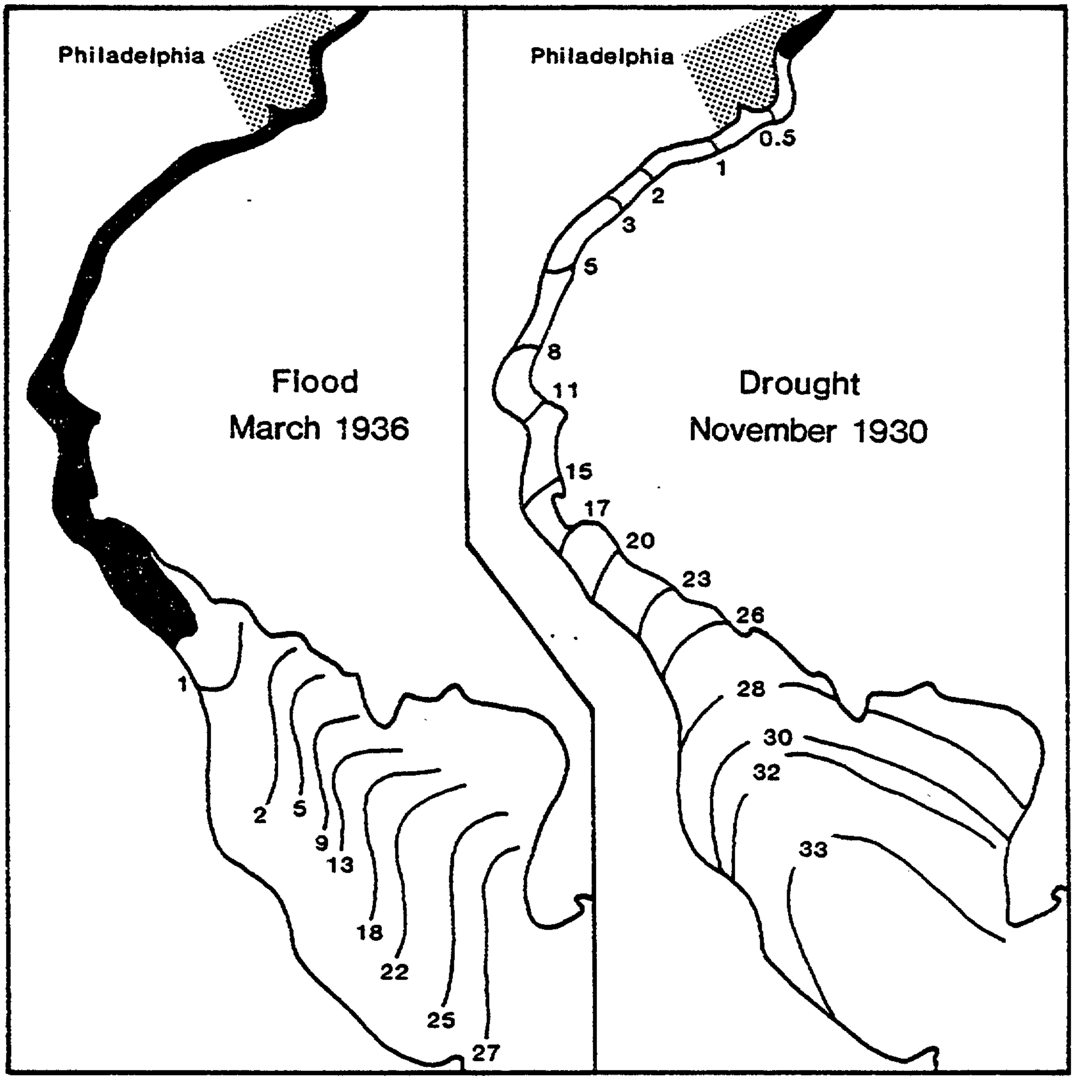


Figure 2-8. Isohalines (lines at equal salinity, °/oo) for an extreme flood and an extreme drought occurring in the 1930s (after Manson and Pietsch 1940).

During periods of low flow, the longitudinal salinity distribution is characterized by a small salinity gradient (i.e. a longer path from the bay mouth to the point of zero salinity in the estuary) and intrusion of high salt concentrations up the estuary. During periods of high flow, longitudinal salinity distribution is characterized by a large salinity gradient and extension of the point of zero salinity farther down the estuary.

Simply stated, saline waters are flushed out of the estuary during high freshwater flow conditions, and saline waters enter the estuary during low flow conditions. However, other factors must be considered with regard to freshwater inflow and its influence on salinity. The most important of these is the duration of the freshwater inflow. Another factor is inflow conditions before the period of concern.

Freshwater inflow also affects the vertical distribution of salinity. Cohen (1957) documented the response of the estuary above Reedy Island to the largest observed discharge event (70 years) on the Delaware, which resulted from two hurricanes that crossed the basin between August 12 to 19, 1955. The two hurricanes struck during a period of steadily decreasing freshwater flow and increasing upbay salinity intrusion. An estimate of the aforementioned Estuary Number for this flow condition yields a result of about 0.09, indicating a stratified system.

As freshwater inflow is the primary control of the dilution of salt in the estuary, sea level is the primary control of the supply of salt to the estuary. Periodic short term changes in sea level, caused chiefly by the tides, cause salinity distribution fluctuations that are periodic on the order of half a day. At any given point in the estuary, salinity varies from a maximum around the time of high-water slack tide, to a minimum around the time of low-water slack tide. At periods of a few days to a week, less energetic variations are found that are driven by the large-scale wind field. As Wang (1979) found for the lower Chesapeake Bay, persistent northerly winds tend to raise the sea level which causes water and salt to move up the estuary. Southerly winds cause water and salt to flow down the estuary to the sea.

Variations in freshwater inflow also produce salinity changes at still longer periods of a week to several months. Under sustained average flows, brackish water may extend up the estuary only 121 km (66 nmi) at high-water slack. During a prolonged dry period, however, salt may intrude as far as 177 km (95 nmi) (COE 1973).

Very long term changes in sea level cause similar long term trends in salinity intrusion. It is believed that in the past sea levels have been as much as 107 meters (350 ft) lower than present and at least 15 meters (50 ft) higher than present (Oostdam 1971). More recently, sea level rose about 0.1 meters (0.34 ft) in the 1930s and 1940s at an annual rate of about 0.006 meters (0.02 ft) (Marmer 1951). The overall sea-level rise in this region since 1930 was more than 0.15 meter (0.5 ft.), a rate which, if continued, will amount to a 0.61 meter (2.0 ft.) rise during the next century. As previously mentioned, the municipality of Chester lost its water supply in 1951, probably due in part to this sea-level rise (Parker et al. 1965). In the tidal areas just below Trenton, the observed maximum concentration of chloride during periods of low freshwater flow (Manson and Pietsch 1940) was only about half that of more recent observations (maxima of 40-50 parts per million chloride; Hull and Tortoriello 1980). If the sea-level rise continues as in the recent past, the salt front will intrude farther and increase the salinities in the municipal region downstream of Trenton beyond those appropriate for municipal and some industrial users (Parker et al. 1964).

CONCLUSIONS

The salinity in the Delaware Estuary is controlled primarily by the saltwater inflow from the adjacent Atlantic Ocean and the flow of freshwater from the Delaware River. Salinity ranges from almost zero near the Philadelphia municipal region to about $30^{o}/oo$ at the mouth of the bay (between Capes May and Henlopen). While the overall salinity range is fairly constant over time, salinity at any geographical point in the estuary, especially the middle estuary, can vary appreciably over a short period of time because of fluctuations in river flow. The Delaware is a relatively well-mixed estuary with no long-term vertical stratification; however, strong vertical stratification can occur for short time periods, especially in the high flow spring runoff period.

The salinity distribution at any one time can be seen as a fairly regular trend going down the axis of the estuary. There is, however, considerable variation in salinity latitudinally across the estuary. These latitudinal variations are ephemeral and influenced by fluctuations in tidal and river flow. To describe adequately the total salinity distribution picture requires a computer-based modeling approach rather than a more extensive monitoring program; this has been discussed in the previous chapter.

The ability to predict the distribution of salinity in the estuary is needed to accurately assess the consequences of impoundment and release of water in the upper portion of the drainage basin. It is imperative to appreciate the influence that controlled river flow has on salinity concentrations down the entire length of the estuary and on the stratification of the estuary.

Chapter 3

CIRCULATION OF THE ESTUARY

R.I.Hires, G.L. Mellor, L.Y. Oey, R.W. Garvine

INTRODUCTION

The circulation in the Delaware Estuary, as in most estuaries, is complex. It is dependent on astronomical tides, freshwater discharge, and meteorological effects. It will prove useful in the subsequent discussion of circulation in the Delaware Estuary to treat separately the tidal and subtidal parts of the overall circulation. Such separation is usual in estuarine studies.

Components of circulation are discussed in the first section followed by a discussion of tides and tidal currents, and then subtidal circulation in the Delaware Estuary. In the fourth section we briefly review the present and proposed studies of the circulation in the Delaware Estuary, with emphasis on the anticipated benefits that will be derived from this research.

COMPONENTS OF CIRCULATION

The currents driven by the astronomical tides are oscillatory; they flood upstream through the Delaware Estuary for about 6 hours, then reverse direction, and ebb seaward for about another 6 hours. The subtidal or residual currents may be defined initially as the average of the observed currents over one or more complete tidal cycles. Thus, the tidal currents represent an oscillatory motion superimposed on a tidally-averaged residual circulation. Typically, the amplitude of the tidal currents in Delaware Bay is an order of magnitude larger than the subtidal currents. For example, peak ebb and flood tidal currents can readily exceed 100 centimeters per second (cm/s), about 2 knots, at various locations throughout the bay while the subtidal currents would more likely have speeds in the range from 1 to 10 cm/s. Tidal currents may transport water 10 to 20 kilometers (km) during either the flood or ebb portions of the tidal cycle but by themselves they do not contribute to a net transport in the estuary. Such net movements are accomplished by the subtidal circulation.

It should be noted here that Coriolis effects caused by the earth's rotation and the interaction of the tidal currents with variations in bottom topography or shoreline geometry can give rise to a tidally-induced residual circulation. Other factors that contribute to subtidal circulation are freshwater discharge, local winds acting directly on the bay waters, and regional winds over the adjacent continental shelf waters. Both freshwater discharge and wind conditions are variable; thus, subtidal circulation should also exhibit variability as it responds to changes in these macroscopic boundary conditions imposed on the estuary.

In view of these introductory considerations a somewhat more precise differentiation between tidal and subtidal circulation can be developed. A long-term record of currents at any particular location in the estuary would reveal variations about the mean velocity over a wide range of time scales, or, in other words, the variance in current velocity would be spread over a range of frequencies. Because of the relatively large amplitude of the tidal currents, the major portion of the current velocity variance will occur at frequencies that correspond to the important tidal periods. In the Delaware Estuary, the predominant tidal constituent has a period of 12.42 hours. Periods of other significant constituents range from 12 to 25 hours. The variance at tidal frequencies can be removed from the record using a suitable low-pass filter. The filtered record would consist of the mean and the variance about this mean only at frequencies lower than the tidal frequencies, that is, at subtidal frequencies. The term subtidal (rather than mean or net) is used to characterize the residual circulation that remains after removal of the tidal currents.

TIDES AND TIDAL CURRENTS

There have been sufficient observations of the tides in the Delaware Estuary to enable a reasonably complete description of their chief characteristics. Polis and Kupferman (1973) provide a summary of tide observations in Delaware Bay. The National Ocean Service (NOS, formerly U.S. Coast and Geodetic Survey) provides daily tidal predictions at three locations: Breakwater Harbor, Reedy Point, and Philadelphia. The location of the two lower reference tide stations is shown on the map of the region in Figure 3-1. The NOS Tide Tables also provide tidal constants at over 60 other locations along the estuary. These constants serve to relate tidal conditions at these sites to the three reference stations.

The tide propagates through the Delaware Estuary from the ocean entrance between Cape May and Cape Henlopen to Trenton and exhibits some of the characteristics of a progressive, shallow-water wave. The high-water phase of this intruding tidal wave requires about 7 hours to propagate from Breakwater Harbor to Trenton. Interestingly, the low-water phase requires over 8.5 hours to traverse the length of the estuary. There are systematic changes in the amplitude and shape of the tidal wave with longitudinal distance along the estuary. There are also significant differences in the tide between the Delaware and New Jersey shores of the lower bay.

Tidal range is the difference in height between one high water and the preceding or following low water. The tidal range is not constant but exhibits significant diurnal, semimonthly, and monthly variations, because the observed tide represents a response to lunar and solar tide-producing forces of various known periodicities. The actual tide may be represented as the sum of constituent sinusoidal variations whose periods correspond to particular periods of the tide-producing forces. Harmonic analysis of the observed tide enables the amplitude and phase of these tidal constituents to be determined.

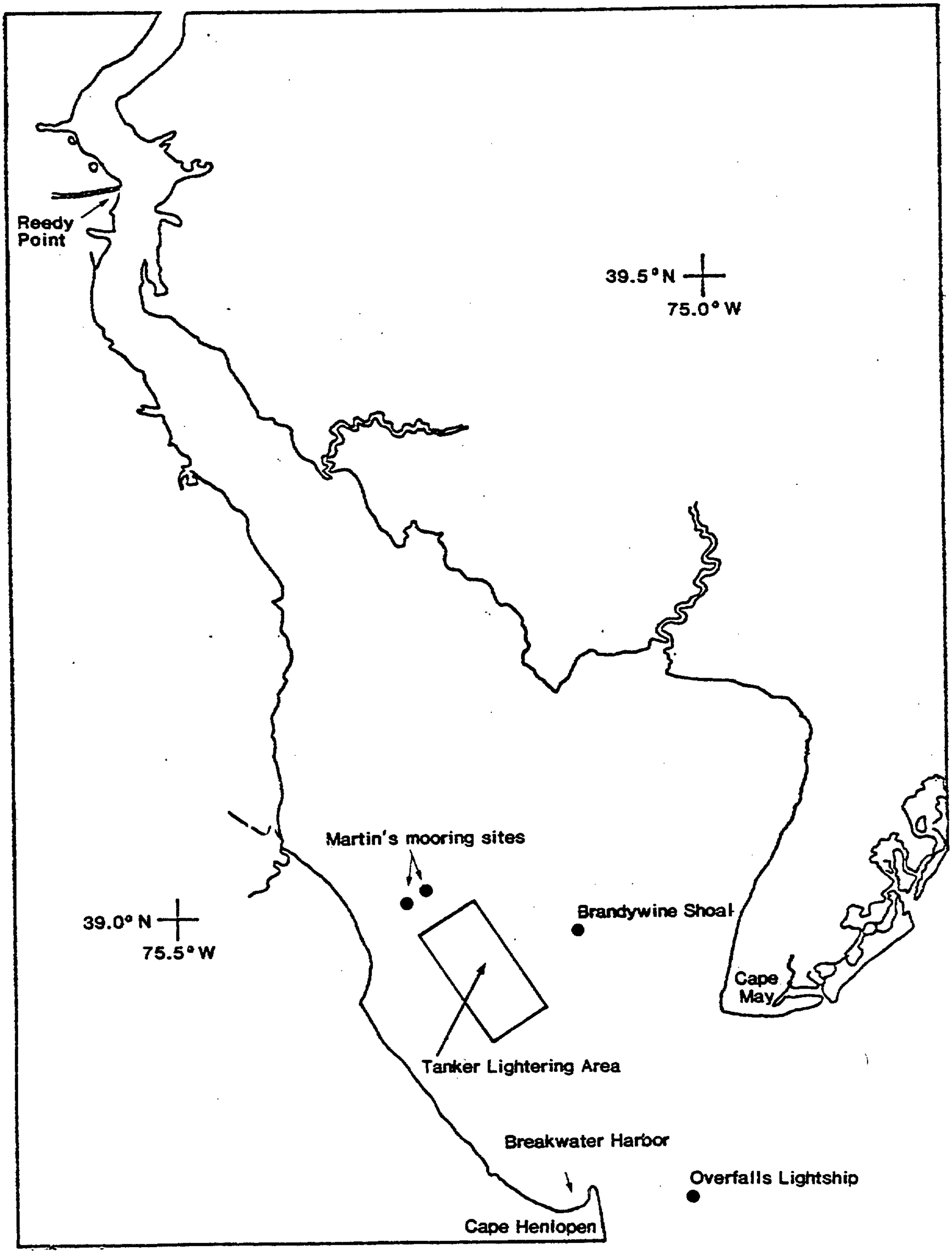


Figure 3-1. The Delaware Estuary with geographic locations discussed in text.

Table 3-1. Tidal constituents at Breakwater Harbor. The first three constituents (M_2, N_2, and S_2) are semidiurnal; the other two (K_1 and O_1) are diurnal.

Tidal Constituent Symbol	Name	Period (hours)	Amplitude (m)
M_2	Principal lunar	12.42	0.609
N_2	Larger lunar elliptic	12.66	0.134
S_2	Principal solar	12.00	0.115
K_1	Luni-solar	23.93	0.106
O_1	Principal lunar	25.82	0.086

The name, period, and amplitude of the five most important tidal constituents for Breakwater Harbor are presented in Table 3-1.

From Table 3-1 it is clear that the M_2 constituent is dominant. The effect of the diurnal constituents, K_1 and O_1 is to produce diurnal variations in the elevations of successive high or low waters. The interaction of the M_2 and S_2 constituents produces a modulation of tidal range over a 15-day period. When these constituents are in phase, the tidal range reaches a relative maximum or spring tide; when out of phase the range reaches a minimum or neap tide. The interaction of the M_2 and N_2 constituents produces a second modulation of tidal range over a 27-day period.

Thus, tidal ranges during successive spring or neap tides may differ substantially. For example, the NOS daily prediction at Breakwater Harbor for September 1980 showed two periods of spring tides. The first was centered about 10 September and the maximum predicted range on that date was 1.4 m (4.5 feet, ft). During the second period of spring tides 15 days later, the maximum predicted range was 1.9 m (6.2 ft). For the intervening neap tides the minimum predicted tidal range was just 0.9 m (2.8 ft). The variation in tidal range at the ocean entrance to the estuary, as illustrated in the foregoing example, produces a similar variation in the magnitude of the tidal currents; the ebb or flood current speeds are approximately proportional to the tidal range.

The average tidal range on both the New Jersey and Delaware sides of the entrance to Delaware Bay is 1.2 m. The tidal range generally increases with upstream distance through the estuary: at Reedy Point it is 1.7 m, at Philadelphia 1.8 m, and at Trenton 2.1 m. At comparable upstream distances in the lower bay, however, the mean range on the New Jersey side exceeds that of the Delaware side by as much as 0.3 m. This difference has been ascribed to the Coriolis effect (from the rotation of the Earth) by Polis and Kupferman (1973). These lateral differences diminish in the upper portion of the bay as its width decreases.

Two other features of the tide in Delaware Bay and River deserve brief mention. First, higher harmonics of the M_2 constituent become increasingly significant at upstream stations. For example, at Philadelphia the M_4 constituent (period of 6.21 hours) has an amplitude of 0.106 m and the M_6 constituent (period of 4.13 hours) has an amplitude of 0.047 m. These higher harmonics serve to distort the shape of the tidal curve. Second, channel improvements have produced substantial changes in tidal range. At Trenton the mean tidal range has nearly doubled between 1890 and the present. Conversely, the range at Marcus Hook has decreased by about 0.3 m during this time.

Tidal currents in the estuary represent the direct response to the changes in astronomical tidal elevation at the ocean entrance. As such, the variation in currents over a tidal cycle can be represented as the superposition of tidal constituents analogous to those described above for the tide. Serial observations of currents have been obtained by NOS at Overfalls Light Vessel at the entrance of the Delaware Bay for a sufficient length of time (369 days in 1940-41) to determine the amplitude and phase of the tidal constituents in the observed current. Table 3-2 shows the amplitude in knots of the five largest tidal constituents. Note that the M_2 constituent is again

Table 3-2. Constituents of the tidal current at the entrace of the Delaware Bay.

Tidal Constituent	Amplitude (knots)
M_2	1.661
N_2	0.295
S_2	0.253
K_1	0.130
O_1	0.059

dominant. The analysis of the Overfalls Light Vessel current observations for the amplitude and phase of the tidal constituents forms the basis for daily predictions of tidal currents at this location provided by the NOS Tidal Current Tables.

Tidal currents at other locations throughout Delaware Bay and River are predicted by use of tables that show the time differences between maximum currents (ebb and flood) and slack water relative to those at the entrace of the Delaware Bay, and ratios of peak ebb and flood currents relative to the peak currents at the entrance. The basis for establishing these tidal current differences are current measurements taken at these locations over periods of 1-4 days. The last comprehensive tidal current survey in Delaware Bay by NOS was performed in 1947. Some additional observations were made in 1953. A graphical depiction of the hourly distribution of near-surface (surface to 6.1 m) currents throughout a tidal cycle is provided by the NOS Tidal Current Charts.

Several general features of the tidal currents can be discerned readily from the NOS Tidal Current Tables and Tidal Current Charts. First, particular phases of the tidal current cycle, such as slack water, peak ebb, and peak flood, propagate upstream. For example, at a location one mile east of Reedy Point, the phase lag in the tidal current cycle is about 3.25 hours relative to Breakwater Harbor; near Philadelphia it is about 5.5 hours. There is also a phase difference across the entrance to the bay, with the current cycle in Cape May Channel leading that at Delaware Bay entrance by about 1.25 hours. In the lower bay there is significant lateral variability in the current strength. Peak ebb and flood currents are largest along the axis of the bay and decrease toward either side. For spring tides, the peak ebb and flood currents along the axis of the bay and river as far upstream as Bristol, Pennsylvania, range between 1.5 and 2.8 knots with values less than 2.0 knots occurring only in the wider portions of the lower bay.

Three concluding comments concerning tidal currents are pertinent to subsequent sections of this chapter. First, the number and geographic distribution of current observation stations in the estuary appear sufficient to provide an overall view of tidal current patterns. They fail, however, to resolve fine-scale variability in tidal circulation. Second, the predicted currents in either the NOS Tidal Current Tables or Charts for a particular location represent estimates of the expected real currents at that location. Thus, the effects of the subtidal component of the current are included in these predictions. Finally, the predictions of tidal currents are for average conditions of winds and freshwater discharge. Extreme events such as hurricanes can affect dramatically both the observed tidal elevations and currents.

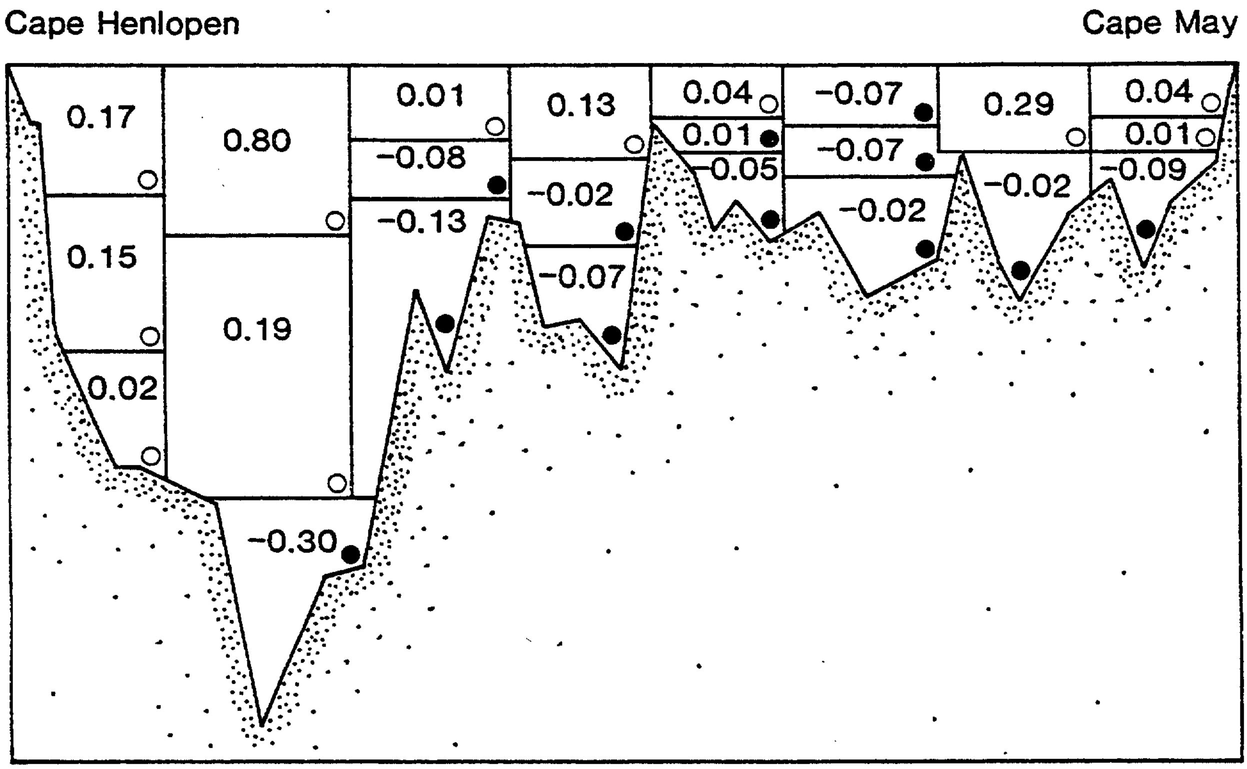
SUBTIDAL CIRCULATION

There are four components that may contribute to subtidal circulation in the Delaware Estuary: (1) a gravitational estuarine circulation driven by density differences between freshwater discharge into the estuary and intruding ocean water; (2) a tidally-induced residual circulation arising from the effects of variations in bottom topography, coastline geometry, and Coriolis force; (3) a local wind-driven circulation; and (4) a circulation driven by subtidal elevation changes at the ocean boundary, which reflects effects of wind variability over the adjacent coastal ocean region. In the following paragraphs each of these components will be briefly discussed together with available evidence for their importance in the Delaware Estuary.

The now classical studies by Pritchard (1952) served to establish the features of the estuarine circulation patterns expected in partially mixed estuaries such as the Delaware. The basic feature of this circulation is a net seaward flow of water in a near-surface layer of less saline water over a deeper inflow of higher-salinity water from the ocean. Tidal currents provide energy for mixing between these layers. The ratio of the volume flux in the upper layer outflow to the freshwater discharge depends inversely on the top-to-bottom salinity difference, i.e., if this difference is small relative to the upper layer salinity, the seaward flux may be an order of magnitude greater than the freshwater discharge rate. On theoretical grounds, Hansen and Rattray (1965) have shown that changes in freshwater discharge should lead to variations in the downstream estuarine circulation.

Polis and Kupferman (1973) have provided a crude estimate of tidally-averaged volume transports at the ocean entrance to Delaware Bay. Data for this computation were drawn from NOS current meter observations in May and June of 1947 and 1953. Figure 3-2 shows the general pattern of net ebb and flood transports. As expected, there is a net outflow of water in the upper layer throughout most of the transect, except for a relatively small segment toward the Cape May side. There is a near-bottom inflow of water, except in the immediate vicinity of Cape Henlopen.

The departures of the observed transport pattern from the simple two-layered estuarine circulation model may possibly be ascribed to Coriolis effects. It has been found, however, in model studies of New York Harbor (Oey et al. 1983) that variations in coastal geometry and bottom topography can produce at the ocean entrance a tidally induced residual pattern, in the absence of Coriolis effects, with a net inflow on the right-hand side (looking upstream), and a net outflow on the left-hand side similar to that suggested for Delaware Bay in Figure 3-2 . It is interesting to note that the calculated total volume flux entering the bay during the flood half of the tidal cycle is 1.9 x $10^5 m^3/s$, about 300 times larger than the average freshwater discharge into the estuary. The calculated net outflow through this section is about 40 times larger than the freshwater inflow. This latter



result agrees with the previously expressed expectation for the magnitude of circulation in the estuary. The very small ratio of river discharge to tidal volume flux minimizes top-to-bottom salinity differences in the bay.

Further evidence of estuarine circulation throughout Delaware Bay has been provided by an extensive surface and seabed drifter study performed by Pape and Garvine (1982). Apparent drifter trajectories were determined and the mean water velocity at each station was computed for each release experiment.

Figure 3-2. Tidally-averaged volume transport through the mouth of Delaware Bay shown with positive numbers indicating transport out of the bay and negative numbers indicating transport in. Transport is an estimate of mean volume flux in units of 10^4 cubic meters per second. Adapted from Polis and Kupferman (1973).

A slight digression at this point is appropriate to distinguish between Lagrangian and Eulerian mean velocities. Lagrangian mean velocity can be inferred by averaging the movement of passive drifters; Eulerian mean velocity represents the time average at a particular location, which could be determined by averaging current meter records. It suffices here to note that the two velocity fields in Delaware Bay may differ. The velocities derived by Pape and Garvine are Lagrangian mean velocities and correctly describe the transport of material through the estuary.

Pape and Garvine found seven features of the mean velocity distribution that illuminate the character of subtidal circulation.

(1) Surface velocities in Delaware Bay are generally directed seaward. There is a persistent deviation in the direction of current toward the Delaware side of the bay. This deflection could be caused by the Coriolis force.

(2) Surface current speeds in the bay increase with distance downstream, which is to be expected for estuarine circulation in partially mixed estuaries. Mean speeds near the bay mouth were about 10 cm/s.

(3) For the stations at the bay mouth and on the continental shelf, mean surface currents were generally directed to the south. Surface current speeds at the shelf stations were consistently greater than at the bay stations.

(4) The near-bottom mean currents at all shelf stations were directed onshore. The seven stations off the bay mouth, located up to 40 km offshore, showed that bottom currents converged to the mouth. For the station to the north of the mouth and 10 km off the New Jersey coast and for another station just 8 km offshore from the Delaware-Maryland border, the bottom currents were directly onshore. The significant offshore extent of an estuarine-type circulation suggested by these results has important implications for the development of numerical models of this circulation.

(5) The magnitude of the near-bottom mean velocities was generally less than 10% of the surface speeds at all stations. This result differs from long-term current meter records obtained by Martin (1978) in the lower bay just north of the Tanker Lightering Area. Martin reports mean speeds of nearly 7 cm/s at a height of just 2 m above the bottom; however, these were Eulerian mean velocities.

(6) Within the bay, the mean bottom currents exhibited a marked tendency to be directed toward the nearest shoreline. For stations on the Delaware side of the deep channels, the bottom currents were directed toward the Delaware shoreline, and a similar pattern was found at stations on the New Jersey side of the ship channel.

(7) Pape and Garvine found significant correlations between wind stress over the coastal region during each of their drifter release experiments and the return rate and calculated mean speeds for both the surface and bottom drifters. Similar correlations with variations in freshwater discharge were not found to be significant. A tentative conclusion is that the effects of wind-forcing on subtidal circulation is considerably more important than variability in freshwater discharge.

What emerges from the work of Pape and Garvine is a picture of subtidal circulation in the Delaware that consists of classical gravitational estuarine circulation, modified to some extent by Coriolis effects, and on which winds can induce a substantial variability. The significance of wind-forcing on subtidal circulation in estuaries has become increasingly apparent in recent years from the analysis of long-term current observations. For Delaware Bay, the only long-term current meter observations that allowed statistical analysis of the impact of winds on the subtidal circulation are those reported by Martin (1978). These observations were at just one location in the lower bay; thus, there is a complete lack of direct field data to reveal the spatial distribution of circulation as it responds to winds. Nevertheless, Martin's results clearly reveal the significance of winds; a summary of his analyses will be provided below. It is useful to consider first, however, the nature of local and regional wind-forcing.

The surface wind stress associated with local winds over the estuary transfers momentum from the wind to the water. Wind-induced near surface current speeds may be on the order of 1 to 3% of the wind speed. For example, a 10-knot wind could induce surface currents with speeds of about 0.1 to 0.3 knots. The local wind-induced current speeds diminish substantially with depth.

An important aspect of local winds over semi-enclosed bodies of water such as the Delaware Estuary is the establishment, by virtue of wind-driven transports, of differences in longitudinal and/or transverse surface elevation. The combined effects of direct wind stress and elevation gradients drive wind-induced residual circulation. Clearly, variability in the winds will contribute to variability in local wind-forced circulation.

A second component of wind-induced circulation arises from the effects of regional winds over the continental shelf adjacent to the Delaware Bay entrance. The chief feature of shelf circulation, which results from a wind component parallel to the coastline, is an along-shelf transport in the same direction as the wind component, on which a less intense cross-circulation is superimposed. The transport component for near-surface waters is to the right of the wind and for near-bottom waters to the left. Depending on its direction, a cross-shelf wind component will either intensify or diminish these cross-shelf transports. For the roughly north-south orientation of the New Jersey and Delaware coasts, a wind toward the north would move surface waters offshore and bottom waters onshore; for winds toward the south, these transports are oppositely directed.

Onshore transport of surface shelf water would raise the sea level at the Delaware Bay entrance, but offshore movement would lower it. Variability in winds over the shelf therefore would produce subtidal elevation changes at the ocean boundary of the estuary that, in turn, would affect net transport through the estuary. These elevation variations at the downstream boundary, generated by regional wind systems over the shelf, may produce a more pronounced effect on subtidal circulation in Delaware Bay than the direct effect of local winds.

Martin (1978) demonstrated the importance of wind-forcing on subtidal circulation in Delaware Bay via statistical analyses of concurrent wind, freshwater discharge, and current observations in lower Delaware Bay. The current velocity data used by Martin consisted of current meter records from either two or three meters on a single mooring, obtained on four occasions over a two-year period with record lengths ranging from 33 to 40 days. The mooring sites for these observations are shown in Figure 3-1. Wind data were obtained during 3 of the 4 observational periods from an anemometer mounted 10 m above the mean water level at Brandywine Shoal. Freshwater discharge rates into the estuary were obtained from U.S. Geological Survey data for the Delaware River at Trenton, the Schuylkill River at Philadelphia, and Brandywine Creek at Chadds Ford, Pennsylvania.

The coupling between variability at various time periods in either the winds or freshwater discharge and variations in observed currents was investigated using cross-spectral analyses and the evaluation of transfer functions. One result of cross-spectral analysis is coherence, a measure of the degree of correlation between two records as a function of frequency. From Martin's analysis, the coherence between wind and currents was statistically significant for several frequency intervals; the strongest response of the currents to winds occurred at frequencies corresponding to period ranges of 1.5-2 days, 2-4 days, and 5-7 days. The coherence levels were generally less for the analysis of the effect of Delaware River discharge on currents, but statistically significant at several frequencies. Coherence between the Schuylkill River discharge and currents was not statistically significant at any frequency.

Martin developed a simple statistical model for the prediction of current variability at subtidal frequencies as a response to wind and freshwater discharge. The inputs to the model were the time histories of the east-west and north-south components of the observed wind and the Delaware River discharge. The outputs were the components of longitudinal and transverse current velocity. Transfer functions, representing the frequency-dependent gain and phase for the current response of the model inputs were derived from spectral analysis of the observations obtained from October to November 1974. These transfer functions were then applied to wind and discharge data obtained from July to August 1976 in order to compare model predictions with the observed currents during this time. Figure 3-3 shows the results of this comparision. Except for some shift in phase, the predicted subtidal current variability agrees remarkably well with the observations. It should be noted that the characters of the wind and discharge data were significantly different during these two periods. For example, the 1976 observations included the passage of Hurricane Belle through the region. No comparable wind event occurred during the 1974 observations.

One conclusion to be drawn from Martin's results is that subtidal circulation, at least in the lower part of Delaware Bay, responds more vigorously to winds than to variations in freshwater discharge. It is not possible from Martin's result, however, to distinguish between the effects of local and regional wind-forcing. A second conclusion is that there is substantial variability in subtidal circulation. Thus, efforts to predict net transports in the estuary must address both long-term average currents and short-term variations about these averages.

The final component of subtidal circulation to be described in this section is that due to tidally induced residual currents. For this discussion, results from present research in the Delaware Estuary provide the basis for a far more comprehensive overview than is available for the other components of the subtidal circulation. The first phase of our study has focused primarily on the development of a vertically averaged numerical model for the prediction of tides and tidal currents with high spatial resolution throughout the entire Delaware Estuary and at reduced spatial resolution for the adjacent continental shelf. The initial intent was to develop two models, one at coarse resolution to study the bay and shelf, and a second at much finer resolution for the bay and river. It has been possible, however, to produce a combined model with variable computational grid-spacing to model simultaneously both the entire estuary and the adjacent shelf region with appropriate spatial resolution.

Figure 3-4 is a map of the bay and adjacent continental shelf region which shows the outline of the model domain (area to which the model is applied). Within Delaware Bay, the horizontal computational grid is 1 km by 1

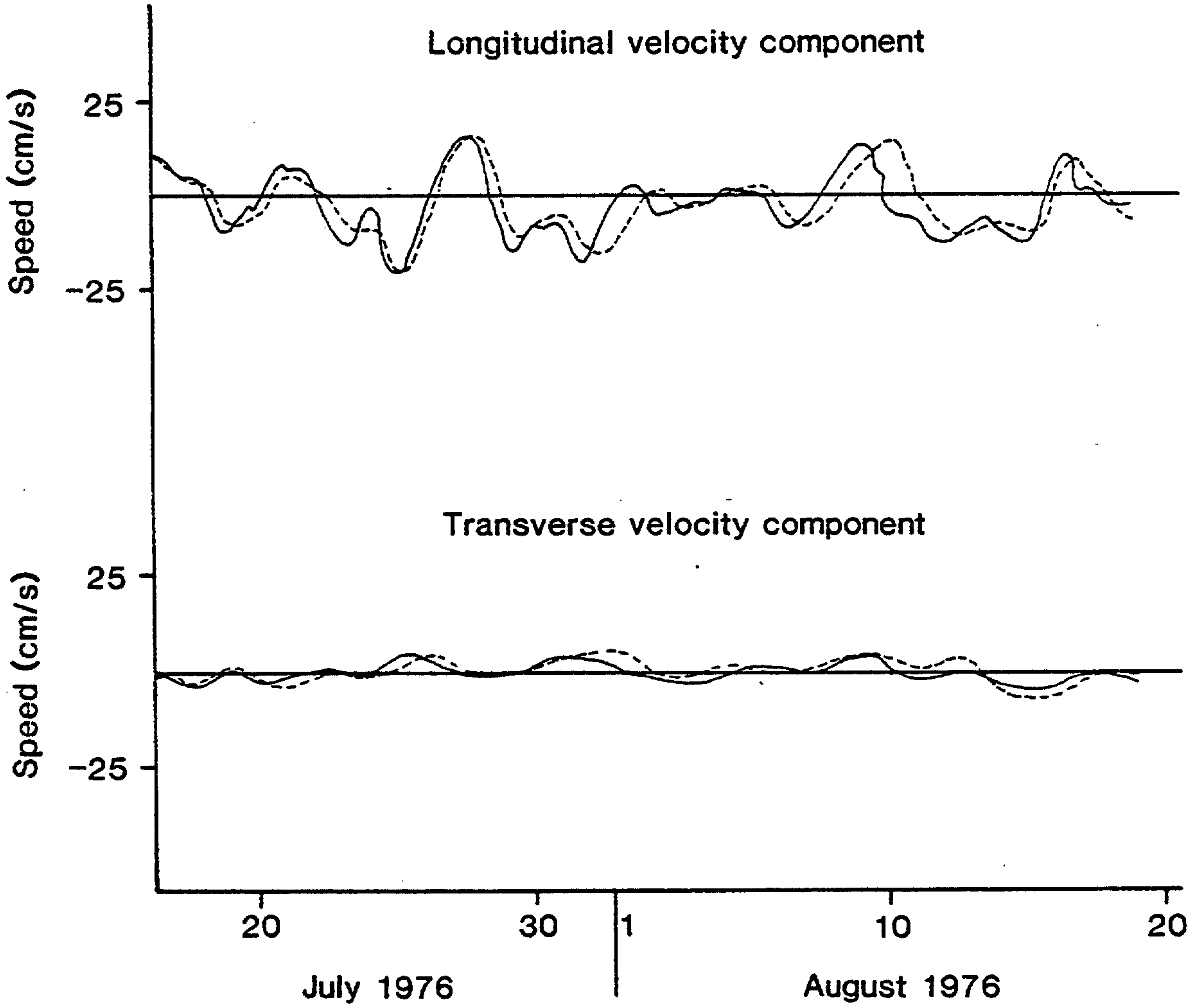


Figure 3-3. Comparison of predicted (dashed line) and observed (solid line) subtidal currents. Adapted from Martin (1978).

km; on the shelf the grid is 3 km by 4 km. Thus, by using this combined model, we can achieve the desired horizontal resolution over both the bay and shelf regions. The computer time required to run the combined model is substantially less than that required to run the two models sequentially. Moreover, the combined model removes the problem of requiring great detail in defining the boundary conditions at the bay mouth that were inherent in the original fine scale model. A further advantage of the combined model is that it enables the investigation of shelf-bay exchange processes, which, according to the results of Pape and Garvine (1982), extend at least 40 km offshore.

An initial series of calculations has been made with the combined model to investigate solely the effect of tidal-forcing on subtidal circulation in the estuary. To achieve this, river discharge was set equal to zero and there was no applied wind stress. The imposed open-ocean boundary condition was the M_2 tidal constituent with an amplitude of 45 cm. The model was run for a sufficient number of tidal cycles to achieve equilibrium. The tidally induced depth-averaged residual currents were then calculated by averaging over one complete tidal cycle. The distribution of these currents in Delaware Bay is shown in Figure 3-5.

A striking aspect of this tidal residual circulation pattern is its complexity. In the lower portion of the bay there is an alternation of seaward and landward currents that appears to correlate with alternations in deep and shoal water. In the upper portion of the bay there are several eddies that further complicate the residual circulation.

At the site of Martin's current meter moorings, the computed tidal residual velocities have a component directed upstream along the longitudinal axis of the bay and a transverse component directed toward the Delaware side of the bay. The computed current speed at this site is about 2 cm/s. An estimate of the depth-averaged Eulerian mean current velocity at this location can be obtained from Martin's results; this observed velocity is directed similarly to the computed velocity. Its magnitude is about 3.5 cm/s. We suspect, therefore, that a substantial fraction of the observed mean velocity at this location may be attributed to tidally-induced residual circulation.

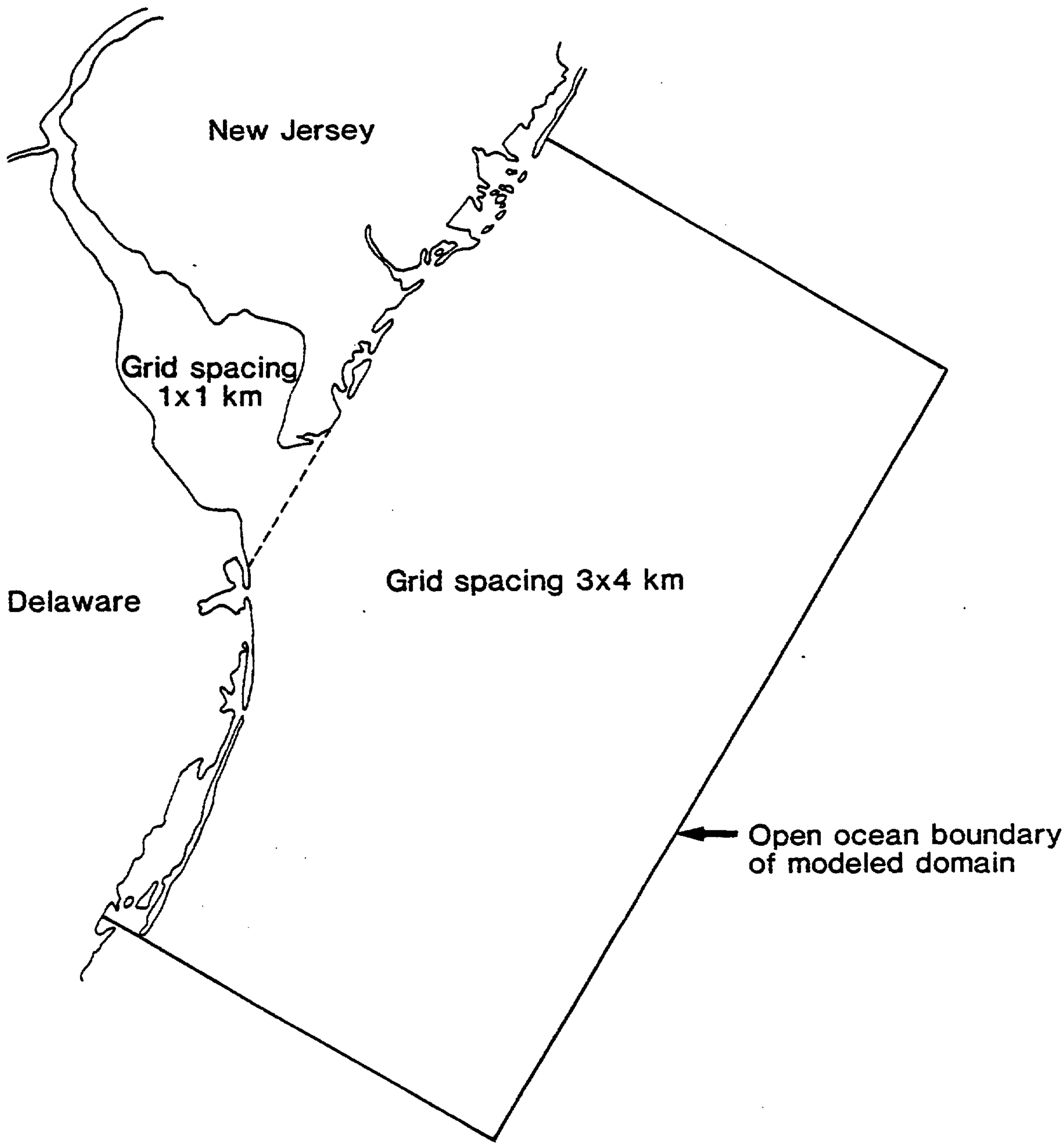


Figure 3-4. Delaware Bay and continental shelf model domain (area to which the model is applied).

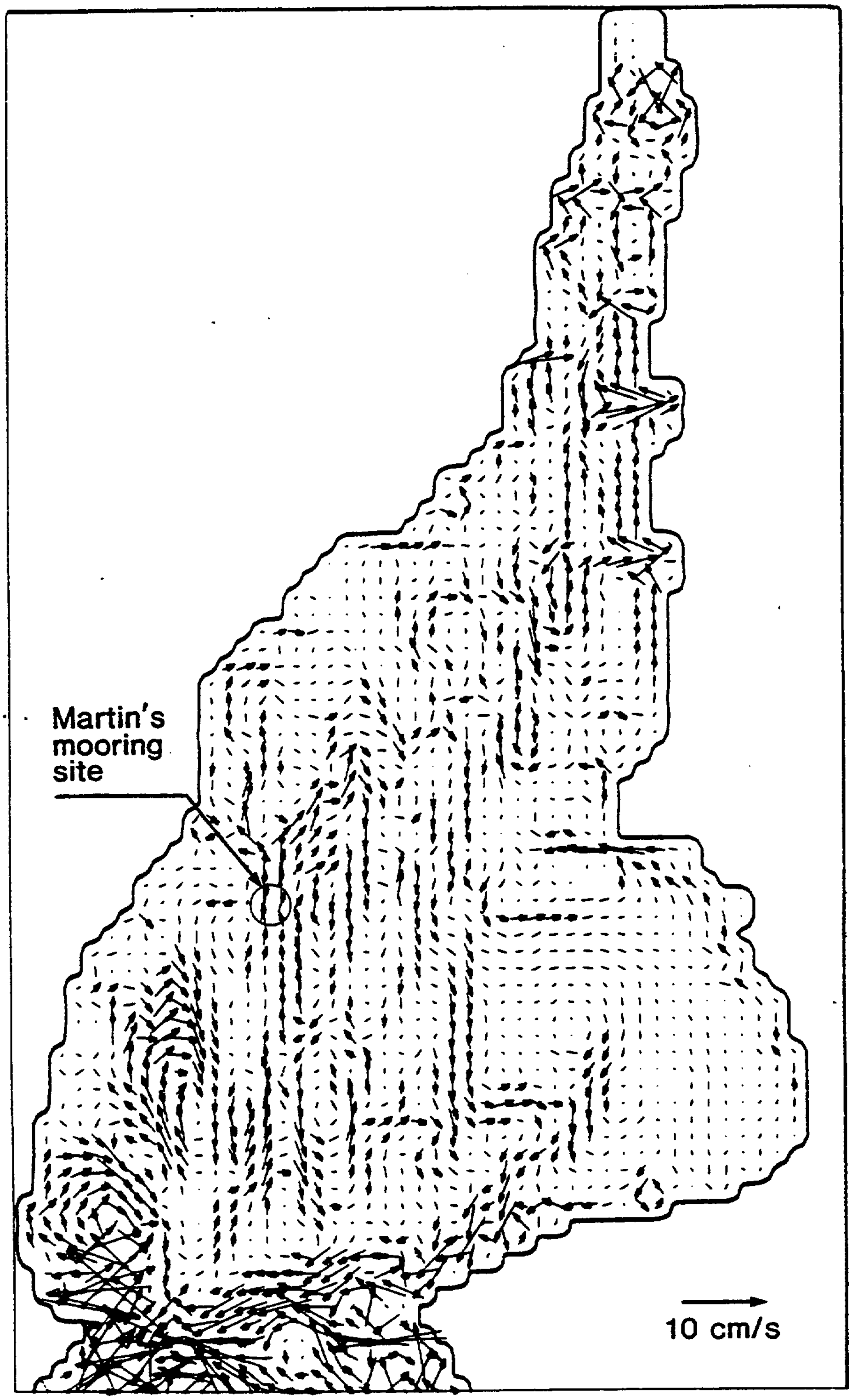


Figure 3-5. Computed tidal residual currents in Delaware Bay for conditions described in the text.

PRESENT AND PROPOSED RESEARCH ON CIRCULATION

A detailed knowledge of the circulation in the Delaware Estuary, the ability to predict both mean and time-varying features of concentration, is fundamental to a rational assessment of biological, chemical, and geological processes in the estuary. These features can be illustrated by a simple example. Suppose a passive substance is introduced at some point in or along the estuary. We wish to have sufficient predictive ability to determine the transport of this substance both over short time periods (within a portion of one tidal cycle) and over longer periods. We recall that for such transport we require Lagrangian rather than Eulerian mean velocities. There are, of course, several other features that we would like to be able to predict, such as subtidal exchange rates between the estuary and shelf, and exchange rates between various subsections of the bay and river and residence times. In all of this, the variability in the circulation's response to variations in the forcing processes also would need to be addressed.

The development of a substantially enhanced capability to predict both tidal and subtidal circulation in the Delaware Estuary and adjacent shelf waters is a major objective of the present and proposed physical oceanography studies within the Delaware Estuary Project. The research to accomplish this purpose consists of two highly interactive components, numerical model studies and field observations. Some preliminary two-dimensional (vertically averaged) model results for the tidal circulation were mentioned above. The development of this tidal model is, however, an intermediate goal of the numerical work. The final objective will be the development of a fully three-dimensional model for the prediction of the velocity, salinity, and temperature distibutions at high spatial and temporal resolution over the domain shown in Figure 3-4. The model requires the specification of boundary conditions that correspond to the processes (previously described in the third and fourth sections) that force circulation in the estuary; astronomical tides at the open-ocean boundary, freshwater discharge to the estuary, and winds.

Field observations will focus on obtaining long-term current meter records. The lack of this type of observational data in Delaware Bay, with the exception of those obtained by Martin at one location, has been previously noted. Thus, the field program will provide a substantial advance in our knowledge of subtidal circulation. In combination with the numerical modeling effort, the results of field work will provide a crucial assessment of the model's predictive skill.

The complete three-dimensional numerical model presently under development for the Delaware Bay and shelf region will provide more detailed information than can be obtained either from two-dimensional (vertically averaged) or from one-dimensional (cross-sectionally averaged) models. These simpler models have an advantage, however, in substantial reductions in computer storage capacity and computational time requirements. It is important to note that the information developed from the three-dimensional model can be used to establish the empirical dispersion coefficients required in these one- or two-dimensional models.

Furthermore, the volume of data that can be developed from the three-dimensional model is extraordinary. A significant aspect of the proposed research is to find ways to present these results in various reduced forms to enhance their immediate utility to other investigators in the Delaware Estuary Project. The final practical goal of these studies will be to use the predictive capability inherent in the full model to assist in the rational management of the estuary.

CONCLUSIONS

The main features of the circulation in the Delaware Estuary that can be summarized from the foregoing sections are these:

(1) Circulation is a complex response to tidal and subtidal elevation forcing at the ocean boundary, freshwater discharge, and winds. With the exception of astronomical tides, the processes driving circulation exhibit considerable variability. The resulting currents from these essentially stochastic driving mechanisms show a corresponding variability over a broad spectrum of time.

(2) Effects of estuarine circulation in Delaware Bay can be observed at substantial seaward distances over the coastal ocean. Conversely, circulation in the continental shelf waters, in particular wind-driven transports, can affect circulation in the bay.

The data base for studies of circulation in the Delaware Estuary is, within limits, reasonably comprehensive for tidal currents. It is noted, however, that the last comprehensive survey of these currents was conducted 36 years ago. The observations that bear on subtidal circulation consist of drifter studies, such as those reported by Pape and Garvine (1982), earlier drift-bottle experiments by Ketchum (1953), and long-term current meter observations by Martin (1978). There is a remarkable paucity of direct current measurements suitable for analysis of subtidal circulation.

The present and proposed physical oceanographic research within the Delaware Estuary Project is a joint numerical-observational study. A major objective of this research is to produce a fully three-dimensional numerical model for the prediction of velocity, salinity, and temperature distribution in the estuary and in the adjacent shelf waters. A second objective is to obtain relevant field data to assess the model's predictive skill. Once established, this model should prove a valuable tool to predict the response of the estuarine system to both natural and manmade changes.

Chapter 4

DISSOLVED GASES AND THE ACID-BASE SYSTEM

C.H. Culberson, J.H. Sharp

INTRODUCTION

The concentration of dissolved oxygen in natural waters is perhaps the most fundamental measure of water quality. Without oxygen normal aquatic life cannot exist. The distributions of four chemical parameters in the Delaware Estuary are discussed in this chapter: (1) dissolved oxygen; (2) acidity; (3) alkalinity; and (4) total dissolved inorganic carbon. Dissolved oxygen is present in the estuary as dissolved oxygen gas (O_2). The acidity is discussed in terms of the pH. The alkalinity is a measure of the concentration of bases, primarily bicarbonate ion, and the total dissolved inorganic carbon (TCO_2) is the sum of the concentrations of the three dissolved species of carbon dioxide.

Severe oxygen depletion in the upper estuary lead to a major cleanup effort starting about two decades ago. This activity, under the jurisdiction of the Delaware River Basin Commission (DRBC), has been successful and improvement of the water quality of the freshwater portion of the estuary can be demonstrated. Improvement in water quality is discussed briefly in this chapter.

Oxygen and carbon are considered together in this section because the processes that affect one generally affect the other, and because they are associated with major gas reactions. Thus, the distribution of inorganic carbon cannot be understood without reference to the distribution of dissolved oxygen. This is discussed in a general section on dissolved gases, followed by sections on dissolved oxygen, pH, alkalinity, and dissolved inorganic carbon.

DISSOLVED GASES

The four most abundant and most important gases in both the atmosphere and the sea are nitrogen, oxygen, carbon dioxide, and argon. Nitrogen is very abundant in all natural waters and is not appreciably influenced by inputs or reactions; argon is inert and does not react at all. Oxygen and carbon dioxide are very reactive and, in estuarine waters, these two gases are intimately tied to biological activity. Oxygen and carbon dioxide, like other gases, dissolve in water when the atmosphere and water mix and their concentrations depend upon their individual solubilities. In general, both gases would be found in natural waters at saturation levels (concentrations determined by solubility) if it were not for biological reactions. All gases are more soluble in colder water so saturation levels are lower in warm water than in cold water.

Natural processes and human inputs influence the concentrations of dissolved oxygen and carbon dioxide in the Delaware Estuary. Natural processes include (1) respiration and photosynthesis; (2) gas exchange across the air-water interface; (3) chemical exchange across the sediment-water interface; and (4) physical mixing. The above processes occur in all estuaries, but their rates are also affected by manmade (anthropogenic) influences. The most important anthropogenic influence on the Delaware Estuary is (5) the discharge of municipal and industrial wastes into the estuary.

The effects of respiration on the distributions of oxygen and inorganic carbon are illustrated by equations 1 and 2.

$$O_2 + CH_2O = CO_2 + H_2O \tag{1}$$

$$2O_2 + NH_4^{\ +} = 2H^+ + NO_3^{\ -} + H_2O \tag{2}$$

In equation 1, the molecule CH_2O represents a hypothetical organic molecule, and the equation represents the net effect of respiration: the consumption of dissolved oxygen (O_2) and the production of carbon dioxide (CO_2) during the degradation (oxidation) of organic matter by organisms.

Nitrification (equation 2), which is the oxidation of ammonium by microorganisms, also consumes oxygen. This process has no direct effect on the concentration of dissolved inorganic carbon. However, it has an indirect effect, in that the acid (H^+) produced during nitrification changes the chemical speciation of the dissolved inorganic carbon.

The effects of photosynthesis on the concentrations of dissolved oxygen and inorganic carbon are shown by equation 3, which is the reverse of equation 1.

$$CO_2 + H_2O = O_2 + CH_2C \tag{3}$$

In photosynthesis, sunlight is used as the energy source for plants to convert dissolved inorganic carbon into organic matter. Oxygen is introduced into the water during this process. In addition to carbon dioxide, nutrients, such as nitrogen and phosphorus are also required during photosynthesis. For simplicity, these are not considered in equation 3.

The inorganic chemistry of dissolved oxygen in water is simple; it is only present as the molecule O_2. In contrast, the inorganic chemistry of dissolved carbon dioxide is complex, and dissolved inorganic carbon can be present in one of three distinct forms: (1) molecular carbon dioxide, CO_2; (2) bicarbonate ion, $HCO_3^{\ -}$; (3) carbonate ion, $CO_3^{\ -2}$. All three forms coexist simultaneously in natural waters, and their relative abundance depends on the hydrogen ion (H^+) concentration of the water.

DISSOLVED OXYGEN

Figure 4-1 shows the distribution of dissolved oxygen in the Delaware Estuary for winter (January-February) and summer (July) conditions averaged for the years 1972-83. It shows two obvious features: (1) oxygen concentrations in the entire estuary are higher in winter than in summer; and (2) dissolved oxygen decreases as the Delaware River flows past Philadelphia. Higher dissolved-oxygen concentrations in winter are due to the greater solubility of oxygen at low temperatures. In the absence of biological effects, dissolved oxygen concentrations in the estuary should be close to equilibrium with atmospheric oxygen. The dotted lines in Figure 4-1 show the equilibrium concentrations of dissolved oxygen at the temperatures and salinities characteristic of winter and summer. The data in Figure 4-1 approach oxygen saturation both upstream and downstream of Philadelphia. During the spring and summer, oxygen concentrations in the estuary north of Philadelphia and south of Port Mahon often exceed saturation due to the production of oxygen during photosynthesis.

The decrease in dissolved oxygen in the estuary near Philadelphia is due to the degradation of carbonaceous and nitrogenous wastes added to the estuary in this region. The consumption of oxygen by these wastes is illustrated by equations 1 and 2.

The data in Figure 4-1 represent average conditions over the period 1972-83. There are both short-term and long-term processes which cause perturbations on these average conditions. Short-term effects include diurnal (day-night) effects due to photosynthesis and respiration. These are illustrated in Figure 4-2 in which the results of an experiment during September 1981 are plotted. In this experiment, one body of seawater was monitored over a 30-hour period to detect changes in water chemistry due to biological processes. The data show that respiration and photosynthesis can change the observed oxygen concentrations by more than 10% over the course of a day. Much larger day-night effects have been observed in the upper freshwater portion of the estuary (Thomann 1974).

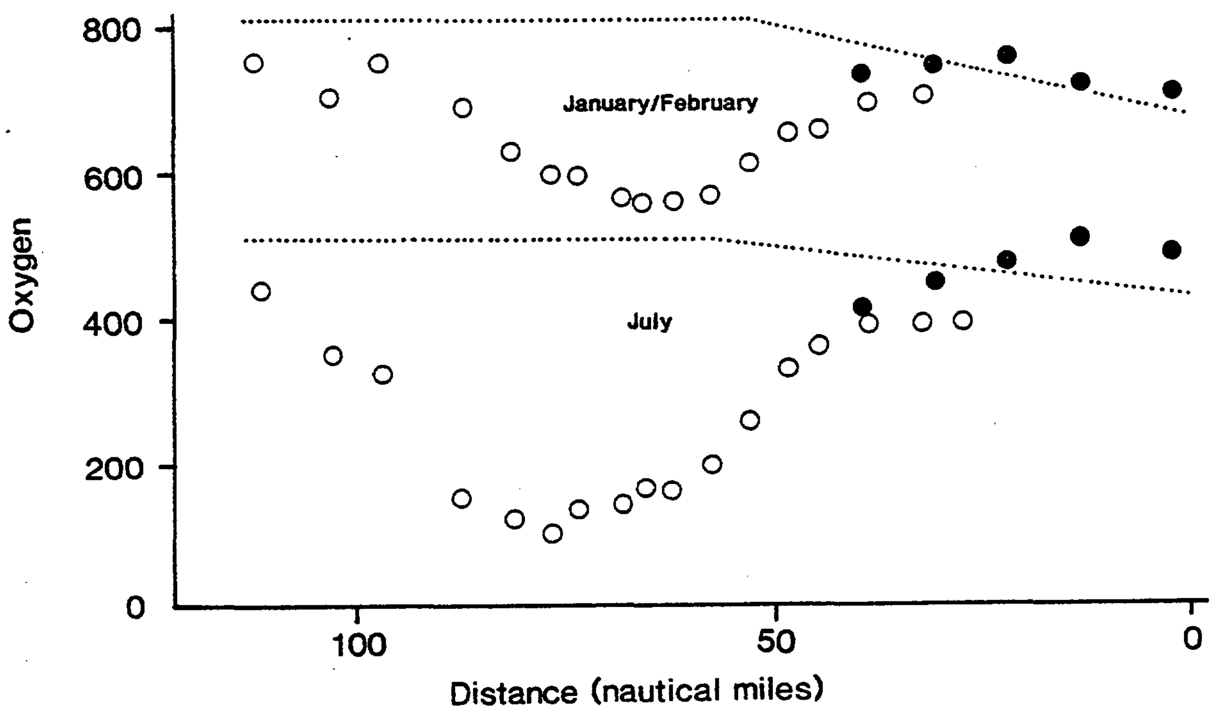


Figure 4-1. Distribution of dissolved oxygen (microgram-atoms oxygen per liter) vs. distance from the mouth of the estuary. Data from averaged summer (July) and winter (January/February) sampling. Delaware River Basin Commission (DRBC) data from 1972-81 - open circles; data from our study from 1978-83 - solid circles. The dotted lines indicate saturation levels (see text).

Long-term effects on the concentration of dissolved oxygen include changes in anthropogenic inputs to the estuary. Albert (1982) has shown that average oxygen concentations in the estuary have significantly improved over the 20-year period from 1961 to 1981 due to major cleanup of sewage effluents (Figure 4-3). The average oxygen concentration at the Delaware-Pennsylvania state line (70 miles from the bay mouth) has more than doubled over this period.

The data in Figure 4-1 show that oxygen concentrations in the lower estuary south of Port Mahon (refer to Figure 1-1) are everywhere greater than 90% saturation with respect to atmospheric oxygen. In the winter,

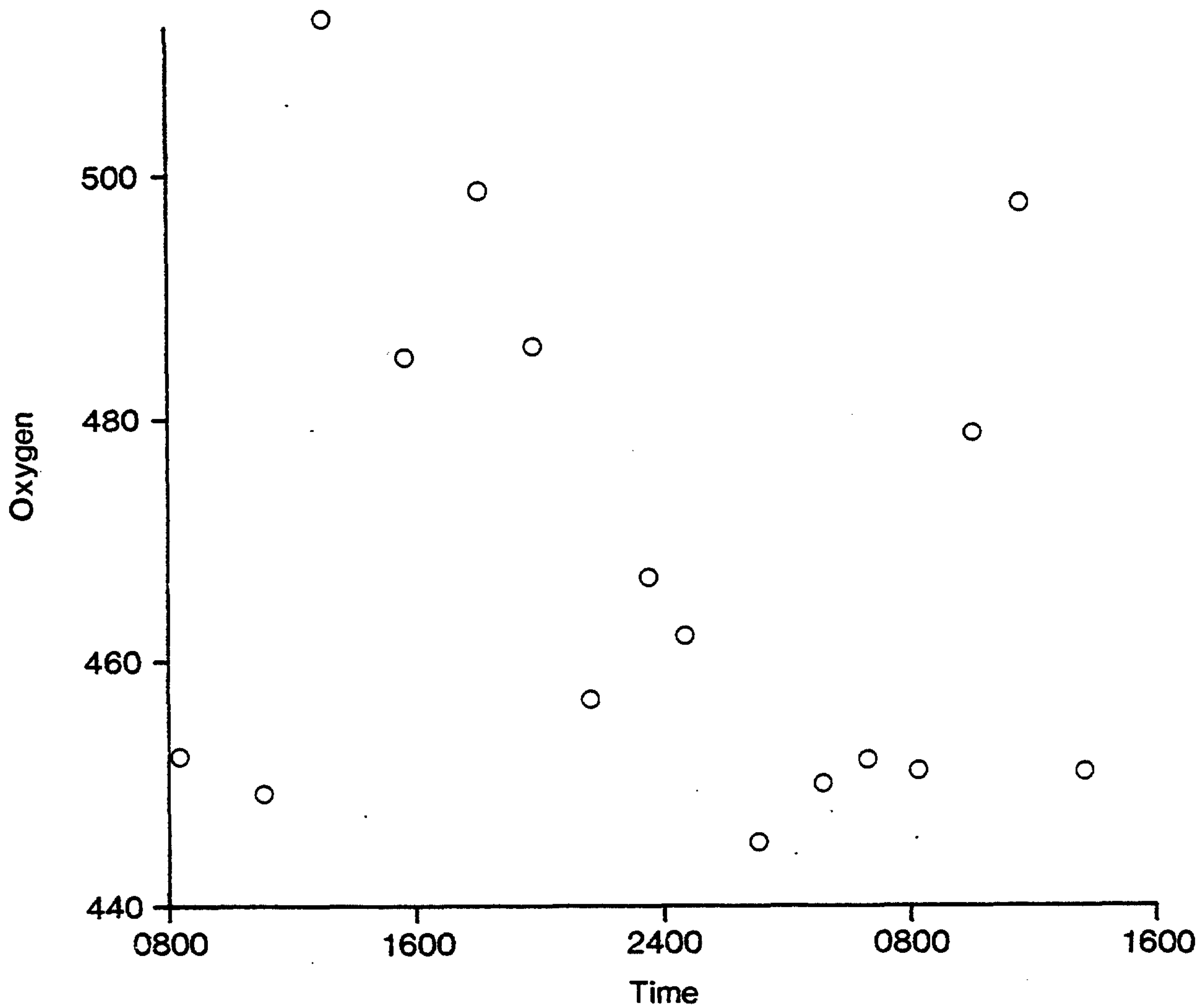


Figure 4-2. Dissolved oxygen (microgram-atoms oxygen per liter) over time. Sampling done in September 1981 by following a constant salinity of 12.5 ^{o}/oo for a period of 30 hours.

concentrations are close to 100% saturation due to intense mixing and reduced biological activity, whereas in the summer, oxygen concentration often exceed 100% saturation due to oxygen produced during photosynthesis.

The biological oxygen demand (BOD) is a measure of the maximum amount of oxygen consumption that can occur in a water sample due to its load of suspended and dissolved wastes. Discharge of BOD into the Delaware Estuary is

Table 4-1. Input of biological oxygen demand (BOD) to the Delaware Estuary from major municipal and industrial effluents. Allocations are the maximum pounds per day permitted by the Delaware River Basin Commission (DRBC). These allocations are the ones current as of April 1980; those listed constitute 90% of the total allocations made by DRBC.

Discharger	Allocation
Philadelphia NE Sewage Treatment Plant (STP)	72,500
Philadelphia SW STP	37,020
Philadelphia SE STP	33,600
City of Wilmington	20,800
E.I. duPont, Chambers Works	14,000
City of Camden, Main STP	11,900
Delcora STP (Delaware County, PA)	10,500
City of Trenton	5,000
Gloucester Co., NJ	4,320
Mobil Oil (Paulsboro, NJ)	4,250
Getty Oil (Delaware City, DE)	3,750
Monsanto Co. (Bridgeport, NJ)	3,170
Atlantic Richfield (Philadelphia)	2,590
U.S. Steel (Falls Twp., PA)	2,500
Lower Bucks Co., PA	2,410
Gulf Oil (Philadelphia)	2,170
Hamilton Twp., NJ	2,160

regulated by the Delaware River Basin Commission (DRBC). Table 4-1 lists the major municipal and industrial contributors of BOD in terms of their permitted allocation as of 1980. The improvement in dissolved oxygen concentrations over the last 20 years (Figure 4-3) in the Delaware Estuary is due to improved methods of waste treatment which have significantly reduced the level of BOD in the estuary (Figure 4-4).

Another way of looking at oxygen demand is with the concept of apparent oxygen utilization (AOU) which comes from seawater chemistry (Redfield et al. 1963). The AOU is the difference between the dissolved oxygen that should be present from equilibrium of the water and atmosphere and that which is present. Figure 4-5 is an envelope of AOU vs. salinity for all our center-channel surface samples from 1978-83. Negative AOU values indicate that waters are

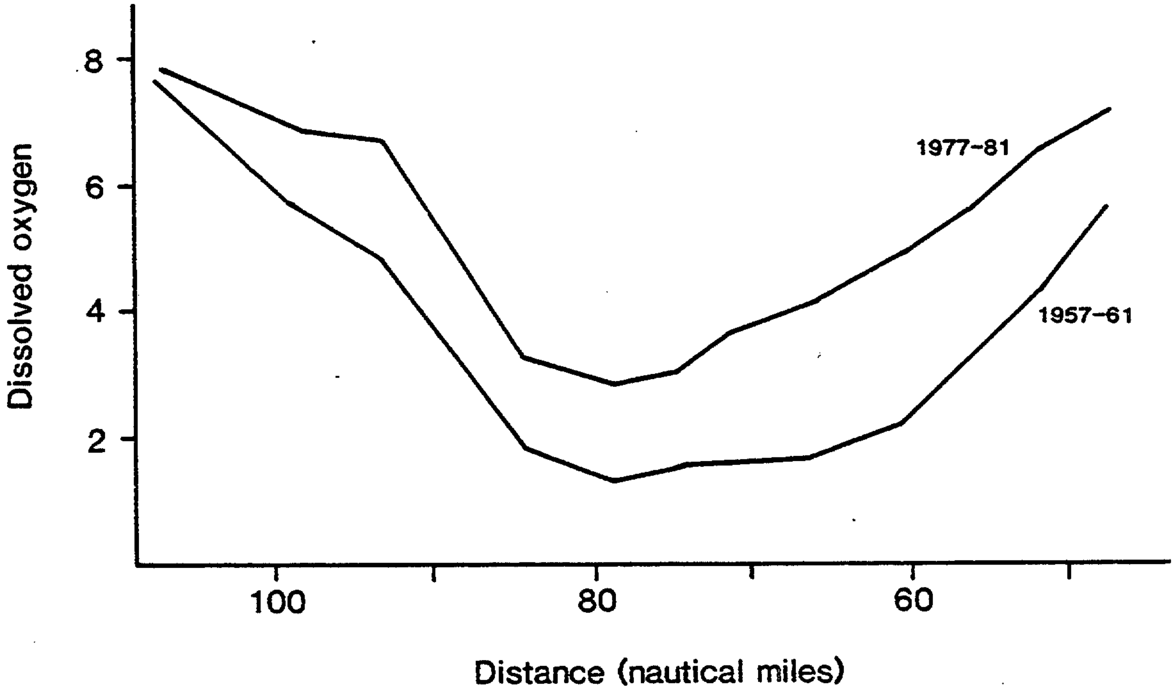


Figure 4-3. Comparison of mean dissolved oxygen values (milligrams/liter) for 1957-61 and 1977-81 from sampling in the period of June through October. From Albert 1982.

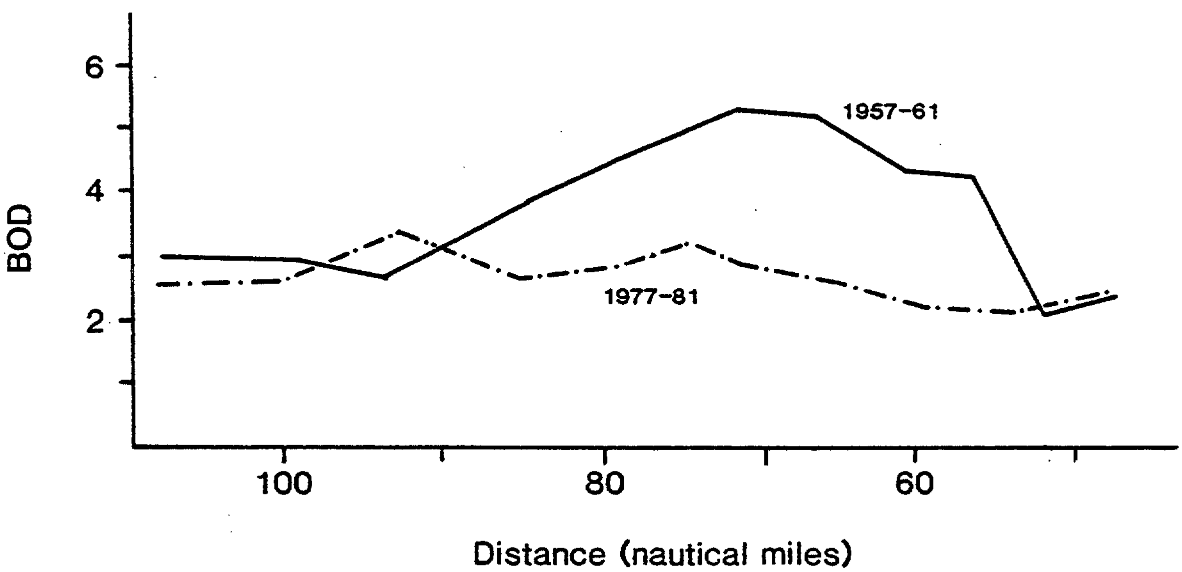


Figure 4-4. Biological oxygen demand (BOD) compared for the same period as shown in Figure 4-4. BOD in units of milligrams/liter of dissolved oxygen. From Albert 1982.

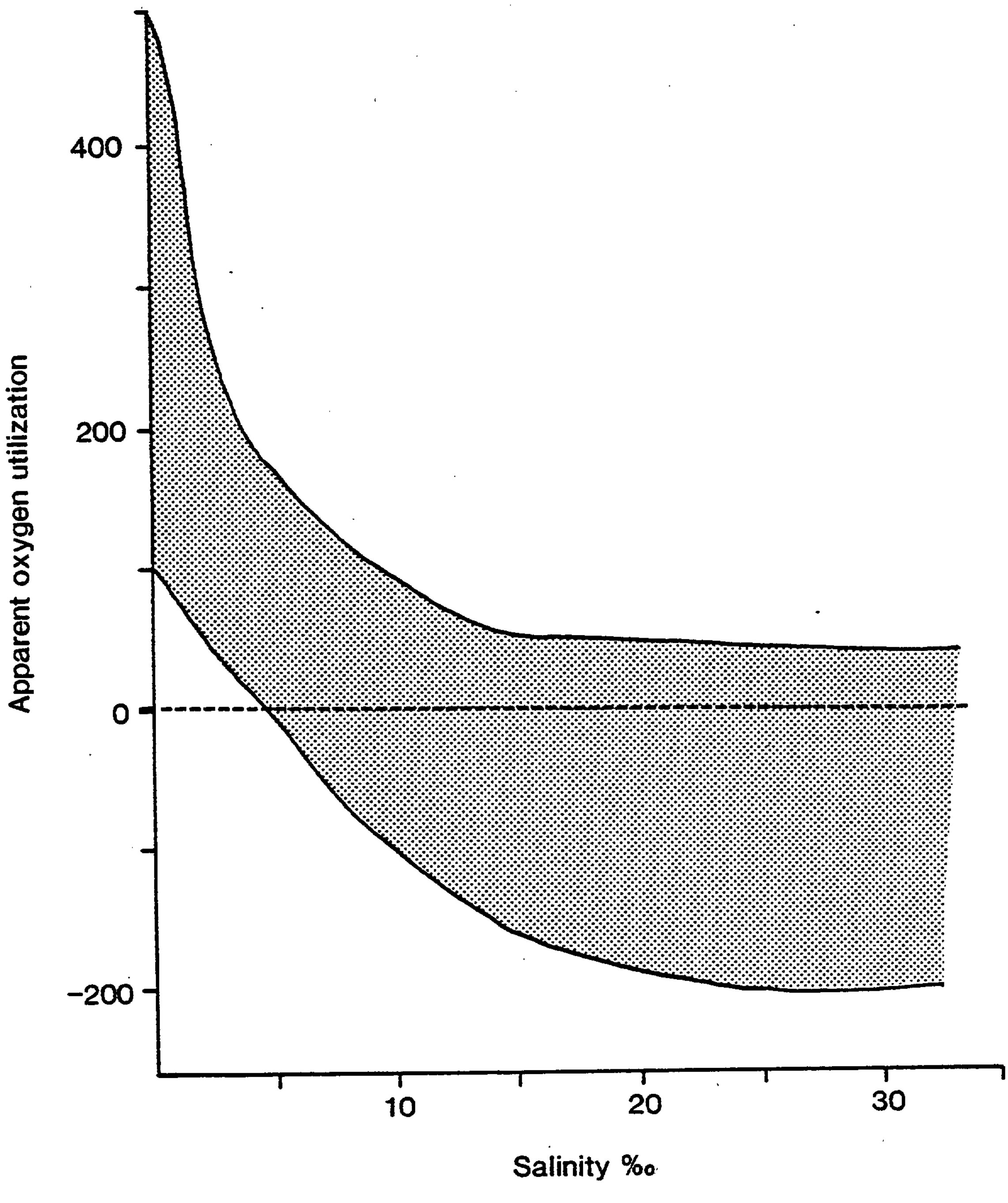


Figure 4-5. Apparent oxygen utilization (microgram-atoms oxygen per liter) vs. salinity for surface central channel samples from the Delaware Estuary from 1978-83.

supersaturated with oxygen; positive values indicate undersaturation and approximate the extent of the oxygen demand. The data set is from all seasons for a five-year period. It is obvious that the upper estuary continually has a pronounced oxygen demand while the lower estuary does not. This concept has been discussed with consideration of the chemistry in Sharp et al. (1982).

DISTRIBUTION OF pH

Carbon dioxide is a weak acid and when it is produced during respiration (equation 1) it reacts with water according to the equation,

$$CO_2 + H_2O = H^+ + HCO_3^- \quad (4)$$

to yield hydrogen ion (H^+) and bicarbonate ion (HCO_3^-). The hydrogen ions produced by equation 4 make the water more acidic and lower the pH which is defined as

$$pH = -\log(H^+) \quad (5)$$

A pH decrease of one unit corresponds to a 10-fold increase in the hydrogen ion concentration.

The pH is an important measure of water quality because its value reflects the biological processes occurring in the estuary and pH controls the distribution of many trace metals through its effects on solubilities, adsorption, and complexation.

Since both dissolved oxygen and pH decrease during respiration and increase during photosynthesis, there is a direct correlation between these two parameters down the length of the estuary. This is illustrated in Figure 4-6 which shows pH profiles for winter and summer conditions from the same samples as those used for Figure 4-1. It is clear that the pH minimum in Figure 4-6 occurs at the same location as the oxygen minimum in Figure 4-1.

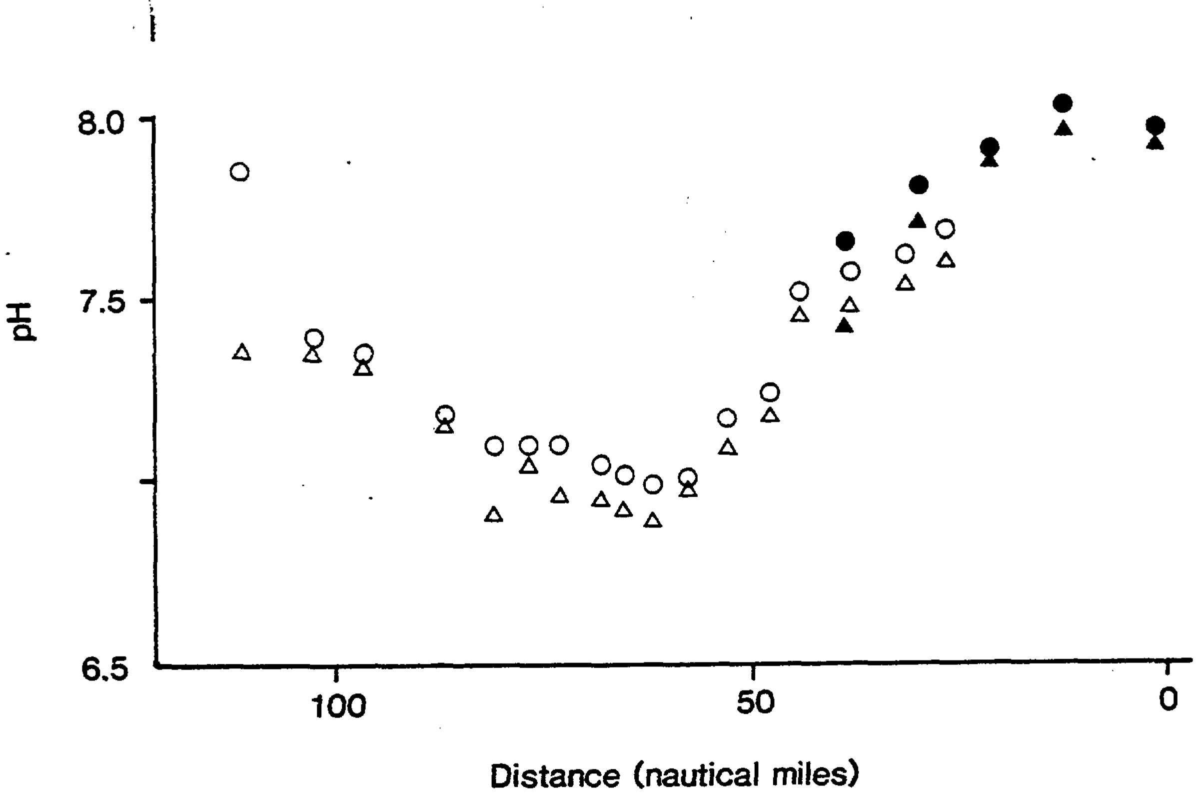


Figure 4-6. Values of pH for the same sample averages as in Figure 4-1. Open circles - DRBC summer data (July); open triangles - DRBC winter data (January/February); solid circles - our summer data and solid triangles - our winter data.

The pH is subject to the same day-night effects as dissolved oxygen, and Figure 4-7 shows the variation of pH in one water mass over the same 30-hour cycle as the oxygen data in Figure 4-2. The correlation between pH and oxygen is evident.

As the water quality of the Delaware Estuary has improved, there have been long-term changes in the pH of the estuary south of Philadelphia, and the pH in this section of the estuary has increased over the last 20 years (Albert 1982).

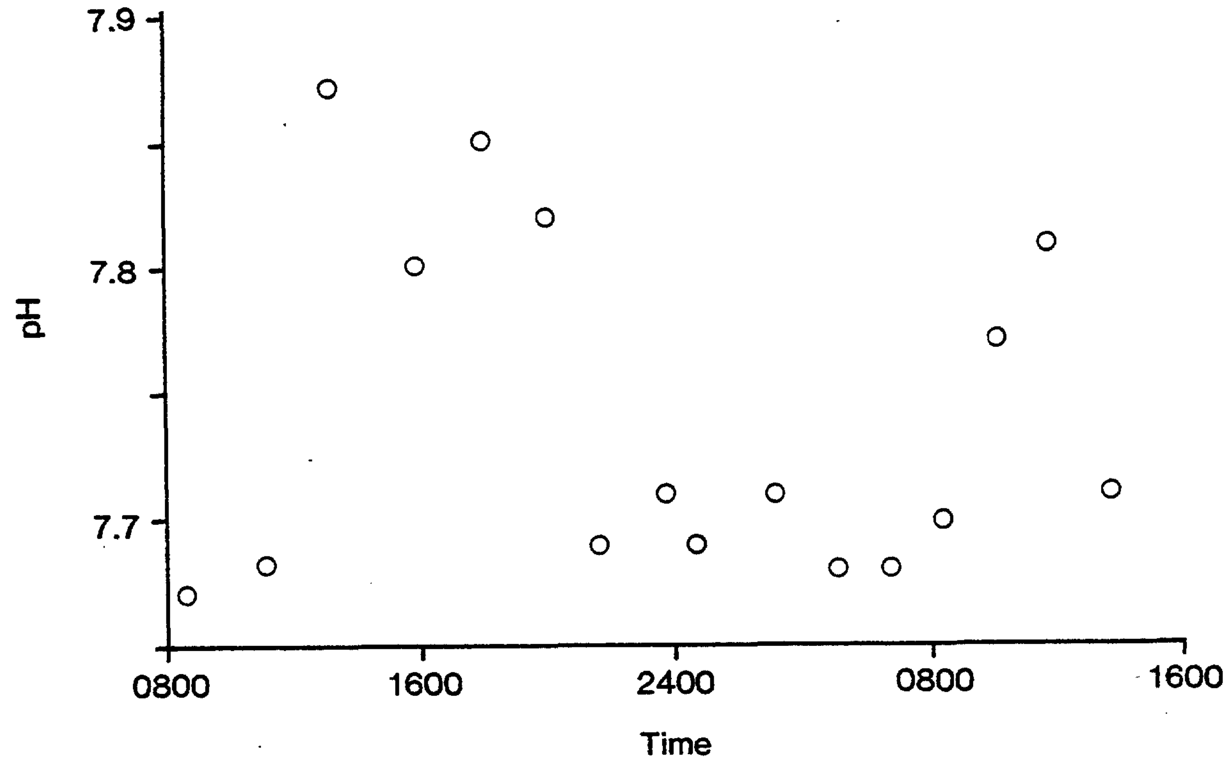


Figure 4-7. Values of pH over time for the same 30 hour sampling period shown in Figure 4-2.

ALKALINITY

The alkalinity is a measure of the buffer capacity of natural waters, and in the Delaware Estuary the alkalinity is essentially equal to the concentration of bicarbonate ion (HCO_3^-). Since the bicarbonate ion is the most abundant of the three carbon dioxide species, the concentrations of alkalinity and total inorganic carbon are approximately equal.

The alkalinity is a major constituent of seawater, and at salinities greater than 1^{o}/oo, alkalinity behaves conservatively in the Delaware Estuary. That is, a graph of alkalinity vs. salinity is linear for salinities greater than 1^{o}/oo. This is clearly shown in Figure 4-8 which is based on samples from 1978-83.

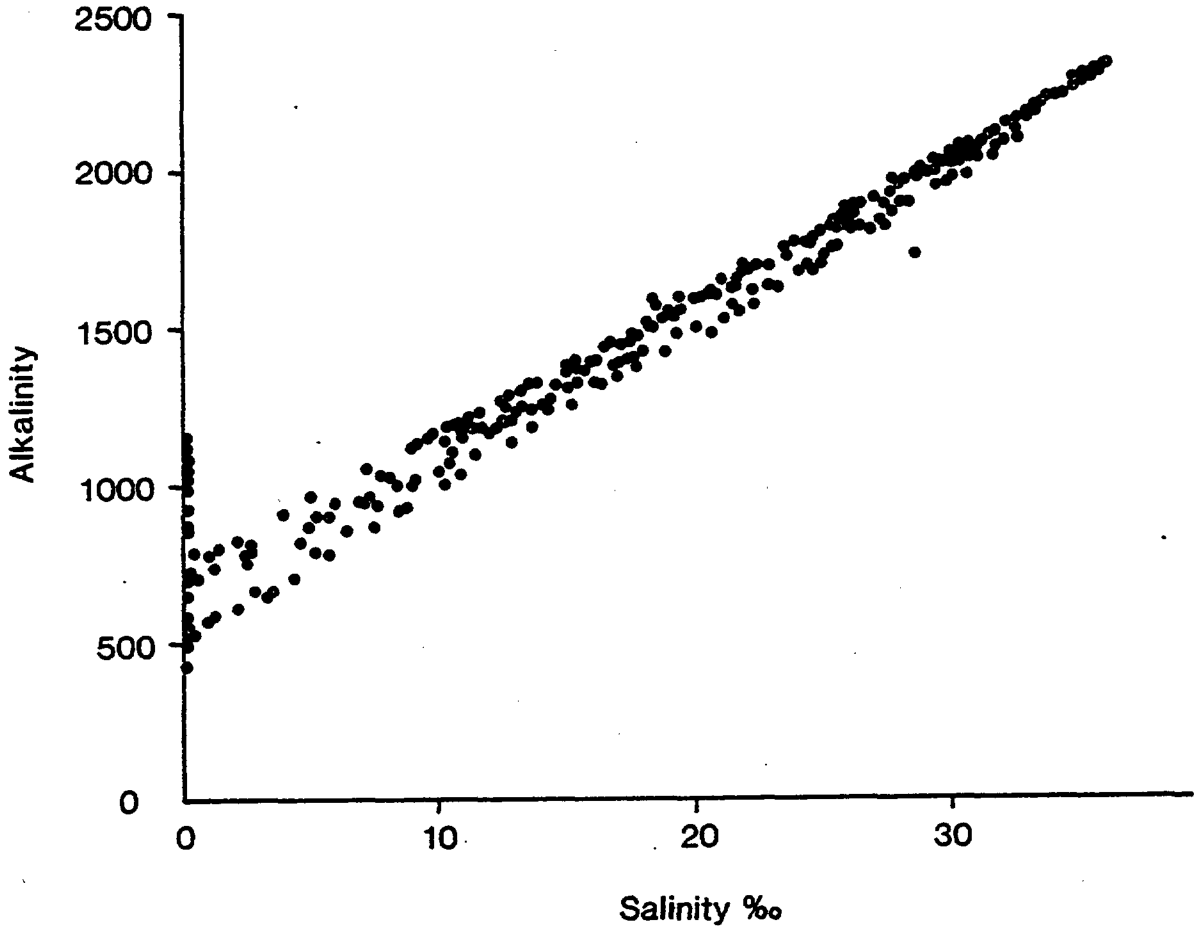


Figure 4-8. Alkalinity (microequivalents per kilogram) vs. salinity for all samples from 1978-83.

Alkalinity is not conservative in the freshwater portion of the estuary as is illustrated in Figures 4-9 and 4-10. In July 1979 (Figure 4-9), the alkalinity decreased by 50% between Trenton and Marcus Hook. The alkalinity decrease is also shown in the historical DRBC data for July (Figure 4-10). In this case the alkalinity decrease averaged over a 14-year period was 36%. The cause of this alkalinity decrease is not known, but part of it may be due to the production of hydrogen ions (acid) during nitrification as is indicated by equation 2.

As the water quality of the Delaware Estuary has improved over the last 30 years, there have been long-term changes in the alkalinity of the estuary south of Philadelphia, and the alkalinity in this section of the estuary has

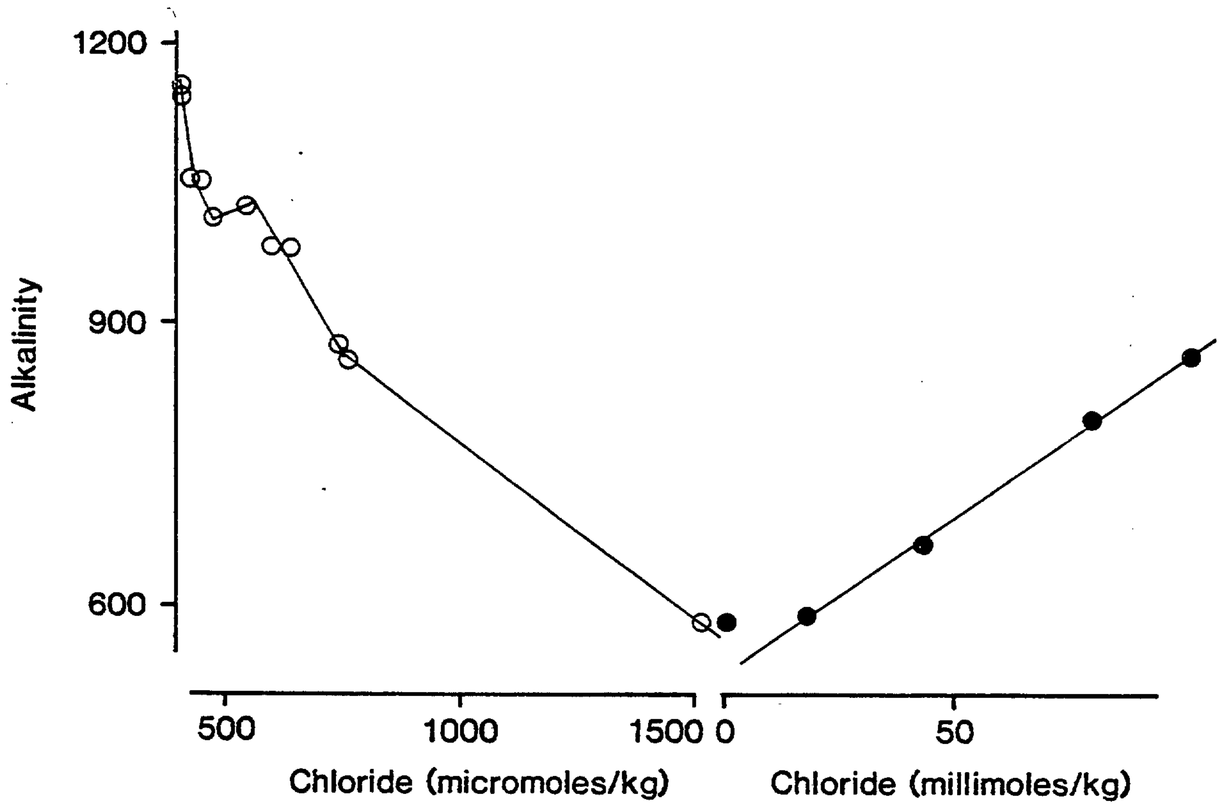


Figure 4-9. Alkalinity (microequivalents per kilogram) vs. chloride (both micromoles per kilogram and millimoles per kilogram) for sampling in July 1979.

increased. The average alkalinity at Marcus Hook for the period of 1964-65 was 204 microequivalents per liter and in 1977-78 the average value was 616 microequivalents per liter. The average alkalinity at this station has tripled apparently due to the cessation of acid waste discharge into the estuary by industry (DECS 1966).

DISSOLVED INORGANIC CARBON

Because of the relatively low pH of the estuary (Figure 4-6), the concentration of carbonate ion ($CO_3^{=}$) is low, and the two major species of inorganic carbon are bicarbonate (HCO_3^{-}) followed by molecular carbon dioxide (CO_2). The term TCO_2 refers to the sum of all the species. The inorganic carbon system in the estuary is dominated by two processes: the mixing of freshwater and saltwater illustrated by Figure 4-8, and the input and

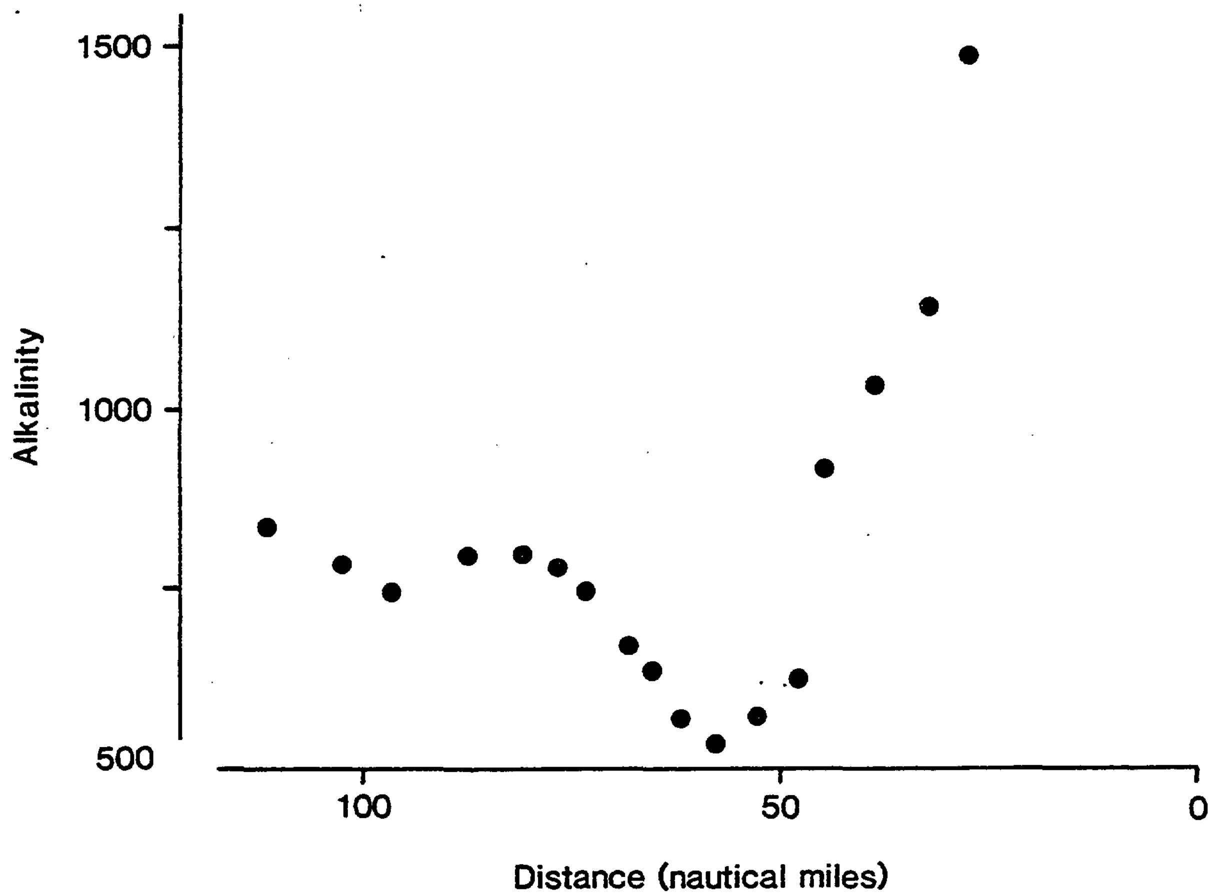


Figure 4-10. Alkalinity (microequivalents per liter) vs. distance from the mouth of the estuary. Values averaged for July sampling for 1967-81.

subsequent decomposition of organic carbon in the Philadelphia area. Due to the production of molecular carbon dioxide during respiration (equation 1), the entire upper estuary from Philadelphia to Port Mahon is supersaturated with respect to atmospheric carbon dioxide, by as much as 25 times near Philadelphia (Sharp et al. 1982). The supersaturation of carbon dioxide and the undersaturation of oxygen result from the carbon dioxide that is released and oxygen that is consumed during respiration. The relationship between oxygen consumption (AOU) and carbon dioxide production was shown in Sharp et al. (1982).

CONCLUSIONS

The distribution of dissolved oxygen, pH, alkalinity, and carbon dioxide in the Delaware Estuary are very much interrelated. Concentrations of these parameters are controlled by microorganisms in photosynthesis-respiration reversible activities. Microscopic algae add oxygen to the water and remove carbon dioxide in photosynthesis; bacteria remove oxygen and add carbon dioxide in respiration. These classical seawater chemistry balances hold throughout the salinity regime of the estuary with the minor exception of excess acidity in the municipal region.

Levels of dissolved oxygen and pH have increased over the last 20 years with improvements in waste treatment in the Philadelphia region. At present, the oxygen demand in the upper salinity reaches of the estuary is measurable, but probably not of a magnitude to be considered dangerous to the water quality of the saline portion of the estuary.

There are several aspects of the oxygen and carbon dioxide systems in the estuary that are poorly understood and need further research. These are the following: (1) the oxygen demand of the sediments in the estuary; (2) the cause of the alkalinity minimum found in the Phildadelphia region; (3) the effect that the low pH in the Philadelphia region has on trace metal and nutrient concentrations in the estuary. It is very important to recognize that changes in the gas chemistry of the estuary profoundly influence metals and nutrient chemistry.

Chapter 5

NUTRIENTS (NITROGEN, PHOSPHORUS, SILICON)

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INTRODUCTION

Nutrients in the water are necessary to support the growth of phytoplankton and marsh grasses. In turn this plant material supports the rest of the food web, including zooplankton, shellfish, and finfish. The growth of plant material is also dependent upon light, temperature, and physical processes that are discussed in other chapters of this report.

The major nutrients required for plant growth are carbon, nitrogen, phosphorus, and silicon. These nutrients are found in both inorganic and organic forms with the exception of silicon, which exists only in the inorganic state. Nutrients may also be subdivided into two classes based on whether they are found in the particulate or dissolved state in the water. The inorganic dissolved forms of nitrogen (ammonium, nitrate, nitrite), phosphorus (phosphate), and silicon (silicate) are the subject of this chapter. Dissolved and particulate organic fractions are discussed in Chapter 6; particulate silicon is treated in the Chapter 7.

This study posed several questions related to nutrient dynamics. What are the sources of nutrients? How are nutrients distributed temporally and spatially? What are the processes affecting their distribution? Accordingly, they form the three sections of this chapter.

SOURCES OF NUTRIENTS

Nutrients enter the estuary from natural sources and they may be introduced by man. Natural sources of nutrients include the Delaware River and other tributaries, marshes along the estuary, sediments, and the ocean. Man's input to the estuaries are from sources such as municipal sewage effluents, industrial effluents, and urban and agricultural runoff. Atmospheric precipitation is a source of nutrients to the estuary that has natural as well as man-induced components.

A majority of the nutrients enters the estuary at the freshwater end. Comparisons of nutrient inputs from primarily natural sources (Delaware and Schuylkill Rivers) and human sources (municipal and industrial effluents) are shown in Table 5-1. The rivers are a major source of nitrate to the estuary while effluents are the main sources of ammonium and phosphorus. Comparison of the two major types of effluents shows sewage as the predominant source of ammonium and phosphorus, and industrial effluents as the main source of nitrate.

DISTRIBUTION OF NUTRIENTS

Natural and human sources of nutrients in the upper estuary result in freshwater nutrient concentrations much greater than those at the mouth of the estuary. Mixing of high-nutrient, low-salinity waters with low-nutrient, high-salinity waters sets up a natural gradient for studying nutrient distributions. Plotting the concentration of any constituent against salinity should result in a straight line if the constituent does not undergo any biological, chemical, or geological changes during the mixing of freshwater and saltwater. If a constituent shows a curvilinear relationship when plotted against salinity, it is probably nonconservative and should have an estuarine sink if the curve is concave, or an estuarine source if it is convex.

The conservative or nonconservative behavior of any nutrient can change seasonally due to changes in inputs, flow rates, and utilization or production within the estuary. Over the past four years of this study, seasonal trends

Table 5-1. Discharges of nutrients to the Delaware River. Values are averaged from data reported on a monthly basis by the Delaware River Basin Commission. All values are as moles of the element (nitrogen or phosphorus) discharged per second. NO_3 = nitrate, NH_4 = ammonium, PO_4 = phosphate.

A. River discharges-averaged for the period of 1964-1979.

	NO_3	NH_4	PO_4
Delaware River at Trenton	20.7	2.5	0.6
Schuylkill River at Phila.	14.7	1.7	0.5
Total	35.4	4.2	1.1

B. Most significant discharges from major effluents averaged for the period of 1976-1980. Total phosphorus (TP) reported rather than phosphate ion. STP = Sewage Treatment Plant.

Sources	NO_3	NH_4	TP
Trenton STP	0.02	1.42	0.06
Hamilton Twp., NJ	0.06	0.38	0.06
U.S. Steel Sanitary	0.19	0.42	0.02
Lower Bucks Co.	0.03	0.55	0.08
Phila. NE STP	0.24	7.67	1.07
Camden Main STP	0.03	1.2	0.15
Phila. SE STP	0.28	2.16	0.55
Phila. SW STP	0.29	5.33	0.91
Gloucester Co., NJ	0.13	0.55	0.1
Mobil Oil (Paulsboro, NJ)	0.15	0.06	0.01
DuPont (Gibbstown, NJ)	1.47	0.22	0.00
Delcora STP	0.21	0.4	0.1
Wilmington STP	0.07	4.06	0.46
DuPont (Deepwater, NJ)	3.93	6.49	0.11
Total	7.10	30.91	3.68

in nutrient distribution have remained consistent from year to year. For the Delaware Estuary, we consider three seasons: winter (November-February), spring (March-May), and summer (June-October). These same three seasons were delineated for river flow in Table 2-2 (Chapter 2).

To examine the seasonal distribution of nutrients in the estuary, we analyzed data from surface samples down the main channel in two ways, depending on year-to-year variation in concentrations. For phosphate and nitrate, which show relatively little year-to-year variation, data were pooled into 10 salinity intervals: 0-1, 1-2.5, 2.5-5, 5-7.5, 7.5-10, 10-15, 15-20, 20-25, 25-30, and 30-32^{o}/oo. Data from the 23 cruises were then grouped according to season for analysis. For ammonium and silicate, which show greater year-to-year variation, data from one year are presented to show the seasonal fluctuations in concentrations.

Highest phosphate concentrations occur in the upper estuary during the summer, decrease slightly during the winter, and are lowest in spring (Figure 5-1A). In the middle estuary, phosphate levels remain approximately 1.5 micromolar (uM) during summer and winter. During spring, unlike other seasons, phosphate is rapidly removed in the middle and lower estuary. Some areas of the estuary show total depletion of phosphate at this time. Phosphate concentrations in the lower estuary remain approximately 0.6 uM in winter and summer.

Nitrate-vs-salinity diagrams for the estuary indicate conservative mixing occurs throughout winter and spring, although nitrate is lower in spring than winter throughout the estuary (Figure 5-1B). There is no rapid removal of nitrate during spring as there is for phosphate and ammonium. In summer, nitrate sometimes shows nonconservative behavior, indicating an estuarine sink. Nitrite is typically less than 5% of the total inorganic nitrogen pool (nitrate + nitrite + ammonium).

In general, ammonium concentrations in the estuary are highest during winter and decrease in spring and summer throughout the estuary (Figure 5-2A). In winter, ammonium shows nonconservative behavior and has an estuarine sink. During spring, ammonium decreases rapidly in the middle and lower estuary,

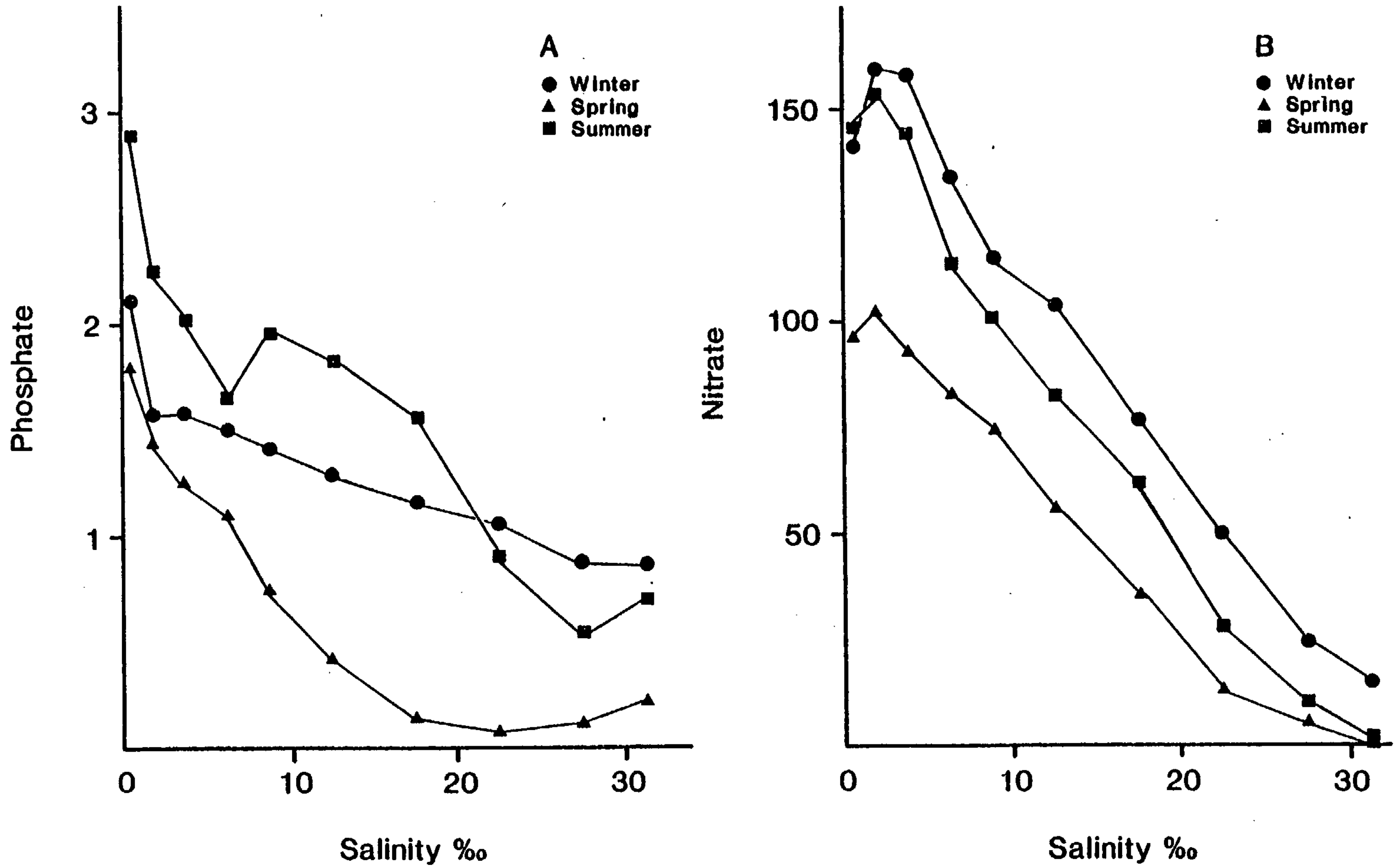

Figure 5-1. Mean nutrient concentrations (uM) in the Delaware Estuary vs. salinity for winter, spring, and summer. A. Phosphate, B. Nitrate. Mean values are from sampling from 1978-83.

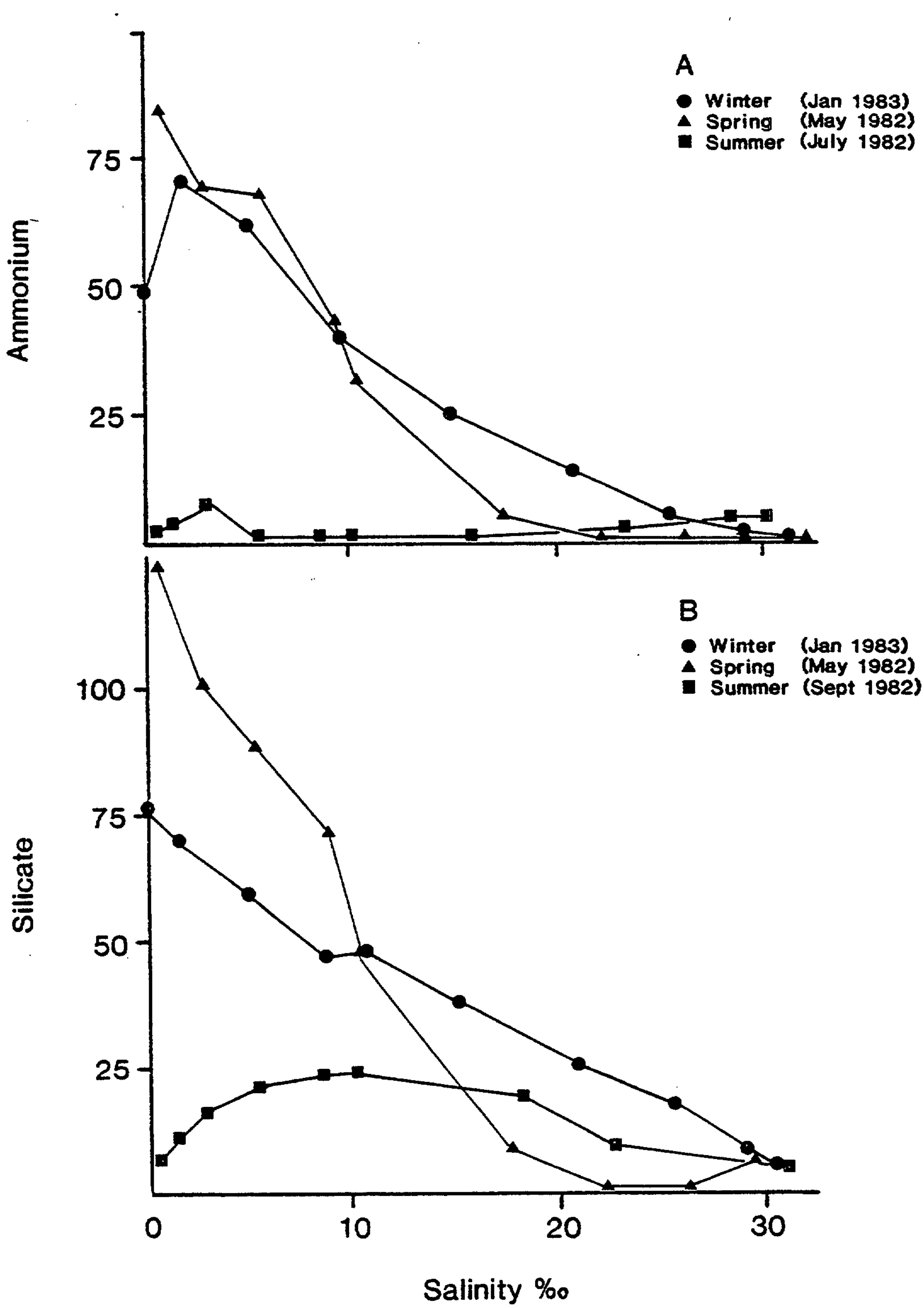

Figure 5-2. Nutrient concentrations (uM) in the Delaware Estuary vs. salinity for typical winter, spring, and summer. A. Ammonium, B. Silicate.

often to less than 1 uM. In summer, ammonium concentrations are uniformily low - less than 5 uM throughout the estuary. Levels of ammonium are higher in the lower estuary in summer than in spring.

Silicate concentrations are highest in the upper estuary during spring but decrease rapidly in the middle and lower estuary. In winter, when silicate shows conservative behavior, concentrations in the upper estuary are lower than in spring, but higher than in spring in the middle and lower estuary (Figure 5-2B). In summer, silicate shows nonconservative behavior with low concentrations in the upper estuary, a major input of silicate in the middle estuary, and higher concentrations in the lower estuary than during spring.

Nutrients were measured in the surface and bottom waters to examine vertical concentration gradients. In the upper estuary, nutrient differences between surface and bottom waters are not significant because the estuary here is generally well mixed. In the lower estuary, concentration differences between surface and bottom waters are evident when there is a vertical salinity gradient. In general, concentrations are higher in the surface waters due to the higher nutrient concentrations in the outflowing freshwater.

In some areas, there are also patterns in nutrient distribution across the estuary. There are no concentration gradients between the central channel and the shoal areas in the upper estuary. In the lower estuary, lateral differences in nutrient concentrations exist between the central channel and the shoal areas along Delaware and New Jersey. In summer, shoal waters have higher concentrations of ammonium, nitrate, and silicate than does the water of the central channel (Figure 5-3A). In spring, when runoff is greatest, the situation is reversed: the central channel has significantly higher concentrations of ammonium, nitrate, and silicate than the shoal areas (Figure 5-3B).

Extensive temporal sampling of the New Jersey shoals has shown seasonal patterns in ammonium and phosphate concentration similar to those described for the central channel; this is shown in Figure 5-4 for sampling from the

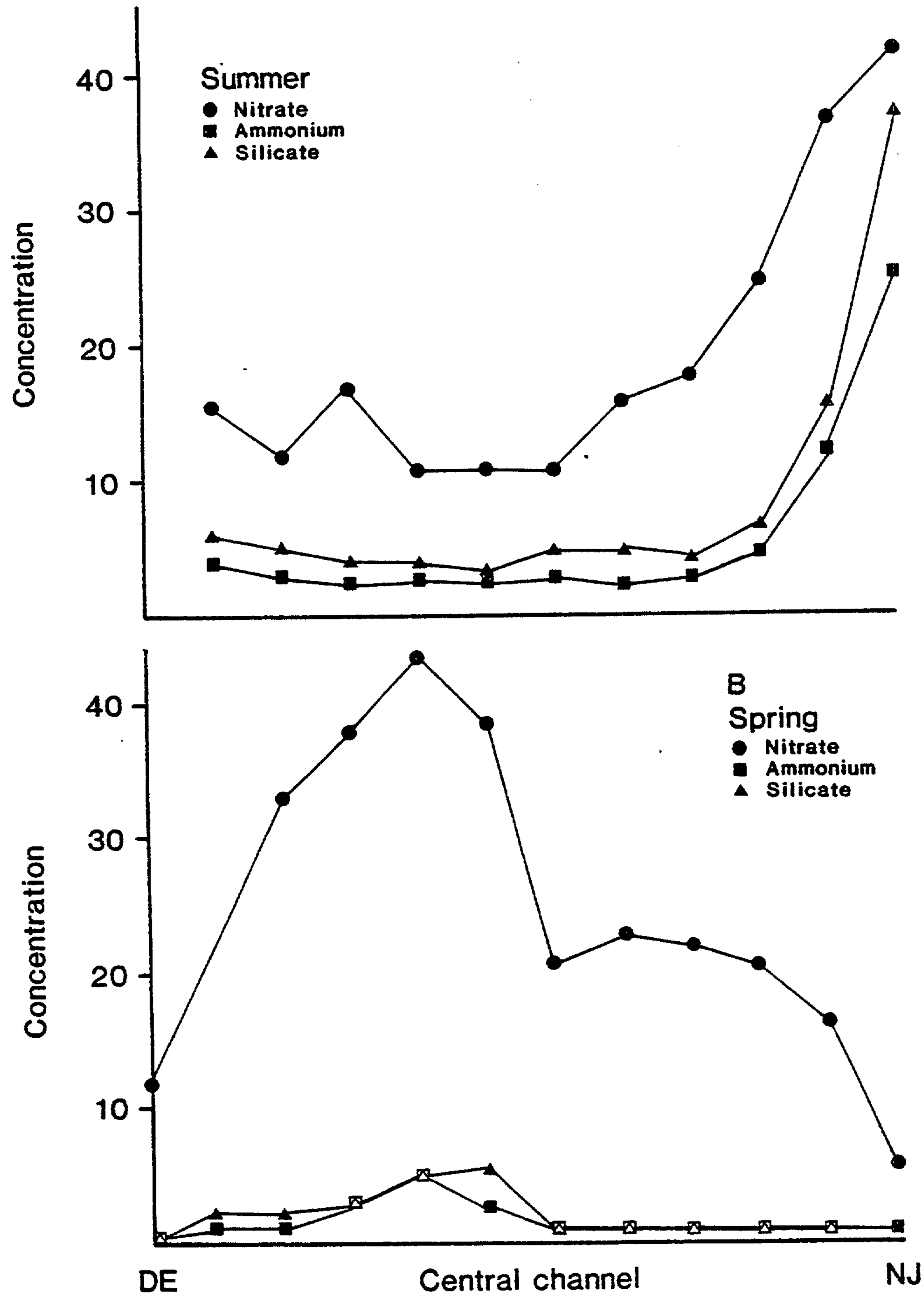

Figure 5-3. Nitrate, ammonium, and silicate (uM) against position from Delaware side of the estuary to New Jersey side. A. July 1982. B. May 1982.

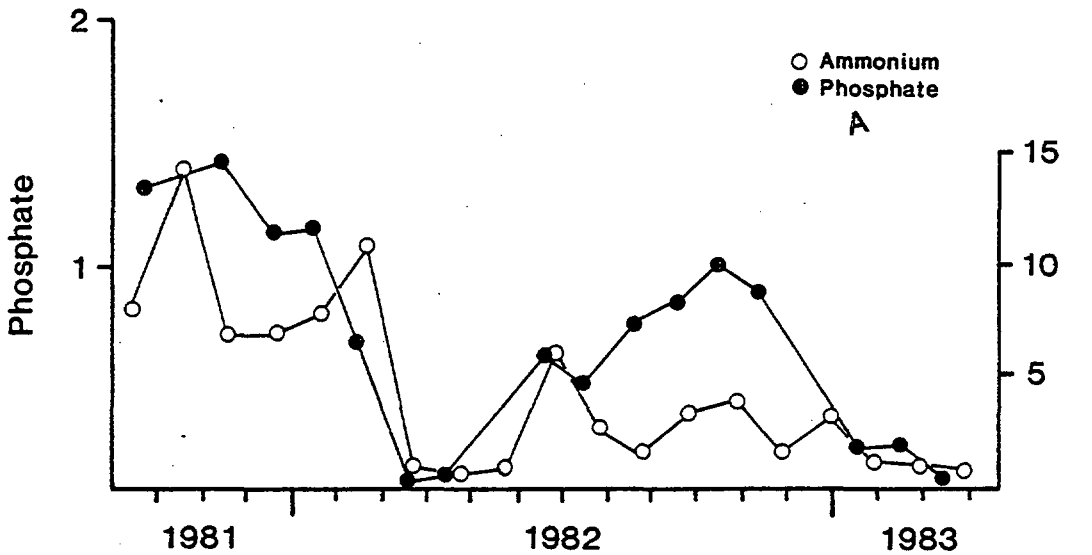

Figure 5-4. Yearly cycles of ammonium and phosphate (uM) for the Ridge station in the New Jersey shoals.

ridge station (see Figure 13-1 for location). During spring, phosphate is almost totally removed from the water, and ammonium concentrations are less than 2 uM throughout the region.

PROCESSES THAT INFLUENCE NUTRIENT DISTRIBUTIONS

Physical, biological, and chemical processes occur in the estuary that influence the distribution of nutrients. Physical processes that affect distributions include the mixing of freshwater and saltwater and the movement of freshwater through the estuary.

Biological processes that influence nutrient dynamics include phytoplankton utilization, nitrification, and regeneration. In spring we observe decreases in silicate, ammonium, and phosphate in the middle and lower estuary (Figures 5-1 and 5-2). These nutrients are almost depleted at times, and their supply is crucial in sustaining the high rates of production observed in spring.

Turnover times measure how long it would take phytoplankton during photosynthesis to deplete all the nutrients present in the water column. Turnover times are calculated by converting estimates of carbon fixation into equivalent fixations of nitrogen, phosphorus, and silicon, using the Redfield ratio (Redfield et al. 1963) and then dividing that estimate into the concentration of nitrogen, phosphorus, or silicon present in the water. These calculations show how rapidly nutrients are cycled in the highly productive portion of the estuary during spring. Average spring turnover times for nitrogen, phosphorus, and silicon at the mouth of the estuary are 0.5, 1, and 3 days, respectively. In the upper estuary the corresponding rates are 20, 7, and 100 days, respectively. For comparison, winter turnover times are considerably longer due to decreased production and higher nutrient concentrations. In the freshwater end of the estuary, average turnover times for nitrogen, phosphorus, and silicon are 800, 230, and 7000 days, respectively. Values for the lower estuary are 10, 5, and 20 days for nitrogen, phosphorus, and silicon, respectively, in the winter. These estimates show that nutrients in the lower estuary are rapidly utilized and recycled during periods of high productivity. They also show that the high nutrient levels in the upper estuary are not being used rapidly by the phytoplankton.

In the lower estuary it appears there are insufficient quantities of nutrients to sustain primary production during spring and summer. Other sources of nutrients to the lower estuary could be marshes, the ocean, and regeneration from the sediments and water column.

A large study of the Delaware marsh indicates salt marshes do not provide a source of nutrients to the estuary (Meredith 1982). In localized areas, however, marsh runoff may be important (Figure 5-3). Infrequent storm events may also cause localized nutrient inputs.

Regeneration of nutrients within the water column and in the sediments is an important process in the estuary. Some of the organic matter formed in the water column sinks to the bottom, where bacteria convert this material into inorganic constituents. Nutrients formed during this process may remain in the sediments or diffuse upward into the water column. We are currently performing experiments to measure the short-term flux of nutrients to or from the sediments. The flux of nutrients from the sediments may be an important source of nutrients in localized areas and to the entire estuary over longer time periods. Sediment regeneration of nutrients has shown to supply 10-100 percent of nutrients for production in various estuaries (Nixon 1981, Harrison 1978).

While benthic fluxes of nutrients are important, water column regeneration causes a considerably larger flux than benthic regeneration. Utilization of organic material by both heterotrophic bacteria and zooplankton results in the release of inorganic and simple organic compounds of nitrogen and phosphorus, which are then available for uptake by phytoplankton. Indeed, bacterial release of ammonium from amino acids is a significant source of nitrogen for phytoplankton (Hollibaugh 1976, Hollibaugh et al. 1980).

During spring, primary production in the lower estuary requires more nutrients than are available in the water column. Regeneration of nutrients in the water column must be an important source of nutrients in sustaining the spring bloom. This has been demonstrated in other estuaries (Harrison 1978, Stanley and Hobbie 1981). Bacteria in the water column may release inorganic nutrients rapidly enough to maintain the observed primary production. Future studies will attempt to quantify bacterial populations and measure this aspect of their activity in the estuary. Also, in shallow waters the metabolic activity of filter-feeding bivalves could contribute a considerable fraction of the recycled nutrients, especially amino compounds appearing as soluble reactive ammonium, which are directly available to the phytoplankton (Galassi and Canzonier 1977). Further study would be needed to quantify the contribution of nutrients from this source.

Ammonium values in the upper estuary are considerably lower in summer than in winter. This reduction is caused by the bacterial conversion, or nitrification, of ammonium into nitrite, then nitrate. Figure 5-5 depicts ammonium, nitrite, and nitrate concentrations as a function of distance from the mouth of the estuary. In the Philadelphia area, most of the sewage input of ammonium is oxidized to nitrite (peak at 80 miles) and then to nitrate

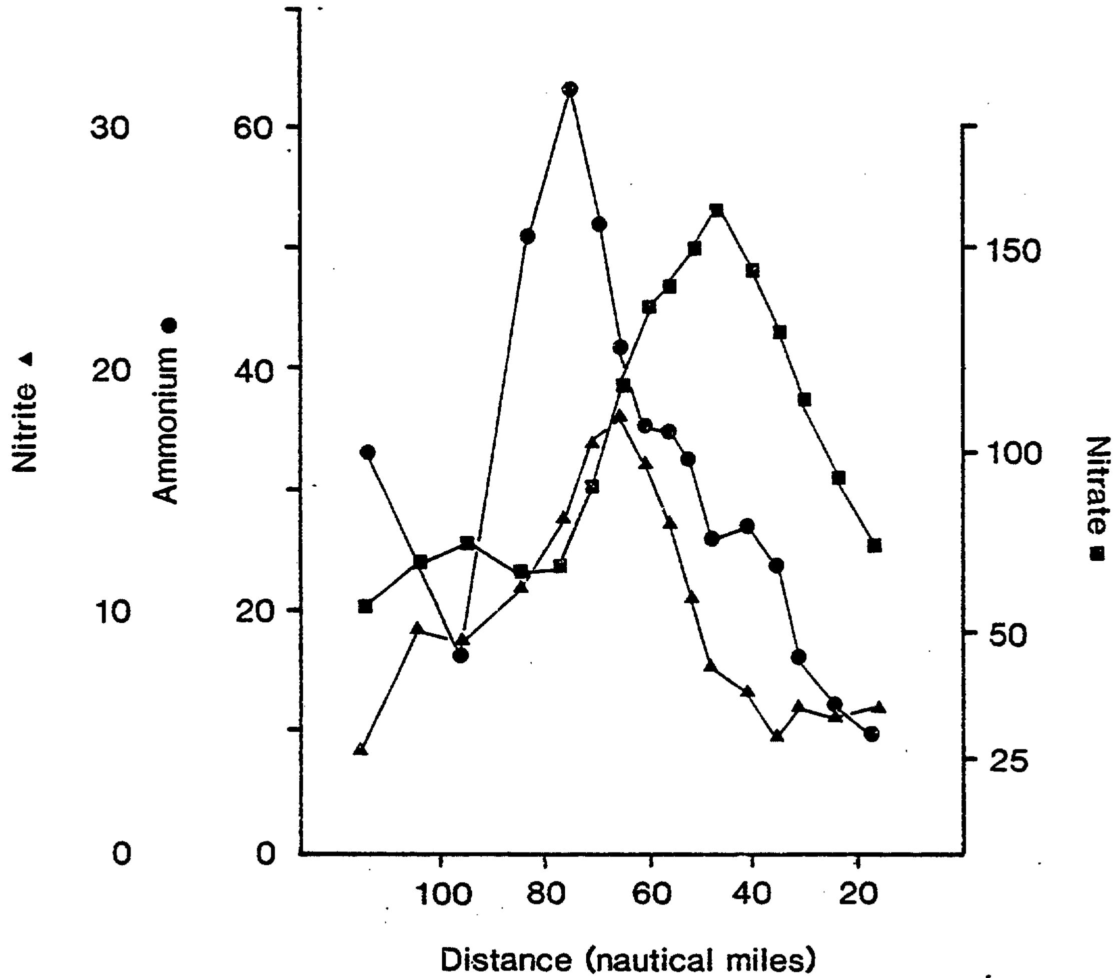

Figure 5-5. Nitrite, ammonium, and nitrate (uM) vs. distance from the bay mouth. Data are averaged August values for 1967-80 from the Delaware River Basin Commission.

(peak at 50 miles). Higher water temperature during the summer increases the rate of conversion from ammonium to nitrate and thus accounts for the diminished ammonium values found throughout the estuary in summer.

The effects of nitrification are also shown in Figure 5-6. Concentration of nitrate in the upper estuary as a function of time show highest values in the late fall when ammonium concentrations are low and water temperatures are high. Nitrification rates are highest at this time. In the winter, when nitrification rates are low because of cold temperatures, ammonium concentrations are high at the freshwater end.

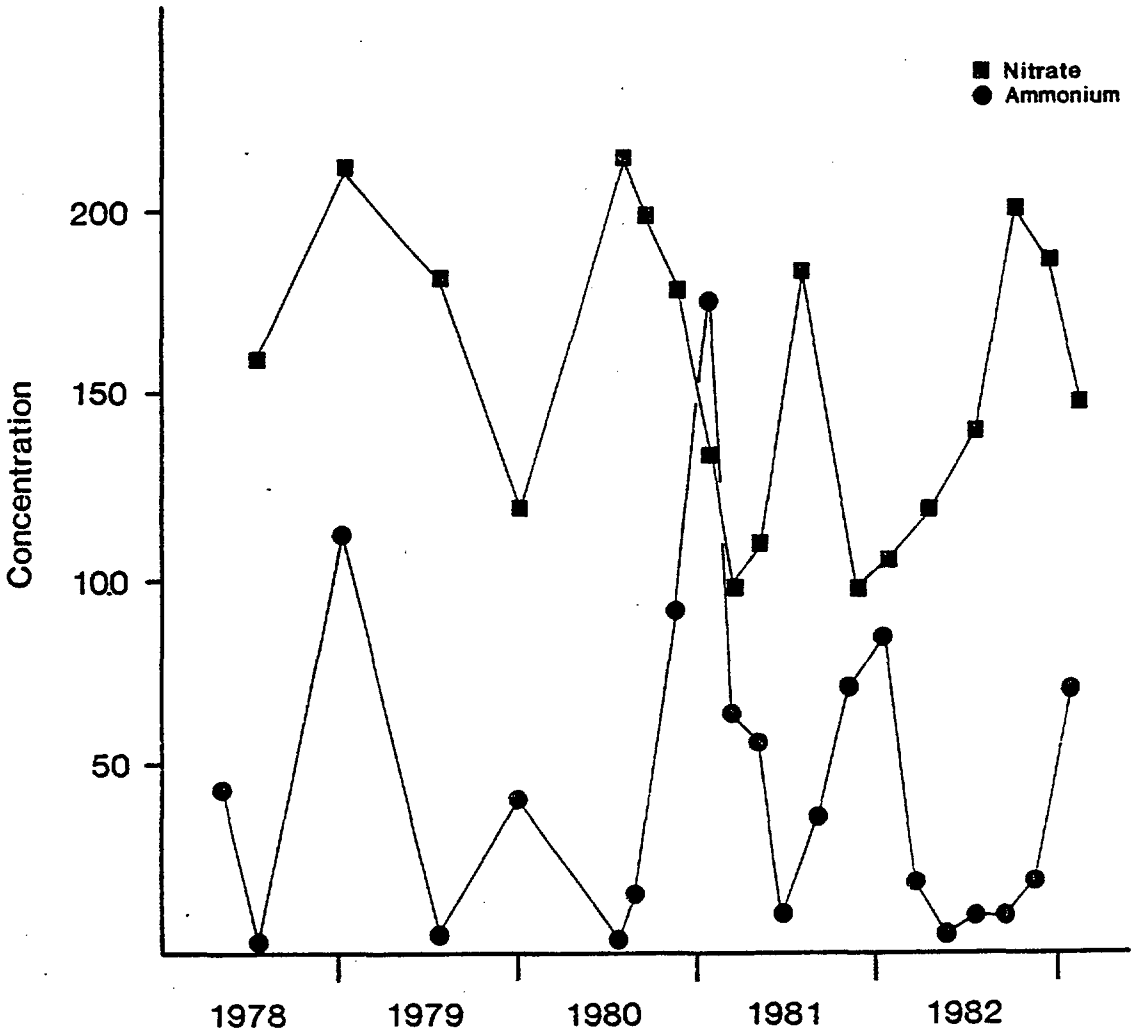

Figure 5-6. Nitrate and ammonium (uM) vs. time. Data are from stations in the upper estuary at the location of the freshwater end member (at 0-2°/oo salinity).

Geochemical processes also influence the distribution of nutrients. With the exception of the spring bloom, there is a relatively constant concentration of phosphate in estuarine waters between 0 and 15°/oo salinity. This can be explained by the operation of a phosphate buffer. In laboratory experiments, phosphate has been shown to move from suspended particulate material into the water column (Pomeroy et al. 1965). This exchange phenomenon maintains the concentration of about 1.5 uM phosphate in the upper Delaware Estuary. The occurrence of this phosphate buffer system has been found in other estuaries (Butler and Tibbitts 1972, Morris et al. 1981).

CONCLUSIONS

High concentrations of nutrients introduced in the freshwater region of the estuary are reduced by mixing with seawater. In spring, ammonium, phosphate, and silicate are depleted from the middle and lower estuary and may limit primary production in the estuary. Physical, biological, and geochemical processes that add and remove nutrients also occur within the estuary.

Increased or decreased inputs of nutrients would have an initial effect on the level of production during spring. Changes in inputs would lower or raise nutrient levels throughout the estuary in summer and winter, but would have little effect on distribution trends. Increased or decreased inputs in spring would affect the level of productivity in the lower estuary. Changes in sediment loading could greatly influence nutrient patterns and processes.

Research on processes is crucial to increase our understanding of the nutrient dynamics of the estuary. Important areas of research presently being undertaken are benthic and water column regeneration and modeling of nutrient behavior.

Chapter 6

ORGANIC MATTER

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INTRODUCTION

Estuarine organic compounds are found in both dissolved and particulate forms, and originate from natural biological systems and anthropogenic sources. The distribution of organics in estuaries depends on source concentration, degree of mixing, transport, geochemical reactions, and biological interactions. Organics can be either beneficial or toxic to phytoplankton productivity and higher trophic levels in food webs. For example, dissolved organic compounds react with trace metals and often decrease the toxicity of metals (Saar and Weber 1982). Labile organics provide material for bacterial remineralization of nutrients which can lead to greater productivity (Williams 1981). On the other hand, in water with high organic concentration the oxidation of organics can result in oxygen depletion. Some manmade organic compounds (e.g. PCBs, DDT) are harmful to the biota even at parts per billion concentrations (Goldberg 1975).

To study organics in natural environments by cataloging and measuring individual organic compounds is an enormous and essentially impossible task. A more successful approach is to divide organics into several classes, such as carbon-, nitrogen-, and phosphorus-containing organics. These classes are usually subdivided into dissolved and particulate groups. The dissolved/particulate division is by definition: dissolved organics are those that pass through a microporous filter (various conventions use cut-offs ranging from 0.2 to 2 microns), and particulate organics are those that are retained on the filter. This size classification is functional, not chemical; the choice of filter is somewhat arbitrary (Sharp 1973).

Recent advances in analytical chemistry have improved the ability to measure specific organic compounds in seawater, particularly those that are important in biological and chemical processes of estuarine systems. Examples include amino acids, sugars, and urea; these are all organic compounds that function in estuarine biochemical cycles. Also of interest are halogenated organics which form when natural waters are chlorinated. Although the exact nature of these compounds is unknown, there is sufficient evidence to suggest that some of them are highly toxic (Tardiff et al. 1978). Natural and altered hydrocarbons are ubiquitous in industrial environments and high concentrations of these compounds can also be harmful to living systems (Goldberg 1975). Finally, humic materials are highly condensed organics naturally derived from runoff of land that can complex metals in aquatic systems (Saar and Weber 1982).

The following section discusses sources of organics to the Delaware Estuary and possible removal during estuarine mixing. Upper and lower estuary seasonal trends are examined next, and biological and geochemical effects on organics are discussed in the final section.

SOURCES AND MIXING OF ORGANIC MATTER

To facilitate examination of sources, transport, and seasonal changes of organic concentration, a large organic data set was reduced. Two years of data from bimonthly cruises beginning September 1980 and ending November 1982 were analyzed in three ways: by pooling data into six estuarine regions and averaging; by pooling data into salinity intervals and averaging; and by taking pooled data, separating into three "seasons", and averaging.

Organic matter comes into estuaries from rivers, exchange with marshes, atmospheric fallout, and exchange with marine waters. In addition, organic matter is produced in situ in estuaries (municipal and industrial sources of BOD are discussed in Chapter 4).

During five cruises (spring and summer only) extensive sampling was also done in shoal areas of the estuary. Data from this set of cruises were separated into six zones to compare regional differences in organic concentration. Zones include the river above 75 nmi, the turbid region of the estuary (30-75 nmi), the central channel of the lower estuary, the coastal area beyond the estuary mouth, the New Jersey shoals, and the Delaware shoals. The average concentration of each constituent was calculated for each zone.

River run-off strongly influences dissolved organic concentrations in the Delaware Estuary. For example, concentrations of dissolved organic carbon (DOC), dissolved organic nitrogen (DON), and humic acid nitrogen (HAN) were highest in the river where terrigenous run-off, and also aquatic production and anthropogenic inputs, all are important (Table 6-1). On the other hand, dissolved organic phosphorus (DOP) concentrations were relatively uniform throughout the estuary. Of the dissolved organics, only humic acid carbon (HAC) had highest concentrations in the shoals and lower estuary.

Results were consistent with earlier studies that, in general, showed higher riverine dissolved organic concentrations than coastal or oceanic organic concentrations (Head 1976). This study is the first to report estuarine concentrations of organic phosphorus. The uniformity of DOP could reflect the biogeochemical reactivity of phosphorus in estuarine systems. Results for humic acids suggest that marshes could be an important source of humic material with a higher carbon-nitrogen ratio than riverine humic material. As expected, dissolved organic concentrations were always lowest in the coastal region; DOP and HAC showed minor differences between the central channel of the estuary and coastal regions.

Table 6-1. Average concentration (five spring-summer cruises) of salinity and organics in six different regions of the Delaware Estuary: river above 75 nmi (region 1), turbid portion of the river - 30 to 75 nmi (region 2), central channel in the lower bay (region 3), coastal region (region 4), New Jersey shoals (region 5), and Delaware shoals (region 6). See text for organic symbols. Units are $^o/oo$ for salt and micromolar of the element (carbon, nitrogen, phosphorus) for the organic matter.

	REGION					
PARAMETER	1	2	3	4	5	6
Salt	0.06	4.30	23.90	31.23	21.02	24.87
DOC	319	325	217	166	289	247
DON	67.7	46.3	25.5	11.1	35.4	29.1
DOP		0.40	0.32	0.41	0.44	0.35
PC	58	102	91	55	159	194
PN	15.3	13.1	9.6	5.2	19.8	24.9
PP	2.38	2.34	0.87	0.42	1.70	2.42
HAC	20.5	13.6	24.1	24.5	29.4	32.0
HAN	3.6	1.7	1.7	1.4	2.4	2.3

Measurements of urea and dissolved amino acids (nitrogen containing compounds) were made throughout the estuary during the first year of this study. Results showed higher urea concentrations in the upper estuary, whereas amino acid concentrations were higher in the lower estuary (Figure 6-1). Nitrogenous effluent inputs could account for high river concentrations of urea. Removal indicated by the property-salinity diagram probably resulted from biological uptake. High dissolved amino acid concentrations are likely to be found in highly productive areas. Low values in the turbid region of the estuary were due either to low production or to adsorption on particulates and subsequent removal.

High particulate organic concentrations were found in regions of high suspended load. Particulate carbon (PC) and particulate nitrogen (PN) concentrations were highest in shoal areas. Particulate phosphorus (PP) was highest in the upper estuary and the New Jersey shoals. However, when normalized to seston values, PC concentrations were lower in the entire upper estuary and the Delaware shoals. Normalized PN and PP concentrations were

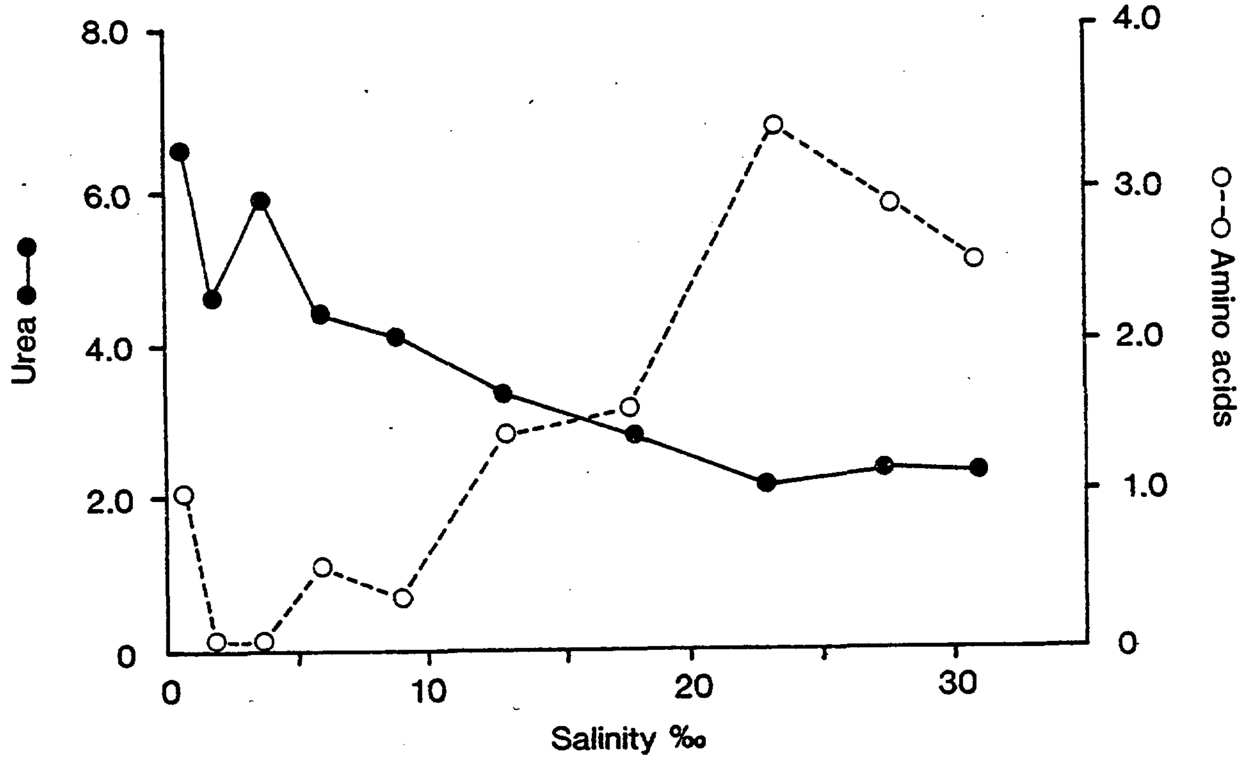


Figure 6-1. Urea and amino acids vs. salinity. Data are from salinity intervals (see text for explanation) from six sampling periods, 1980-81. Concentrations in micromoles nitrogen per liter.

lower in the turbid and Delaware shoal regions. In shallow turbid regions, organic matter in suspended sediments is diluted by inorganic silts and clays. This effect is not as strong in the New Jersey shoals in spite of high seston concentration.

In estuarine mixing of organics, removal, addition, and chemical alteration are important processes. Removal mechanisms of organic matter in estuaries include sedimentation, geochemical removal, and biological uptake. Addition occurs by in situ production, sediment resuspension, and lateral inputs (e.g. marshes, tributaries). Chemical changes are discussed below.

Data (15 cruises) from stations taken down the longitudinal axis of the estuary were pooled into 10 salinity intervals: 0-1.0, 1-2.5, 2.5-5.0, 5.0-7.5, 7.5-10.0, 10.0-15.0, 15.0-20.0, 20.0-25.0, 25.0-30.0, and greater than 30.0^{o}/oo. Salinity intervals were chosen to emphasize physical-chemical

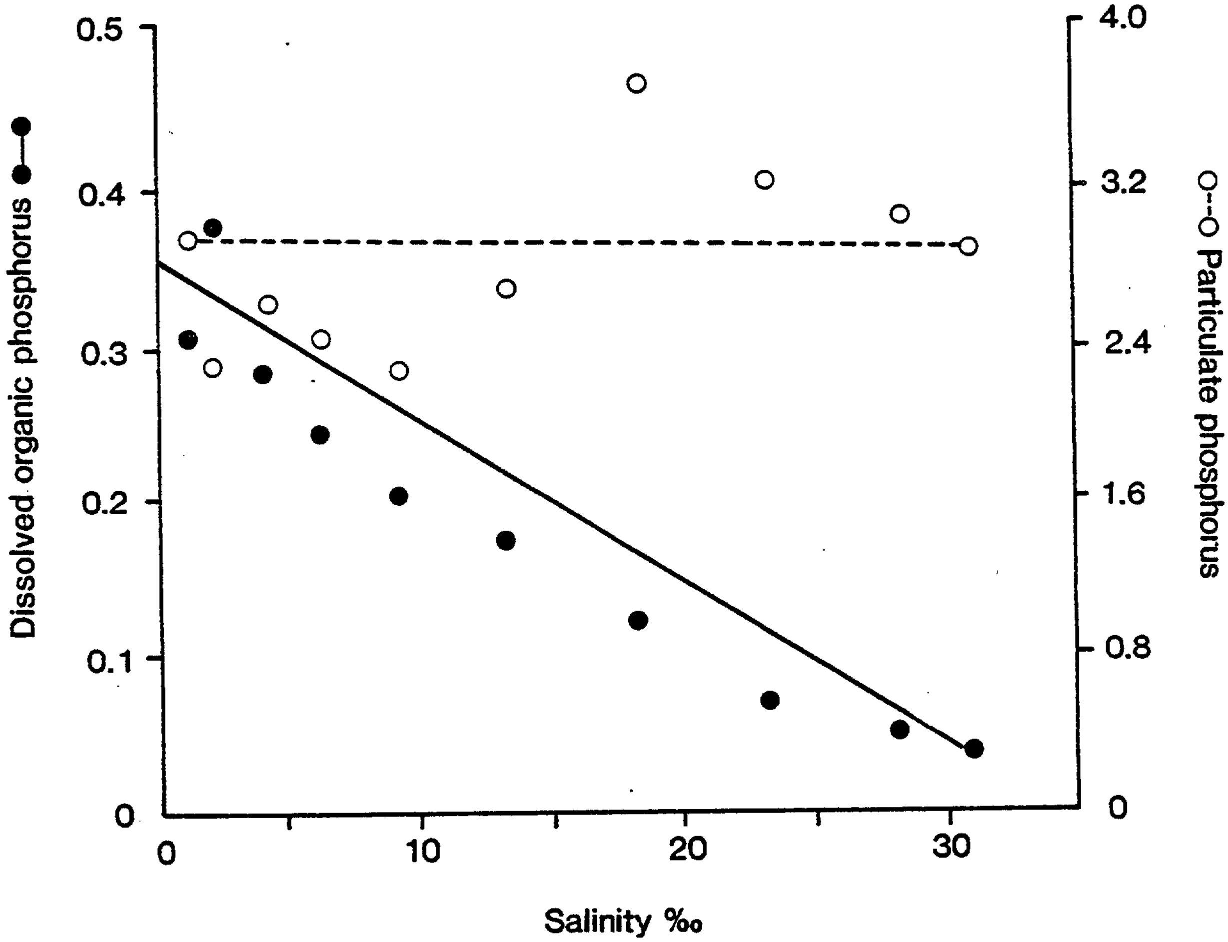


Figure 6-2. Dissolved organic phosphorus (DOP) and particulate phosphorus (PP) vs. salinity. Data are averages (see text for explanation) from fifteen cruises, 1980-82. Concentrations in micromoles phosphorus per liter.

processes in the upper estuary, particularly increasing ionic strength and high suspended sediment loads. For each constituent, data within each salinity interval were averaged.

Property-salinity diagrams were generated from these reduced data. A straight mixing line between river end-member (0-1.0°/oo interval) and coastal end-member (30.0°/oo) would indicate that a constituent is mixed conservatively

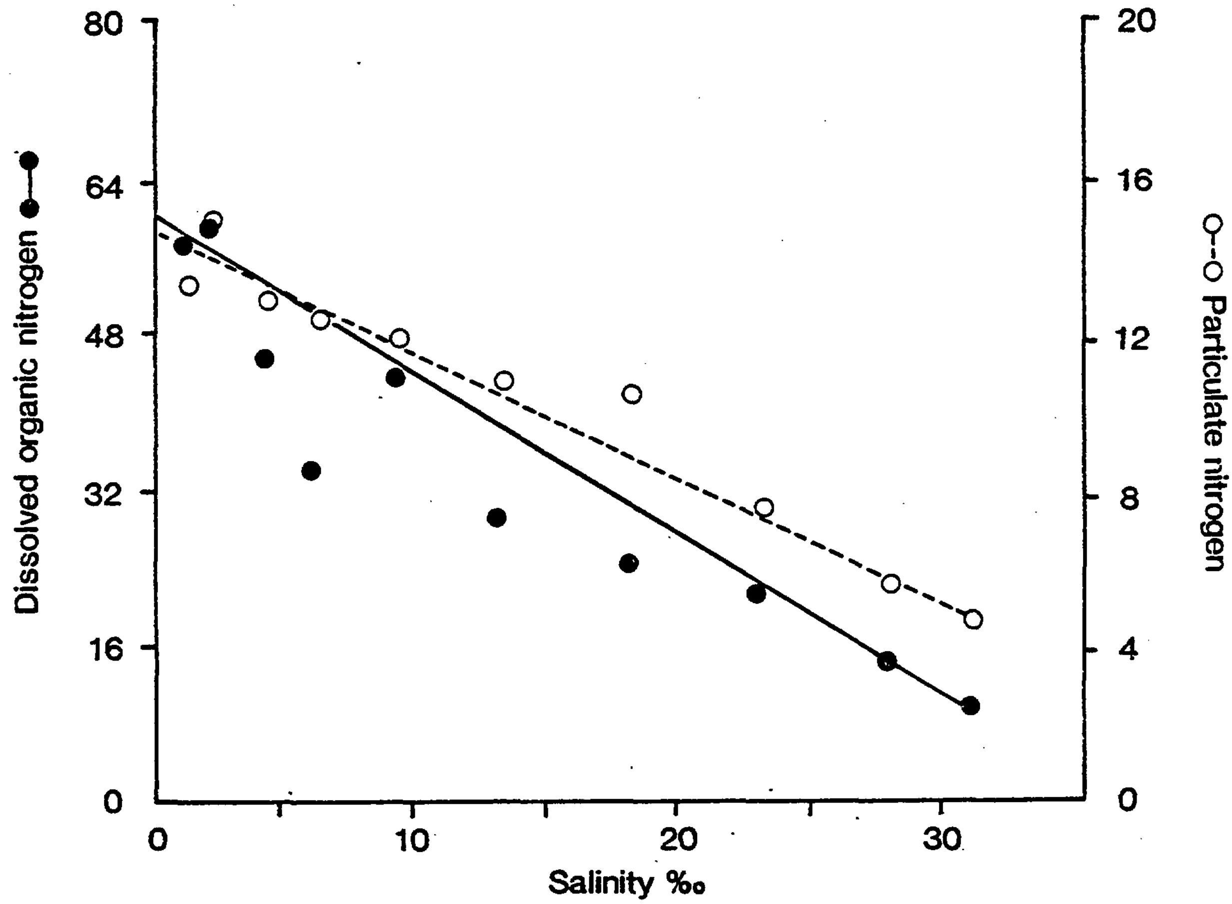


Figure 6-3. Dissolved organic nitrogen (DON) and particulate nitrogen (PN) vs. salinity. Data are averages (see text for explanation) from fifteen cruises, 1980-82. Concentrations in micromoles nitrogen per liter.

in the estuary; in effect, there are no other sources or sinks. A concave-down curve would suggest constituent removal, whereas a concave-up curve would suggest constituent addition. Property-salinity diagrams only indicate net loss or addition of constituent relative to the concentration predicted by end-member mixing. No information can be drawn from property-salinity diagrams regarding the nature of removal or addition mechanisms.

Removal was implied for DOP and PP (Figure 6-2) in the upper estuary while the removal of DON occurred in the upper and middle estuary (Figure 6-3). The removal of DON and DOP could be biological. Particulate phosphorus and, perhaps, some DOP removal could be attributed to phosphate buffering in this region.

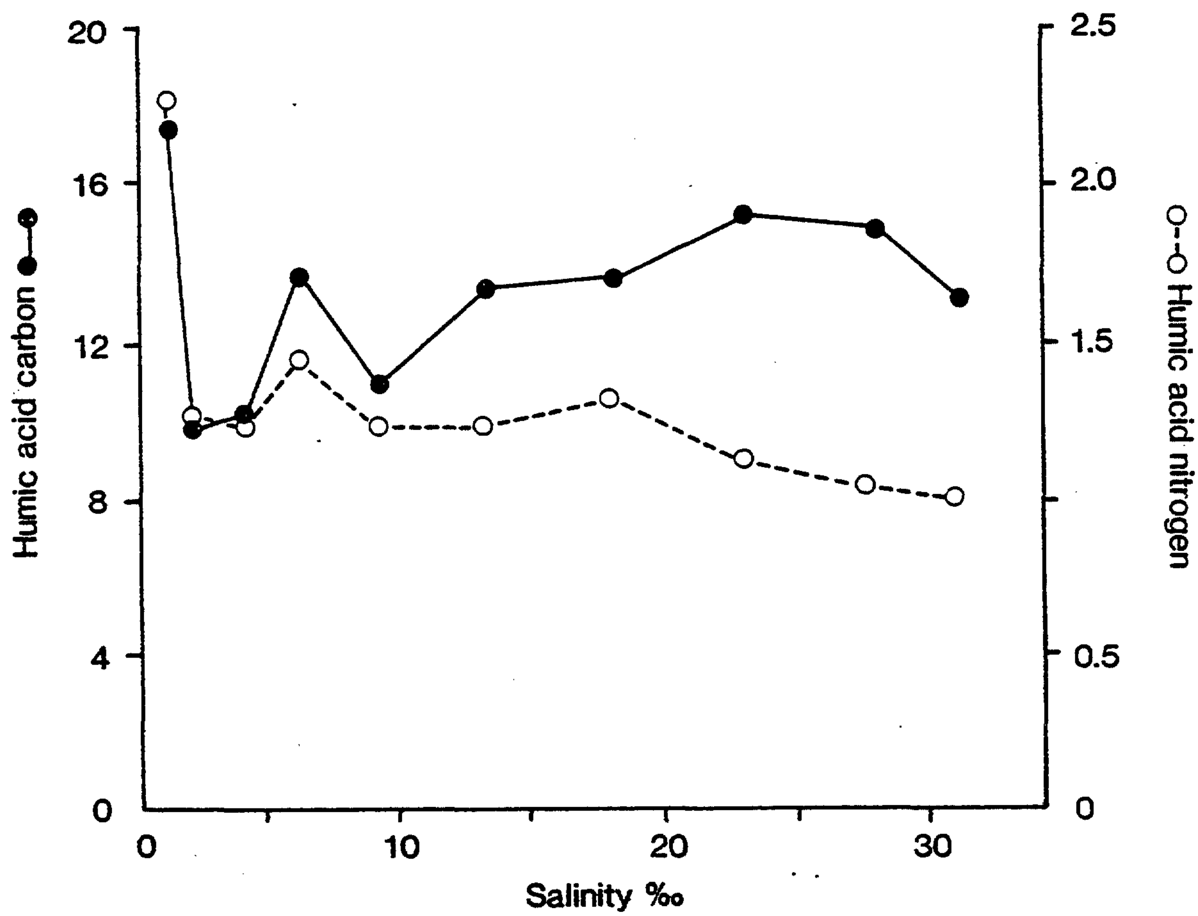


Figure 6-4. Humic acid carbon (HAC - micromoles carbon per liter) and humic acid nitrogen (HAN - micromoles nitrogen per liter) vs. salinity. Data are averages (see text for explanation) from fifteen cruises, 1980-82.

Removal of HAC and HAN occurred in the upper estuary (Figure 6-4). Similar behavior is found in other estuaries (Fox 1982). It is thought that humic acid removal in estuaries is geochemically controlled (Sholkovitz 1976). During individual cruises, particularly during the spring bloom, the removal curves for HAC were shallow. A possible explanation is that humic material produced in situ in the estuary behaves differently from river humic material dominated by terrigenous sources (Fox 1982). In addition, changes in humic carbon-nitrogen ratio (discussed below in Biogeochemistry of Organic Matter) in the upper estuary suggested either selective removal of HAN or another source.

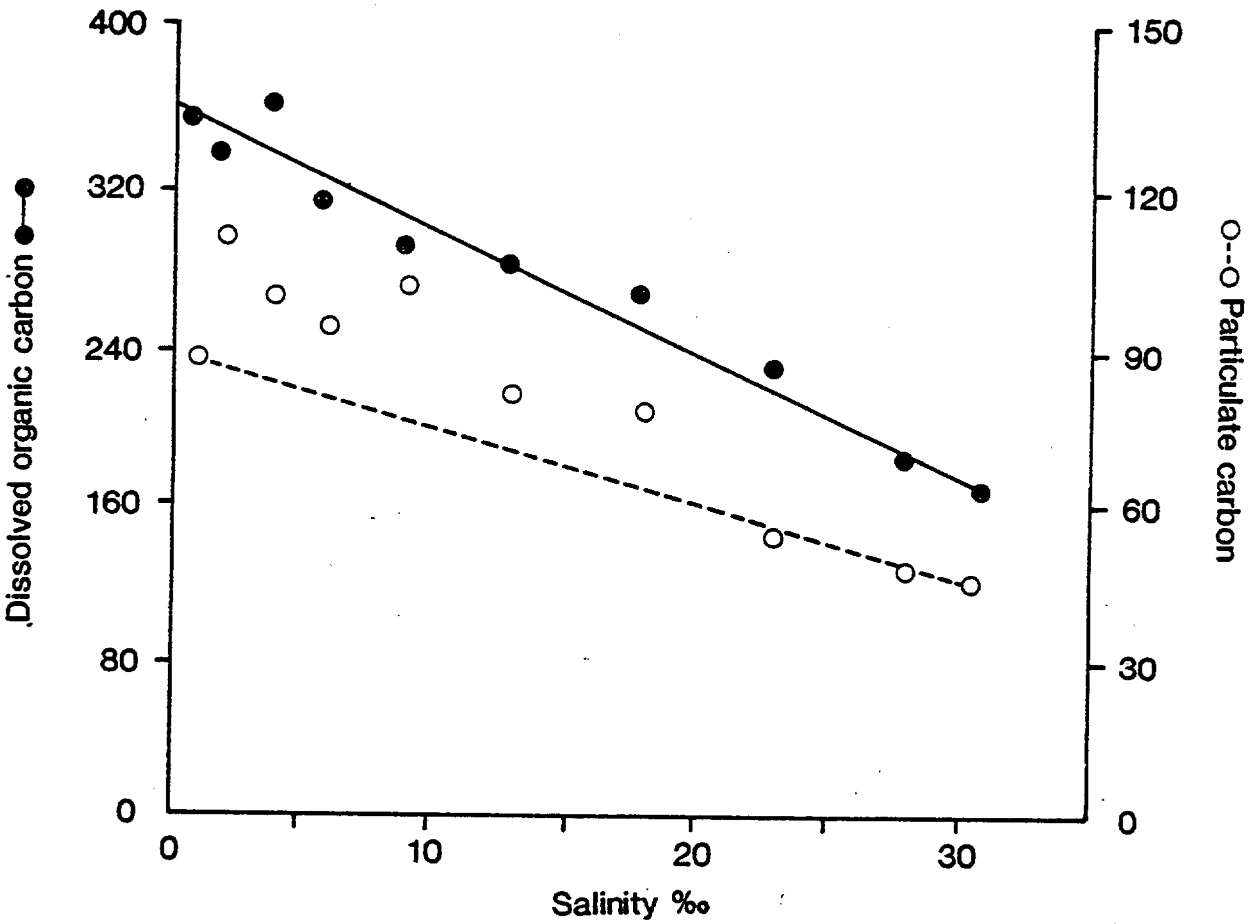


Figure 6-5. Dissolved organic carbon (DOC) and particulate carbon (PC) vs. salinity. Data are averages (see text for explanation) from fifteen cruises, 1980-82. Concentrations in micromoles carbon per liter.

Inspection of mixing diagrams showed conservative mixing for DOC (Figure 6-5) and PN (Figure 6-3). Higher concentrations of these constituents in shoal regions do not appear to be mixed into the central channel of the lower estuary. Small increases in the PN concentration probably reflected increases in suspended sediment concentration.

Only particulate carbon showed addition throughout the estuary (Figure 6-5). While HAC and DOP also showed addition, it was only in the lower estuary (Figure 6-2, 6-4). In the upper estuary, PC increase probably resulted from resuspension. Lower estuary increase in PC, HAC, and DOP probably resulted from in-situ production and from marsh sources that are mixed into the central channel of the estuary. If lateral mixing were the major source of increased organic concentrations in the central channel, similar increases in DOC and PN would be expected.

Organic carbon concentrations in the Delaware Estuary are average for coastal plain estuaries (Mantoura and Woodward 1983). No pronounced increases were found in the vicinity of Philadelphia, Pennsylvania, or Wilmington, Delaware. However, organic nitrogen concentrations are relatively high. There is a large nitrogenous oxygen demand in the Delaware River (EPA Report 1973), primarily from ammonium inputs. Based on our measurements, biogenic nitrogen compounds (urea, amino acids, proteins) account for less than 50% of the organic nitrogen (Cifuentes 1982). Some of the uncharacterized pool of organic nitrogen could be organic amines. The role of the uncharacterized organic nitrogen in biological and geochemical cycles merits future study.

A recent study of hydrocarbons in the Delaware Estuary (Wehmiller and Lethen 1975) suggests that there is recent deposition of estuarine organic material in the turbid region of the estuary (see Chapter 7). In the rest of the estuary, it is difficult to distinguish between diagenetically altered organic material and petroleum deposition. Thorough studies of the organic composition of sediment in all the regions of the estuary are needed to distinguish areas of petroleum contamination from areas of impoverished organic deposition or rapid diagenesis.

SEASONAL TRENDS

Seasonal changes in organic constituent concentrations reflect seasonal changes in river flow, productivity, and temperature. Changes in river flow can either increase or decrease concentrations depending on the sources. Point sources are diluted by increased flow, while some runoff products increase in concentration because of increased weathering. During highly productive seasons, particulate organics are formed and dissolved organic concentrations increase because of excretion, leaching, and "sloppy" zooplankton feeding.

Table 6-2. Seasonal averages of 30-day-averaged gauged river flow (m^3/sec) prior to each cruise (Trenton, NJ), areal primary production, and organic concentrations for upper and lower estuary. Summer (June-October), winter (November-February), spring (March-May). See text for organic symbols. Units for organic matter are micromolar of the element carbon, nitrogen, phosphorus.

PARAMETER	SUMMER	WINTER	SPRING
River flow	144	136	571
Upper - main axis stations, 0.0-10 parts per thousand salinity			
Aprod	37.0	5.0	21.2
DOC	351	363	311
DON	64.6	63.2	54.4
DOP	0.38	0.38	0.33
PC	95.4	104	104
PN	10.5	14.6	14.7
PP	1.8	2.4	2.6
HAC	14.4	6.7	16.3
HAN	1.7	0.9	2.0
Lower - main axis stations, 10-32 parts per thousand salinity			
Aprod	79.2	12.7	60.2
DOC	236	230	217
DON	23.1	26.6	26.9
DOP	0.51	0.29	0.37
PC	66.4	67.2	71.4
PN	6.3	8.3	11.1
PP	0.7	1.1	1.0
HAC	18.4	7.3	17.2
HAN	1.4	0.8	1.7

Conversley, increasing temperature stimulates higher heterotrophic uptake of organic matter. Because all of these factors are interrelated, care must be exercised in interpreting seasonal changes in organic concentration.

In order to understand seasonal changes, the organic data were separated into three seasons: summer-fall (June-October), winter (November-February), and spring (March-May); the same three seasons were delineated for river flow in Table 2-2 (Chapter 2). The data were also separated into less than and greater than 10.0°/oo intervals to emphasize the differences in upper and lower estuary processes between seasons. Seasonal trends are discussed in terms of upper and lower estuary averages (Table 6-2).

In the upper estuary, DOC concentrations were low in spring during conditions of maximum river flow. DON and DOP concentrations showed only slight decreases. Particulate carbon, nitrogen, and phosphorus concentrations were lowest during summer, presumably because of low average flow. Humic acid carbon and nitrogen concentrations were much lower in winter.

In the lower estuary, DOC, DON, and PC concentrations were uniform throughout the year. The concentration of DOP was substantially higher in the summer; seasonal changes followed changes in areal production. Particulate nitrogen and phosphorus concentrations were lower in summer. As in the upper estuary, humic acid concentrations were substantially lower in the winter. Seasonal trends in humic materials reinforce the hypothesis that in-situ production could also be an important source of humic materials in the estuary.

BIOGEOCHEMISTRY OF ESTUARINE ORGANICS

The biogeochemistry of estuarine organics is complex. Different types of organics originate from the sources discussed above and these inputs behave differently in the changing environments of estuaries. Our attempts to understand the chemistry of estuarine organics focuses on relationships between estuarine production and ambient concentrations in the Delaware Estuary.

Marine algal material has been characterized by what is called the Redfield ratio of carbon to nitrogen to phosphorus (C:N:P) which is 106:16.1 (Redfield et al. 1963). These values are idealized; there are significant differences among marine environments. For example, these values can be affected by the physiology of algae and the ratio of nitrogen to phosphorus in nutrients available to algae. In complex estuarine environments, major

Table 6-3. Regional particulate, dissolved, and humic carbon-nitrogen (C/N) ratios normalized to Redfield ratios. Regional particulate carbon-phosphorus (C/P) ratios normalized to Redfield ratios. See Table 6-1 caption for location of regions. See text for organic symbols.

	REGION					
PARAMETER	1	2	3	4	5	6
PC/PN	0.6	1.2	1.5	1.6	1.2	1.2
DOC/DON	0.7	1.4	1.6	2.2	1.3	1.5
HAC/HAN	0.8	1.3	2.2	2.7	2.1	2.3
PC/PP	0.2	0.5	1.1	1.1	1.6	1.2

deviations from Redfield ratios occur because of changes in growth conditions of estuarine populations or because of inputs of organic material with different C, N, and P composition.

The river portion of the estuary close to Philadelphia was enriched in nitrogen and phosphorus (Table 6-3). Particulate, dissolved, and humic fractions were similar in carbon-nitrogen ratio. These data suggest that all riverine organic fractions come from similar sources. Nitrogen and phosphorus enrichment could be explained by riverine production in a nutrient-rich environment or by anthropogenic inputs. In addition, phosphorus enrichment could be explained by dissolved-particulate interactions.

In the turbid region of the estuary, suspended sediments were not as rich in organics (Chapter 8). Particulate organics remained phosphorus-rich, but were no longer nitrogen-rich. Inorganic phosphorus and particulate interactions should be important in this region. High PP concentrations may not be truly organic but in fact are probably from adsorbed inorganic phosphate. Since behavior of PN in the estuary was conservative, the increase in carbon-nitrogen ratio suggested inputs of carbon-rich particulates. A likely source was resuspended bottom sediments.

Removal of dissolved organic nitrogen resulted in higher dissolved carbon-nitrogen ratios. This mechanism could not explain higher observed humic carbon-nitrogen ratios. Humic materials are known to be removed from the water column in estuarine salinity gradients (Sholkovitz 1976). However, no studies indicate that humic nitrogen is preferentially removed. Thus, this increase in humic carbon-nitrogen ratio also suggests a source, perhaps resuspension, mixing with lower estuary humic material, or tributary inputs.

In the body of the estuary, there was organic enrichment in particulates. A slight increase in particulate carbon-nitrogen ratio was seen in the central channel relative to the shoal and turbid regions upstream. Particulate material was no longer enriched in phosphorus. There was slight phosphorus depletion in New Jersey shoals compared to the rest of the estuary. Dissolved carbon-nitrogen ratios were uniform and closely resembled particulates. Humic materials had a high carbon-nitrogen ratio and were also uniform throughout the lower estuary. Organics in this region probably represented a mixture of in-situ-produced organic material resembling normal ratios and of marsh inputs enriched in carbon.

The coastal region contained particulates that were comparatively organic rich (Chapter 8). Particulate carbon-nitrogen and carbon-phosphorus ratios resembled those for the central channel. However, dissolved and humic carbon-nitrogen ratios were nitrogen poor.

CONCLUSIONS

Our approach has been to understand the sources and transport of organics in the Delaware Estuary. We have measured gross classes of carbon-, nitrogen-, and phosphorus-containing organic compounds and have made preliminary measurements of amino acids, urea, and humic acids. Using this generalized approach, we conclude that the majority of dissolved and particulate organics in the Delaware Estuary comes from natural sources. There are no indications that manmade organics are quantitatively a major component of the total organic pool. However, they may make up a significant fraction of potentially toxic organics which could be present in the estuary at harmful levels.

During low flow periods, one and a half times the gauged flow at Trenton, New Jersey, could pass through power plants for cooling purposes. Chlorine, added to retard biofouling, is known to react with dissolved organics and to form highly toxic halogenated organics (Tardiff et al. 1978). The high levels of residual chlorine in power plant effluents vanish within a short distance of the effluent plume (Helz and Hsu 1978). In fact, our own measurements near the Edgemoor (Delaware) plant effluent plume recorded no residual chlorine. Future efforts should focus on monitoring levels of halogenated organics. These compounds can accumulate in the estuary and, at sufficiently high concentrations, may severely limit productivity.

While the organic concentrations in our area of study in the Delaware Estuary do not appear to cause severe oxygen depletion, the nature of organics may give insights into future management decisions. In addition to more research on halogenated organics, study is also warranted on the nature of organic matter, especially the uncharacterized organic nitrogen, and on specific organic matter of anthropogenic origin, e.g. petroleum hydrocarbons and coal leachates.

Chapter 7

BOTTOM SEDIMENTS

R.B. Biggs, T.M. Church

INTRODUCTION

Bottom sediments in an estuary can be envisioned as historical records of conditions both within the estuary and in its immediate drainage basin. The bottom sediments of estuaries are important for their influence on water quality because the sediments often contain fallout from waterborne components, which can be remobilized and returned to the water column. Bottom sediments are also significant considerations in transportation management because stable channels needed for port facilities are maintained by dredging.

This chapter is organized into three sections: sediment texture, which treats the size of the sediment components; sediment mineralogy, which deals with the inorganic sediment makeup listed by mineral type; and sediment organic matter, which treats the organic content, and nature of sediments.

SEDIMENT TEXTURE

Figure 7-1 illustrates the texture of bottom sediments. The estuary may be divided into two zones north and south of Liston Point ($39^{o}25'$): the zone

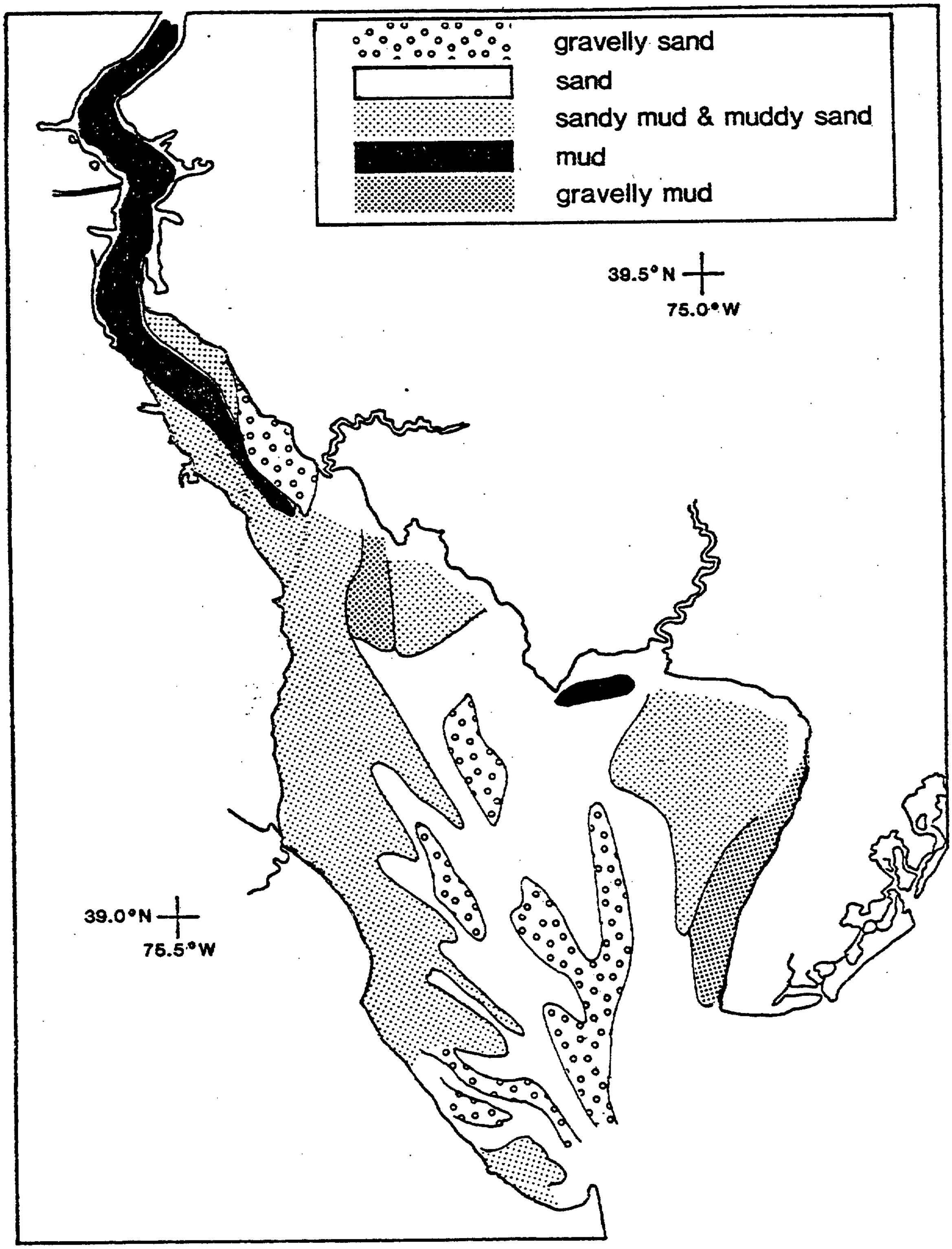


Figure 7-1. Bottom sediment texture in the Delaware Estuary. After Weil (1977), Maurer and Watling (1975), and USACE (1973).

Table 7-1. Sediment characteristics for upper Delaware Estuary open waters, shown with percentages of total area occupied by the sediment type. Upper Delaware Estuary defined as area north of 39°25', south of Marcus Hook and below mean low water. Tabular data obtained from plots of Army Corps of Engineers (USACE 1973). Based on Folk (1974) sediment texture classes.

Sediment Type	% Total Area
Gravel	less than 1
Gravelly sand	less than 1
Slightly gravelly sand	less than 1
Sand	less than 1
Muddy sand	7
Sandy mud	36
Mud	greater than 53
Percent mud in the sediments	
0-10	less than 1
10-25	less than 1
25-50	7
50-75	25
75-100	greater than 66

north characterized by muddy sediments, and the zone south to the sea, characterized by coarser sediments.

The characteristic sediment types found in the upper estuary are over 90% muds and sandy muds. Locally important exceptions can occur, especially in the lower estuary shallow waters where sands may dominate, or in certain channel pockets where silts dominate. These narrow zones are not shown on Figure 7-1 or in Table 7-1. Weil (1977) has described the lower portion of this reach as the submarine delta of the Delaware River. The area in the vicinity of Artificial Island is approximately the null point of the Delaware Estuary (the location in the estuary where bottom currents are exactly balanced during the ebb and flood tidal phases). The null point is a likely place for fine sediments to accumulate. Thus the upper estuary is generally characterized by the sediments from the null zone extending downbay to Liston Point (where the fine sediments are also organic-rich).

Table 7-2. Sediment characteristics for lower Delaware Estuary open waters, shown with areas and percentages of total area occupied by the sediment type. Lower defined as area south of 39°25', north of Cape May-Cape Henlopen, and below mean low water. Tabular data obtained from maps presented in Weil (1977). Based on Folk (1974) sediment texture classes. The area does not include 412 km^2 (159.1 mi^2) of salt marshes that border the estuary.

Sediment Type	Bottom Area (km^2)	% Total Area
Gravel	21	7
Gravelly sand	53	18
Slightly gravelly sand	12	4
Sand	115	37
Muddy sand	30	10
Sandy mud	67	22
Mud	5	2
Percent mud in the sediments		
0-10	155	51
10-25	54	18
25-50	21	7
50-75	67	22
75-100	6	2

Lower Delaware Estuary sediments (south of 39°25') are texturally distinct from those upstream of the null point. While the upper estuary bottom is 90% sandy muds and muds, the lower estuary contains less than 25% sediments of these textures (Table 7-2). Weil (1977), using statistical techniques, has identified three major sedimentary environments in the lower estuary: channel sands and gravels, open estuarine fine sands with mud, and estuarine quiet water muds (Table 7-3). The principal sources of these sediments are shore and bottom erosion, the remains of estuarine organisms, and input from the ocean (U.S. Army Corps of Engineers 1973). The sands just inside the bay mouth appear to be derived from the New Jersey and Delaware coasts or the shallow continental shelf. The New Jersey and Delaware ocean coasts contribute approximately 200,000 and 350,000 tons per year respectively, of sands to the bay (USACE 1973).

Table 7-3. Major estuarine sedimentary environments in the lower Delaware Estuary, shown by dividing the same area of Table 7-2 into three regions defined by cluster analysis of the mud fraction of 411 bottom samples (Weil 1977).

Sedimentary Environment	Bottom Area (km^2)	% Total Area
Channel sands - med. to coarse sands with low mud content (less than 35%)	168	55
Open estuary sediments - fine sands with variable mud content (0-50%)	125	41
Estuarine muds - primarily mud (greater than 50%) with fine sands)	10	4

The principal processes responsible for the observed sediment texture in the lower estuary are the strong tidal currents, which produce coarse sediments in the bottom of deep channels, and windwave suspension of bottom sediments in shallow areas. Superimposed on and modifying these processes is a circulation pattern, influenced by the Coriolis effect, which is caused by the rotation of the earth. This pattern causes the ocean-derived waters to dominate on the New Jersey side of the bay and fresher waters from the river to hug the Delaware shore. Sands containing characteristic minerals derived from the New Jersey ocean coast are swept around Cape May into the bay and can be traced as far upbay as the Cohansey River mouth. Sands derived from the Delaware ocean coast are swept around Cape Henlopen into the bay where they are deposited almost immediately, causing the Cape to grow rapidly to the northwest. Fine sediments, carried downstream from the river in the fresher waters, are preferentially deposited on the Delaware side of the estuary. Figure 7-2 illustrates important paths of sediment transport.

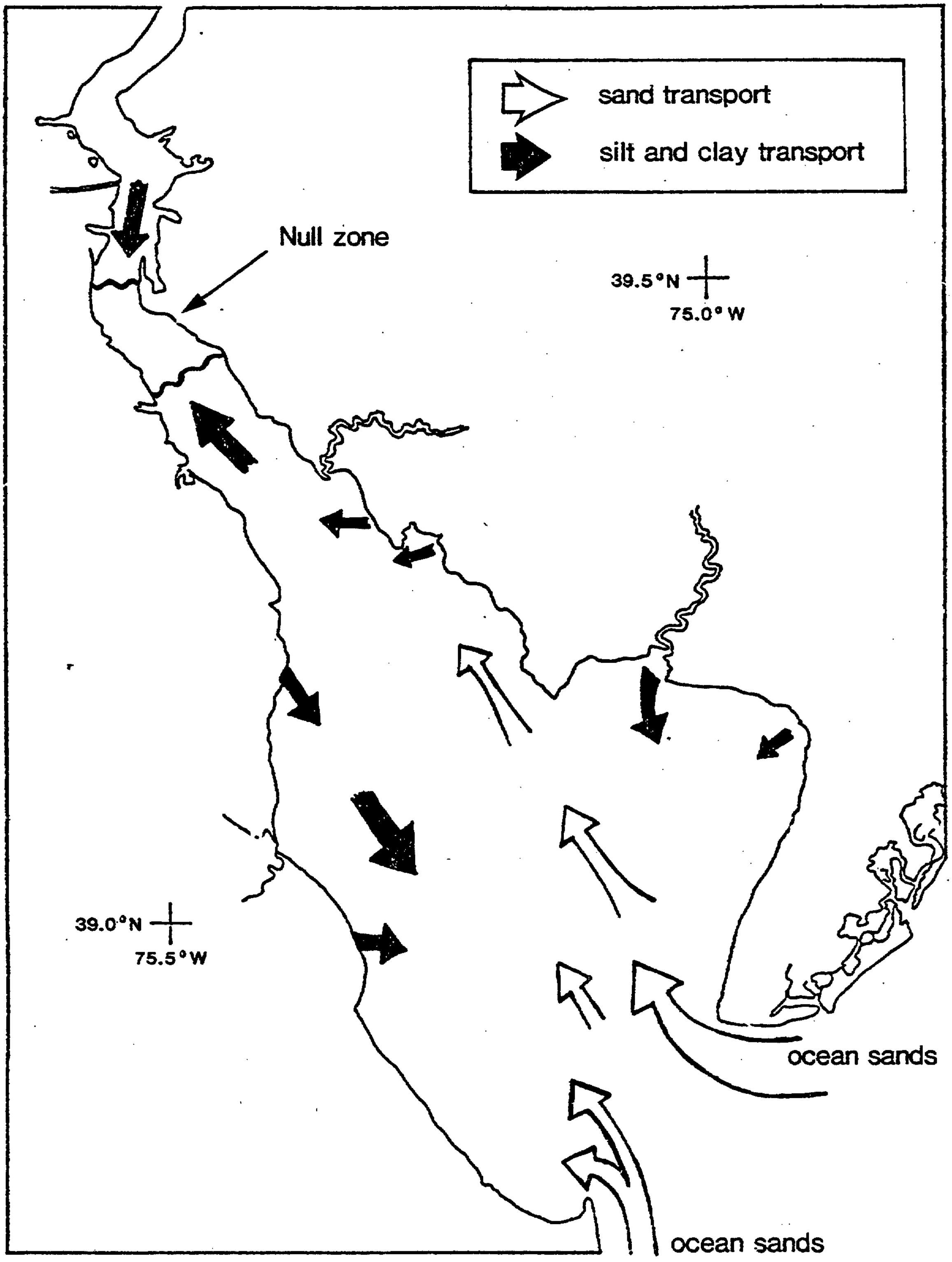


Figure 7-2. Generalized sediment transport pattern for the Delaware Estuary.

Table 7-4. Average mineralogical content of bottom sediments, shown for three regions the Delaware Estuary. The upper region is from Wilmington to Ship John Lighthouse, the lower region is from Ship John Lighthouse to the capes, and bay mouth is the immediate vicinity of the capes. Composition is given as percent of total sediments for that location; additionally, percentages of individual clay minerals are shown in parentheses. Data are from USACE (1973).

Constituent	Upper (%)	Lower (%)	Bay Mouth (%)
Quartz	57	83	93.5
Feldspar	10	6	3.4
Mica	0.7	1	0.2
Heavy minerals	1.1	2.8	0.5
Organic matter	2.2	0.5	0.3
Coal	3.2	0	0
Diatoms	8.0	0.3	0.1
Amorphous iron	0.7	0.1	0.1
Shell, slag, and rock particles	0.2	1.8	0.5
Clay minerals	16.5	4.3	1.4
Individual minerals (as percent of total clays)			
Illite	(65)	(59)	(72)
Chlorite	(20)	(26)	(23)
Kaolinite	(10)	(8)	(3)
Montmorillonite	(5)	(7)	(2)

SEDIMENT MINERALOGY

Table 7-4 summarizes the average composition of bottom sediment for the Delaware estuary. All sediments are predominantly quartz. The percentage of quartz increases, and the feldspar concentration decreases towards the sea, reflecting the quartz-rich, mineralogically mature coastal and shelf sediments, which are the source of the lower estuary sands. Clay mineral, diatom, and organic matter contents decrease down the estuary following the general decline in concentration of fine material. The clay minerals present in Delaware bottom sediments are illite, chlorite, kaolinite, and montmorillorite. There is no measurable variation in bottom sediment proportions of these minerals along the estuarine gradient.

SEDIMENT ORGANIC MATTER

Numerous investigators have studied the distribution of total organic materials in Delaware Estuary sediments (USACE 1973, Maurer and Watling 1975, Strom 1976, and Bopp 1980). Figure 7-3 is a composite of all of the data on organic content for Delaware Estuary sediments. Values are based on measurement of loss on ignition, a standard technique for estimating organic content of materials.

As a generalization, the distribution of organic matter in the estuary sediments follows the mud content. Sediments are richer in organics in the upper estuary and along the Delaware coast where mud content is relatively high, and are poorer in the coarse sediments near the bay mouth and in the deep channels.

Wehmiller and Lethem (1975) have separated and analyzed the hydrocarbon fraction of the organic matter from 23 bottom samples in the estuary. Although hydrocarbons are a minor component of the sedimentary organic pool, they can be used as gross indicators of petroleum contamination. Hydrocarbons are also present in living systems and are dominated by odd-carbon chains (C21-23-25,...). The carbon preference index (CPI) is a measure of the abundance of biologically dominated organic matter (odd carbons) compared with petroleum products or diagenetically altered organic matter (uniform odd-even carbons). Wehmiller and Lethem computed the CPI for sediments in the estuary. Their results are illustrated in Figure 7-4. Low CPIs (equal to or less than 1) indicate extensively altered organic matter or petroleum contamination; high values indicate fairly "fresh" organic matter. In the Delaware River below Philadelphia the CPI is low, perhaps due to sewage or petroleum and other natural organic materials which have been extensively modified. The region from Marcus Hook to Artificial Island has the highest observed CPIs,

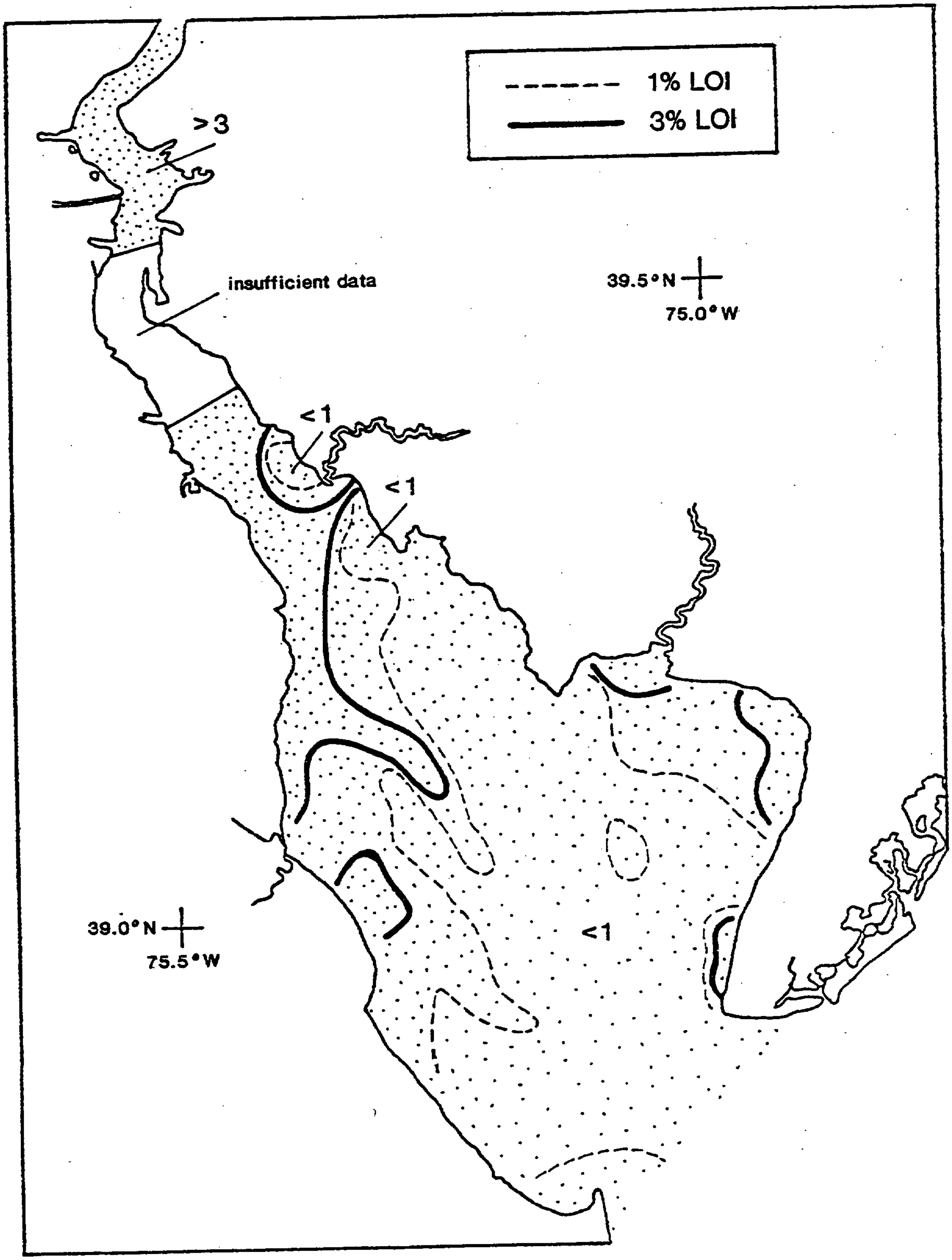


Figure 7-3. Organic content of sediments as shown by loss on ignition (LOI). Composite of data cited in text.

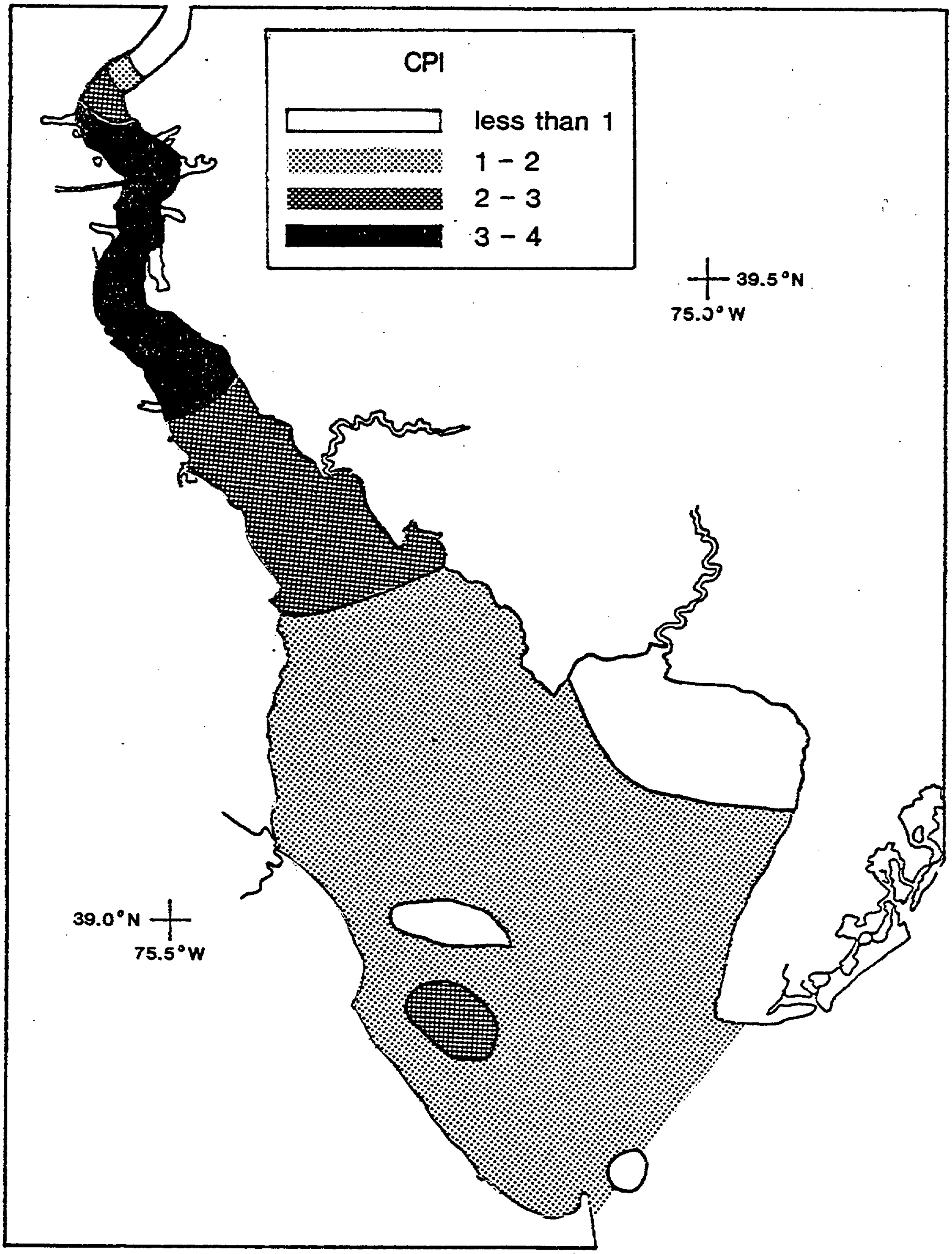


Figure 7-4. Carbon preference indext (CPI) for Delaware Estuary sediments. From data of Wehmiller and Lethem (1975).

indicating the deposition of the freshest organic matter. In fact, the sediments of this area are also found to contain the highest concentrations of diatom remains in the estuary (USACE 1973). Farther downstream, intermediate CPIs are found along the Delaware side of the bay with lowest values found associated with the coarse channel sands. The extent to which this extensively modified organic matter of the lower bay is due to natural or man derived sources is unknown.

Organic matter in the bottom sediments is a complex mixture of natural sources produced by plankton, marsh and upland vegetation, and man-derived sources from sewage and petroleum. All of these can in time be modified after deposition by biogeochemical processes (diagenesis) within the sediments. Thus it is not possible, at the present time, to indicate the sources of this organic matter.

CONCLUSIONS

The bottom of the lower Delaware Estuary is blanketed by sandy sediments dominated mineralogically by quartz with organic content of less than one percent carbon. The upper estuary consists of quartz-rich, muddy sediments with more abundant clays and a higher content of organic matter.

Most of the data on the water depth of the estuary were collected in 1845-55; an extensive survey has not been repeated. The National Ocean Service is now conducting new bathymetry and has completed the survey from Trenton to Wilmington. In the absense of this detailed new bathymetry, we cannot estimate rates or volumes of sedimentation or erosion beneath the estuary in non-navigation areas (see Chapter 8 for a gross sediment budget). However most organic and inorganic toxic materials show a marked preference for attachment to fine-grained particles (see Chapter 9 for trace metals). Since most of the fine material coming from upstream is preferentially deposited on the Delaware side of the estuary, one might expect most of the toxic elements to be also. However, as is seen in Chapter 9, increased concentration of some trace metals are seen on either side of the estuary.

These lateral increases are thus a complex process that combine riverine sources of toxic materials (including some local industrialized tidal rivers of the lower estuary) with processes of fine particle deposition and biogeochemical (sulfate-reducing) effects of trace metal enrichment at the surfaces of bottom sediments.

Chapter 8

SUSPENDED SEDIMENTS

R.B. Biggs, J.H. Sharp, B.A. Howell

INTRODUCTION

Suspended sediments include tiny colloidal particles, phytoplankton algae, organic detritus, clays, silts, and sands present in the water column. These materials affect geochemical processes such as trace metal and pollutant transport and also may affect biological production by reducing the light available to phytoplankton. In addition, deposition of suspended sediments has an economic impact on the maintanence of shipping channels. Suspended sediments are introduced to estuarine waters primarily from erosion of land in the drainage basin and from a number of minor sources.

The distribution of suspended sediments in estuaries is determined by inputs of sediment, circulation, settling characteristics, and resuspension of bottom sediments. Regional differences in suspended sediment concentrations are responsible for differences in the color of various waters. The brown color of estuarine waters is due primarily to inorganic suspended sediments; while coastal waters often appear green because of high concentrations of phytoplankton.

The primary focus of our research has been to examine the distribution of suspended sediments in the estuary and their role in light attenuation. These areas are discussed in the first two sections of this chapter. In the final

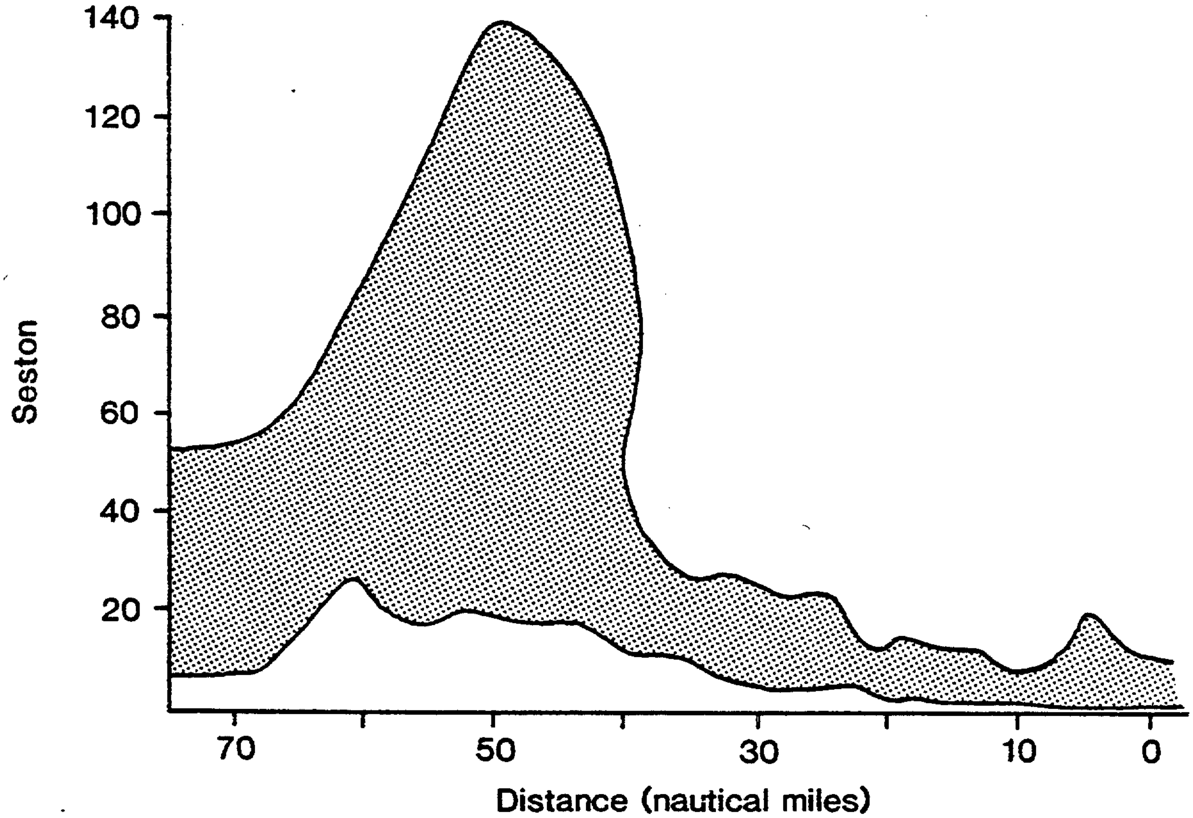


Figure 8-1. Seston (mg/L) vs. distance above the mouth of the estuary; shaded area envelopes all data from 1980-83 sampling.

section a simple suspended sediment budget is presented for use in assessing gross impacts that may occur due to major changes in inputs of suspended material to the estuary.

DISTRIBUTION OF SUSPENDED SEDIMENTS

Seston is defined as the total weight of suspended sediment removed from a sample by filtration. For analysis, suspended sediments are usually separated from the water via filtration through microporous filters with retention pore sizes on the order of one-half to one micron. The material retained on the filter is called suspended sediment or seston, and is often referred to as particulate matter (see Chapters 6 and 9).

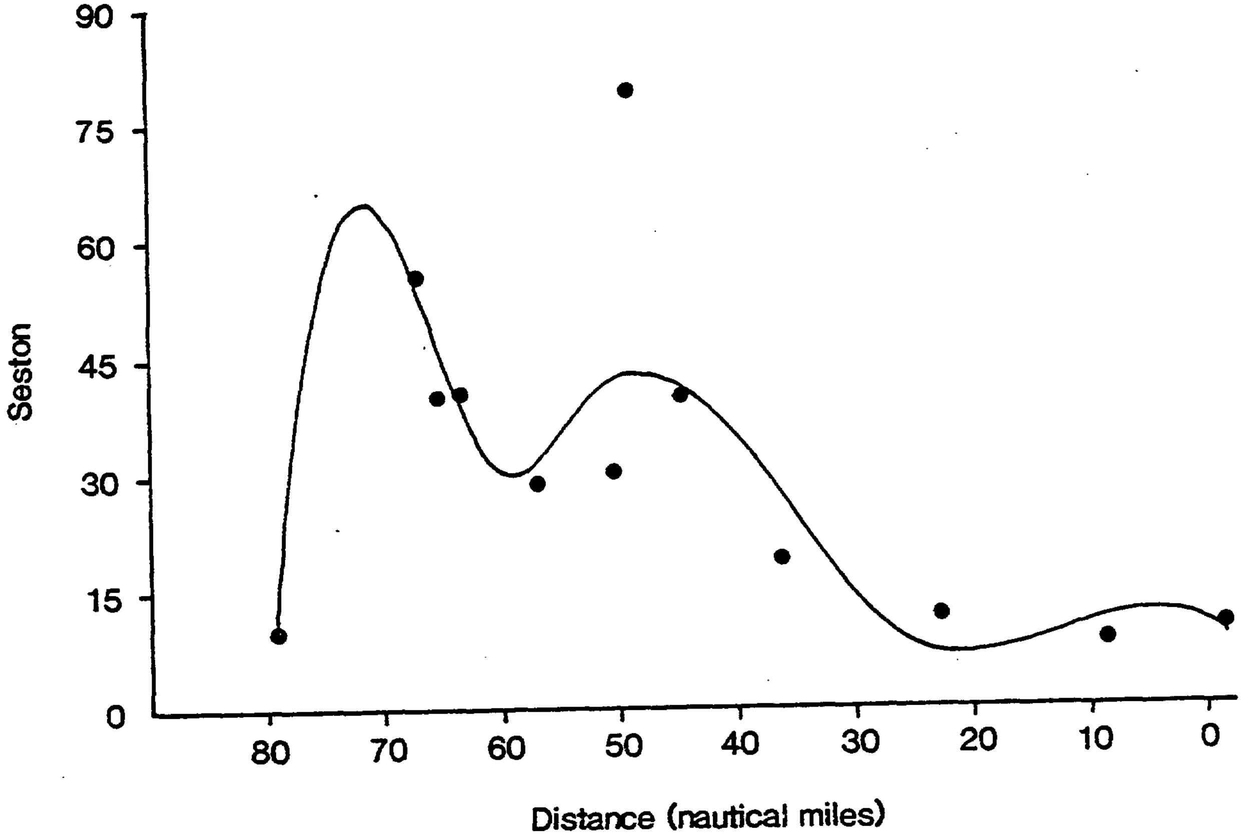


Figure 8-2. Seston (mg/L) vs. distance above the mouth of the estuary for November 1980 sampling. Solid line is a statistical fit of the data by least squares regression.

Figure 8-1 shows concentrations of seston vs. distance for samples taken in the central channel of the estuary. Values for the entire Delaware Estuary range from 0.5 to 230 milligrams per liter (mg/L). Seston concentrations in the river and turbidity maximum regions are high (20-140 mg/L), but not exceptional compared to values for some subtributaries (up to 670 mg/L) or turbid estuarine regions such as the Severn Estuary, England, where values are reported as high as 4000 mg/L (Kirby and Parker 1983).

Along the estuarine main axis, highest seston concentrations are found in the upper estuary. Two turbidity maxima are often observed on individual sampling cruises (Figure 8-2); one below Philadelphia and another in the region 50 miles upstream from the mouth of the bay (Biggs et al. 1983). High seston values, up to 230 mg/L, are also found in the shallow shoal regions where resuspension of bottom sediments often occurs during mixing by strong wind or

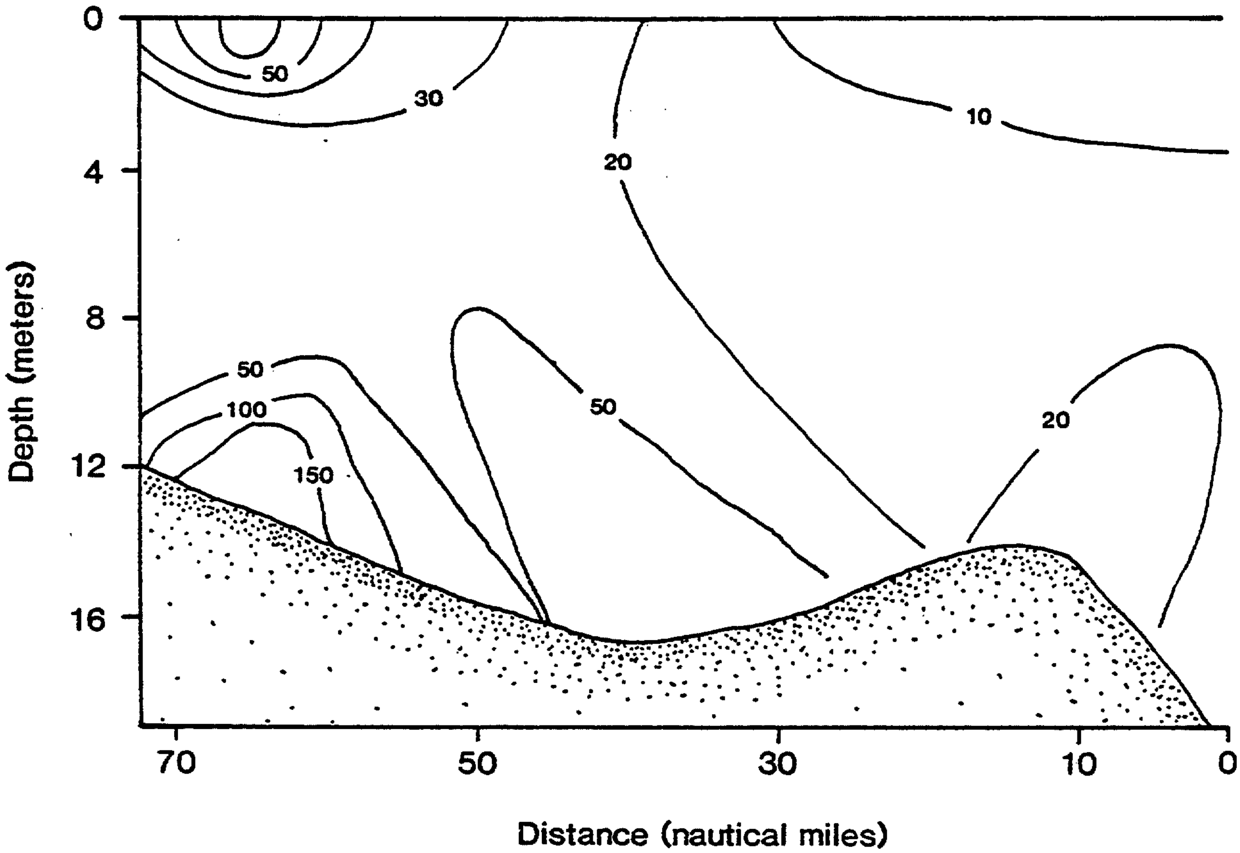


Figure 8-3. Lines of equal seston concentration (mg/L) from sampling down the axis of the Delaware Estuary in January 1983.

maximum tidal currents. In the Delaware Estuary, suspended sediment concentrations in the shoals are almost always higher than in the central regions.

In addition to variations in the surface waters of the estuary there are often increased concentrations of suspended sediments in bottom waters. Figure 8-3 depicts differences in vertical concentration along the main axis. Increased concentrations of sediments on the bottom are often caused by a layer of sediments that are resuspended and carried by strong tidal currents. These near-bottom waters are important because a significant portion of sands and heavier materials are transported in these layers, and microbial breakdown of organic materials is often concentrated in these regions.

Table 8-1 represents seston and values for percent carbon in the six regions of the estuary (described in Chapter 6). In the turbidity maximum

Table 8-1. Suspended sediment concentrations (seston) in the six regions of the estuary described in Chapter 6. Region 1 the upper estuary, 2 - the turbidity maximum, 3 - the central lower estuary, 4 - the mouth of the estuary, 5 - the New Jersey shoals, and 6 - the Delaware shoals. Percent carbon in the suspended sediment is also shown. Values are averages for 16 sampling periods from 1980-83.

Region	Salinity $^{o}/oo$	Seston (mg/L)	% Carbon
1	0.1	15.4	11
2	4.3	44.9	3.4
3	23.9	11.8	13
4	31.2	6.3	20
5	21.0	38.7	16
6	24.9	23.1	15

region, the average content of organic carbon in the seston is low - less than five percent. High seston values are also observed in both the New Jersey and Delaware shoal regions; however, in these regions, seston is comparatively enriched in carbon - about 15 percent carbon. The most organic-rich seston is in the coastal region at the bay mouth. It is likely that suspended sediment in the turbidity maximum region comes from river input and the resuspension of inorganic bottom sedimentary material. In the shoal areas, considerably more biologically produced organic matter and detrital organic matter from marshes is found in the water column. At the bay mouth, productivity of the water column has an even greater influence on seston concentrations.

LIGHT ATTENUATION

Light penetration in water is controlled by absorption and scattering of the light. Absorption is the conversion of light into heat while scattering is the change in direction of light waves, principally because of interactions with particles suspended in the water (Champ et al. 1980). Attenuation of light in water is the combination of adsorption (principally from dissolved substances) and scattering (principally from particles). In the open ocean, blue light penetrates water most deeply; in coastal and estuarine waters,

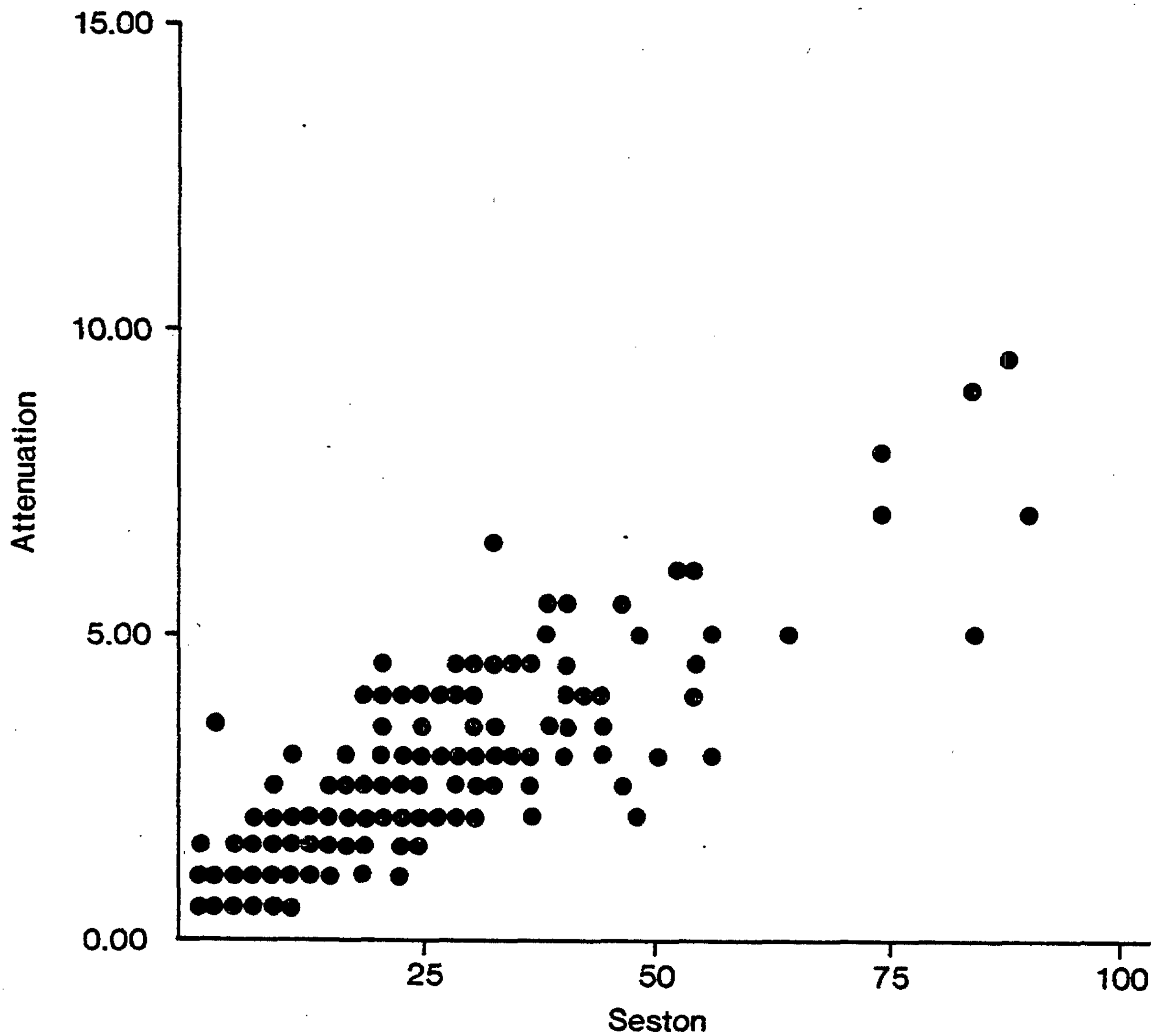


Figure 8-4. Correlation of light attenuation (m^{-1}) with seston (mg/L) for all samples down the axis of the Delaware Estuary from 1980-83 sampling.

yellow or orange light penetrates farthest. This is explained by high concentrations of suspended sediment and dissolved organic compounds that selectively attenuate the shorter, blue wavelengths of light.

Light attenuation is measured using a light meter that records the amount of light penetrating to a specific depth. The attenuation coefficient k is an estimate of how quickly light is scattered and absorbed in the water column, usually recorded in units of reciprocal meters. High values of k represent strong attenuation of light (i.e. high turbidity); low values indicate deep light penetration. Typical coastal values range from 0.1 to 0.5 per meter. Values of k for the Delaware Estuary range from 0.5 to more than 10 per meter. Figure 8-4 illustrates the relationship between k and seston for all samples from 1980-83. The observed linear relationship shows that seston dominates light attenuation in the Delaware Estuary. Absorption by dissolved substances and scattering by phytoplankton or detrital organic matter are minor components of the overall light attenuation.

SEDIMENT BUDGET

Sediment budgets for the Delaware Estuary have been proposed by the Army Corps of Engineers (Wicker 1973) and by Oostdam (1971). Using data from both of these studies and from our current work, we present a new sediment budget that represents the best present estimate for the Delaware Estuary. These models consider the estuary as a closed system. Using the assumptions that no sediment leaves the estuary and that all inflowing material is trapped within the shoaling regions, estimated sources and sinks for suspended sediments should balance.

Eight sediment sources have been considered and evaluated. They are: (1) erosion from non-tidal watercourses, (2) erosion of shores, (3) dredging leakage, (4) storm and sanitary sewer outfalls, (5) industrial effluents, (6) accumulation from phytoplankton, (7) the Atlantic Ocean, and (8) airborne particulates. Net erosion of the bed of the estuary cannot be estimated at this time because of lack of adequate historic bathymetric data.

Only two sediment sinks are considered. The estimated amount of materials lost from the estuarine waters represents: (1) sediment removed by dredging and deposited on upland areas and (2) sediment lost to the marshes.

Suspended sediment introduced from gauged tributaries, along with inferences for contributions from ungauged areas, represent 68% of the total of 2,927,000 tons (Table 8-2) estimated input of sediment to the Delaware Estuary.

Table 8-2. Estimated annual sediment budget for the Delaware Estuary. See text for derivations and references for values. All values are annual averages in thousands of tons.

Sources	Amount	% of Total Inputs	Sinks	Amount	% of Total Sinks
Rivers-upland	2,000	68%	Dredge spoil	3,300	78%
Shore erosion	260	9%	Marsh accumulation	935	22%
Dredging leakage	175	6%	Total	4,235	
Sewer outfalls	121	4%			
Industrial effluents	52	2%			
Phytoplankton production	233	8%			
Atlantic Ocean	NA				
Airborne particulates	86	3%			
Total	2,927				

The estimate from literature review of upland river inputs, 2,000,000 tons per year, compares well with Mansue and Commings' (1973) earlier estimate of fluvial transport of 1,50C,000 tons.

Shore erosion, dredging leakage, and phytoplankton production are minor but significant sources of sediment to the estuary (5-10% each). Erosion of upper estuary banks (between Trenton and Wilmington) is not a significant source of sediment, as extensive industrialization and commercial buildup has bulkheaded much of the shoreline. On the other hand, the marshy shorelines of the lower estuary are actively eroding at about 1.5 m per year and supply the total estimate of erosional inputs. Wicker (1973) includes dredging of the estuary as a source of sediment, despite the fact that the major result of dredging is removal of sediment from the estuary. The source of sediments comes from the resuspension of silts and clays, and from runoff of newly deposited dredge wastes. Again, most of this runoff contains fine-grained materials. Biological production of particulates within the estuary was estimated from our productivity data, based on a net production equal to 25% of gross primary production (see Chapter 10), plus a contribution from diatom skeletal material.

The remaining sources of suspended sediment, including sewer outfalls, industrial effluents and airborne particulates, are each less than 5% of the annual estimated inputs. The Atlantic Ocean is considered a source of sediment both by Wicker (1973) and by Oostdam and Jordan (1972). However, its contribution is not well quantified, and was considered to be a minor input; therefore it will not be included in this budget. Analysis of bottom sediments in the lower estuary shows that sandy materials enter Delaware Bay through the mouth of the bay from the continental shelf and/or from erosion of the ocean coast. Materials that enter the bay around Cape Henlopen are principally deposited in or near the Cape; sands entering the bay around Cape May are transported over wide bottom areas as far up the bay as the mouth of the Cohansey River.

Dredge spoil and salt marsh accumulations remove 4,200,000 tons of suspended sediment per year. Dredge spoils account for 78% of the suspended sediment sinks in the estuary. The remaining 22% is attributed to marsh accumulation (Table 8-2).

The total annual input of sediments from the eight sources listed above is about 3,000,000 tons; the total loss from the two sinks listed is about 4,000,000 tons (Table 8-2). There is an obvious discrepancy between the amount of material coming into the estuary compared to that which is removed. A possible explanation is that riverine contribution may be underestimated, because neither gauged tributaries nor the main river system are monitored continuously. It is possible to miss the influx of significant amounts of material due to storm activity. These storm floods may occur an average of 2 to 3 times per year, and may contribute close to 20% of the yearly discharge. A second explanation may be that extreme events such as hurricanes have not been accounted for, but they are likely sources of sediment. Another explanation is that the Atlantic Ocean's contribution, not included in the budget because of difficulty in obtaining quantitative measurements, is significant. For example, the bay could receive about 1,000,000 tons of material per year if 5 to 6 gm/m^3/sec of material are carried in and deposited during each flood tide. This is a reasonable, but undocumented, assumption. Finally, the estuary may well be out of equilibrium. Because of continued dredging, man has modified the cross-sectional area of the bay to the extent that materials are being eroded from the shoals and deposited in the navigation channels. If this process is occurring and has not reached a steady state, then only a portion of the material removed in maintainence dredging is from rivers or shore erosion.

CONCLUSIONS

Throughout the estuary, the turbidity of the water is predominantly caused by suspended inorganic sediment. Seston values range from less than 1 to over 200 mg/liter, with highest concentrations found in the upper estuary turbidity maxima and in lower bay shoals. The high suspended sediments are the major cause of attenuation of light and are related in a direct predictable fashion to the attenuation.

The major sources of these sediments are rivers and shore erosion. Suspended sediment entering Delaware Estuary is either dredged and disposed of on upland areas or transported onto the salt marshes that surround the estuary. Our suspended sediment budget does not balance. This indicates that one or more of the sources may be underestimated or that the estuary may not be in balance.

It is important in future research to attain a better estimate of all sediment sources and sinks so that a better budget can be considered. Associated with that research is a better estimate of the causes of suspended sediments, sorting between new inputs and resuspension of bottom sediments. This latter assessment is necessary prior to any management decisions on sedimentation and erosion controls.

Chapter 9

TRACE METALS

T.M. Church, J.M. Tramontano, R.B. Biggs, G. Luther, R. Bartha

INTRODUCTION

Trace metals are those elements that are not the primary components of crustal rocks or seawater. Usually included in this category are metals that are moderately rare in the natural environment, including iron, manganese, cobalt, nickel, copper, and cadmium. Other trace metals, some of which are quite rare in the natural environment, are also of interest because of their role as pollutants; these include mercury, lead, zinc, and arsenic. Metals are found in natural environments either attached to particles or in solution. By convention, these forms are referred to as particulate and dissolved, respectively, with separation usually accomplished with a filter of about 0.5 - micron pore size.

The role of trace metals in the estuarine environment is the subject of the first section of this report. This is followed by sections on the distribution of trace metals in the water column, trace metals from tributaries, and trace metals in bottom sediments.

THE ROLE OF TRACE METALS

Trace metals enter estuaries by diverse routes. Naturally, trace metals enter as runoff through the weathering of crustal rocks and more indirectly by the base flow of groundwaters. The activities of man can also contribute trace metals to estuaries. These include point source discharges of waste effluents, secondary runoff of contaminated surface and groundwaters, and atmospheric input from industrial emissions. On reaching the estuarine environment, trace metals display a variety of behaviors. Encountering the first traces of sea salt, many of the metals carried in river water are converted from dissolved to particulate form by the general action of flocculation. Flocculation occurs because many trace metals have different oxidation states and upon introduction to estuaries they exist in a more reduced and soluble state. When reduced trace metals reach the more oxygenated turbid waters of an estuary, they are often oxidized to less soluble forms which flocculate, or can be adsorbed onto particles. With increasing salt concentration farther down an estuary, some adsorbed trace metals can in turn be converted to dissolved form by the action of ion exchange; others may be involved with algal production that can result in uptake and recycling of metals; while still others may be cycled by oxidation-reduction in sediments of the estuary.

As a result of their estuarine behavior, trace metals can undergo a number of fates on their way to the sea. Trace metals flocculated from dissolved to particulate form may settle out as integral components of the bottom sediments. Due to their fine particle size, some of these flocculated precipitates may also be exported to surrounding saltmarsh areas or to offshore coastal areas. After deposition in estuarine sediments, degradation of organic matter can dissolve trace metals, which can result either in their return to the water column or in the formation of new solid phases. This process, a form of diagenesis, is largely promoted by the presence of sulfate ion in estuarine waters and is referred to as sulfate reduction. Since a primary byproduct of sulfate reduction is sulfide, many trace metals in estuarine sediments are converted to sulfide precipitates. Another outcome for trace metals in estuaries is uptake by estuarine biota and conversion to organic forms.

Ultimately trace metals have two fates in estuaries. One is incorporation into estuarine sediments and the other is export in dissolved or particulate form to offshore waters.

Trace metals provide several unique geochemical roles in the transport of materials from the land to the sea. The flocculation of trace metals can coprecipitate other materials such as nutrients and remove them from the water to the sediments. Trace metals are involved in bacterial activity in sediments and thus serve to recycle other trace elements from sediments.

DISTRIBUTION OF TRACE METALS IN THE WATER COLUMN

Trace metals have been sampled from the water column of the Delaware Estuary for over three years resulting in good documentation of seasonal distributions for both dissolved and particulate metals. Dissolved trace metal samples were collected with metal-free sampling bottles on non-metallic wire and were processed in a metal-free environment of ultra-filtered air. These precautions are essential for accurate low-level analysis and without them serious sample contamination occurs. Dissolved samples were acidified and frozen onboard pending analysis. Particulate samples were collected on 0.40 - micron Nuclepore filters and subjected to a cold 0.1N HCl leach; thus, in the present study, the term particulate means only "environmentally active" metals.

Generally the trace metal results fall into two groups. Metals in the first group, iron (Fe), manganese (Mn), and cobalt (Co), are characterized by rapid conversion from dissolved to particulate state at low salinities (Figure 9-1), thus these are called geochemically active. The extent and rate of this removal is highly dependent on season such that conversion to particulates is apparently faster during warmer drought or low-flow conditions; and there is probably a greater contribution from natural sediment inputs in higher-salinity portions of the estuary. Conversely, during cold or high-flow conditions the conversions were slower with appreciable amounts of dissolved metals reaching the lower bay (noted during winter 1981-82). The geochemically reactive trace

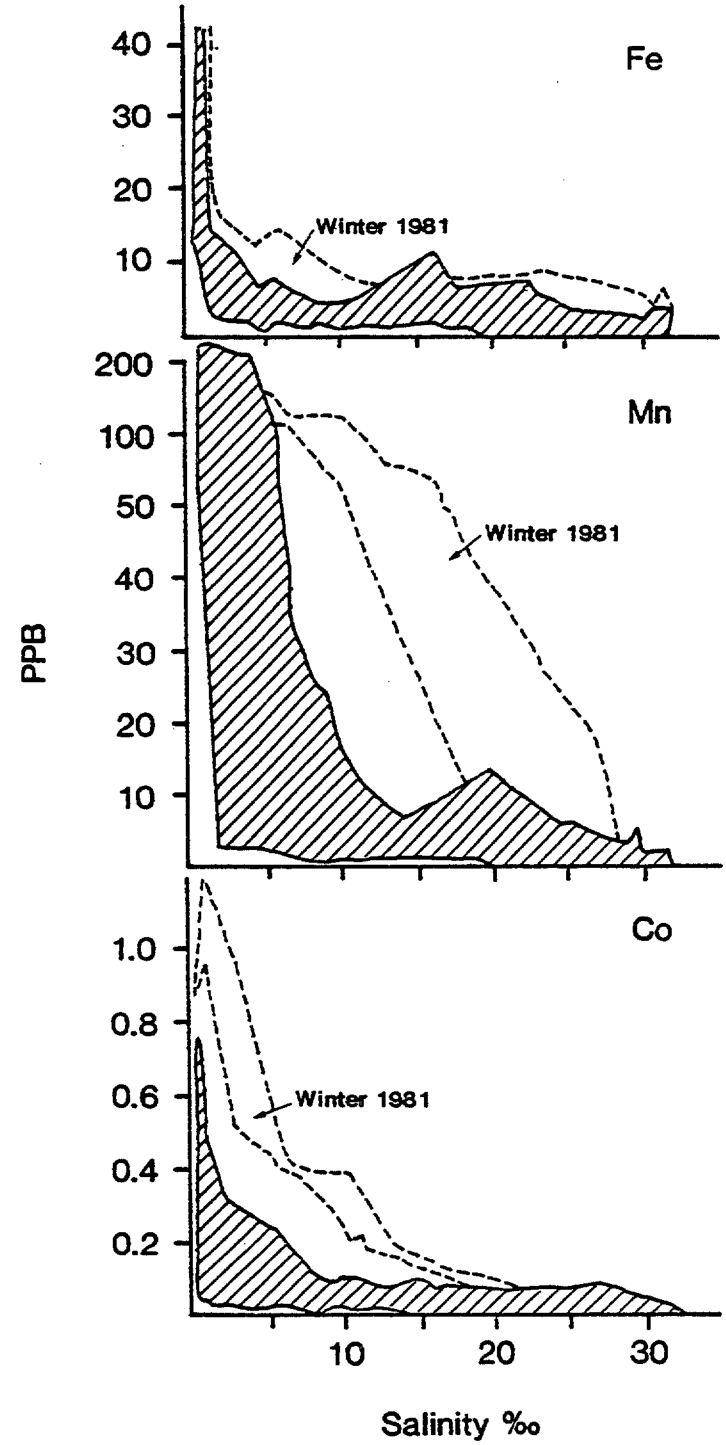


Figure 9-1A. Geochemically reactive trace metals (iron, manganese, cobalt) vs. salinity in the Delaware Estuary, dissolved metal concentrations in parts per billion.

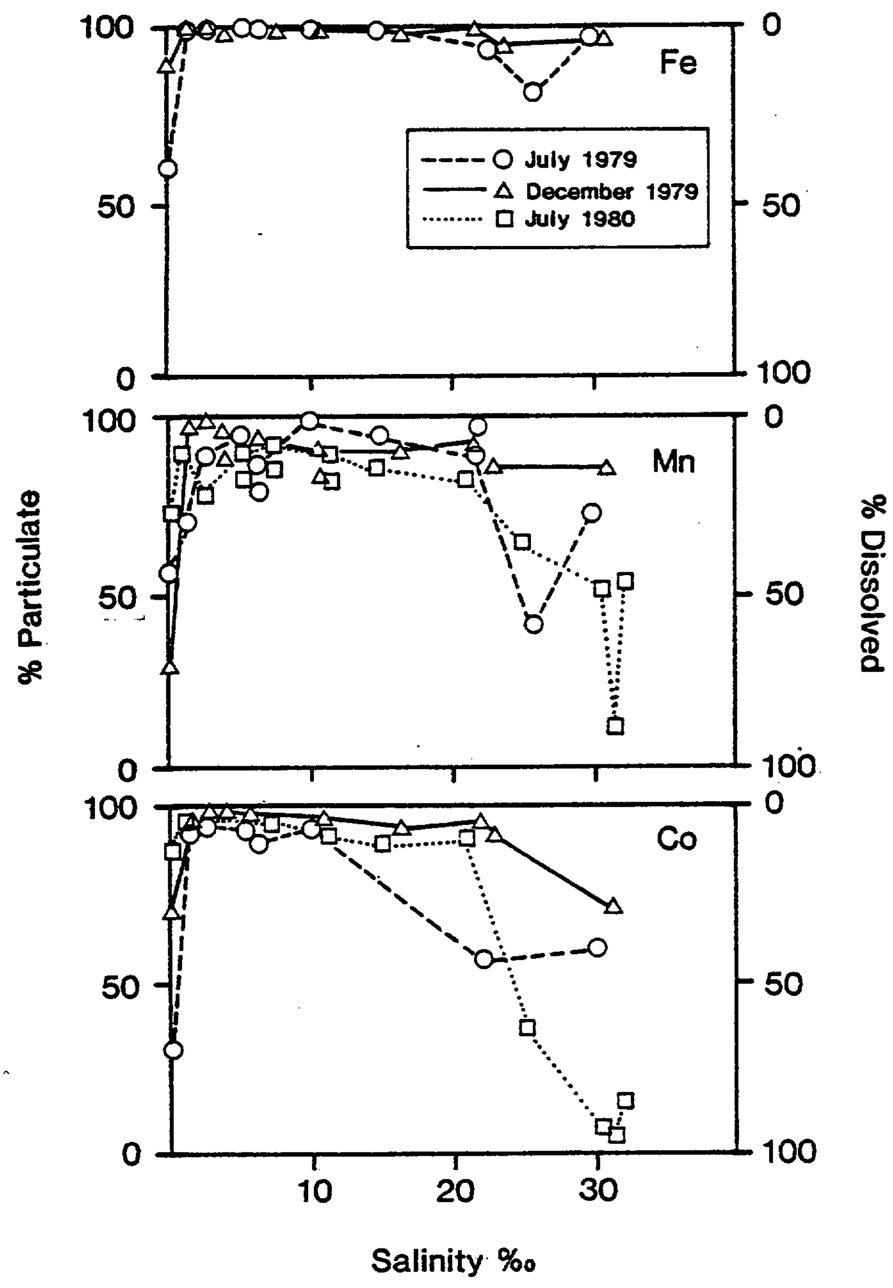


Figure 9-1B. Geochemically reactive trace metals as percent dissolved and particulate vs. salinity.

metal group appears to undergo removal from the dissolved state by the formation of fine-grained metal-rich oxides. This is demonstrated by enriched metal particulates accumulating in the turbidity maxima of the estuary, while being diluted in the intermediate null zone (Biggs et al. 1983). Fe, Mn, and Co is the order of less to greater reduction of the metal to more soluble ion species. As a consequence, the dissolved proportion for these metals (Figure 9-1B) varies in the reverse order (Co, Mn, Fe). Previous results for dissolved iron by the U.S. Geological Survey (USGS 1965-69) and by the U.S. Army Corps of Engineers (USACE 1973) are consistent in quantity and behavior with this study. However the quantities of dissolved manganese reported by this study are significantly lower than those of the USGS.

The second group of trace metals, copper (Cu), nickel (Ni), and cadmium (Cd), show rather gradual mixing with saltwater, and show equal distributions between particulate and dissolved phases at the freshwater end (Figure 9-2). The enriched riverine proportion is then gradually diluted throughout the remaining length of the estuary with trace-metal-poorer particulates from offshore (Figure 9-2B). The behavior of the second group of metals resembles in many ways the nutrients (Chapter 5), suggesting the involvement of these metals in biological processes of the lower bay. Thus, this group of trace metals is called the nutrient type. Ni and Cd show behaviors closely parallel to phosphate uptake and release down the salinity gradient, including greater proportions as dissolved during the winter.

In a detailed study of mercury (Hg), Lepple (1973) analyzed Delaware Bay waters. No simple relationship was found between salinity and Hg content, although the middle bay had concentrations higher than either the upper or lower bay, by as much as several fold. No difference was observed between surface water and deeper waters. A hypothesis was presented that attributed the maximum concentrations in the center of the bay to association of adsorbed Hg onto smaller-sized, organic-rich particles.

Discrete particles from the Delaware Estuary have been inspected using scanning electron microscopic analysis. The results show some anomolous metal-rich particles such as oxides of iron and titanium near the freshwater

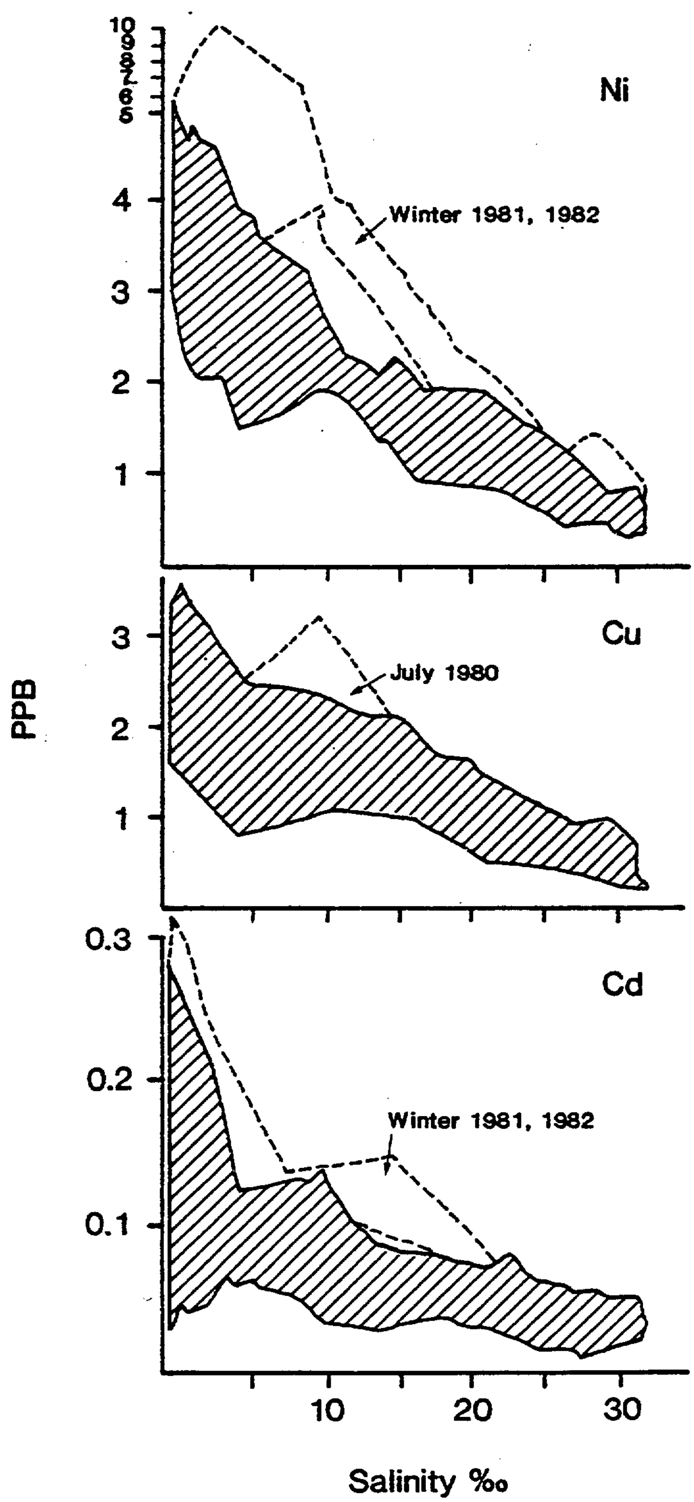


Figure 9-2A. Nutrient-type trace metals (nickel, copper, cadmium) vs. salinity in the Delaware Estuary, dissolved metal concentrations as parts per billion.

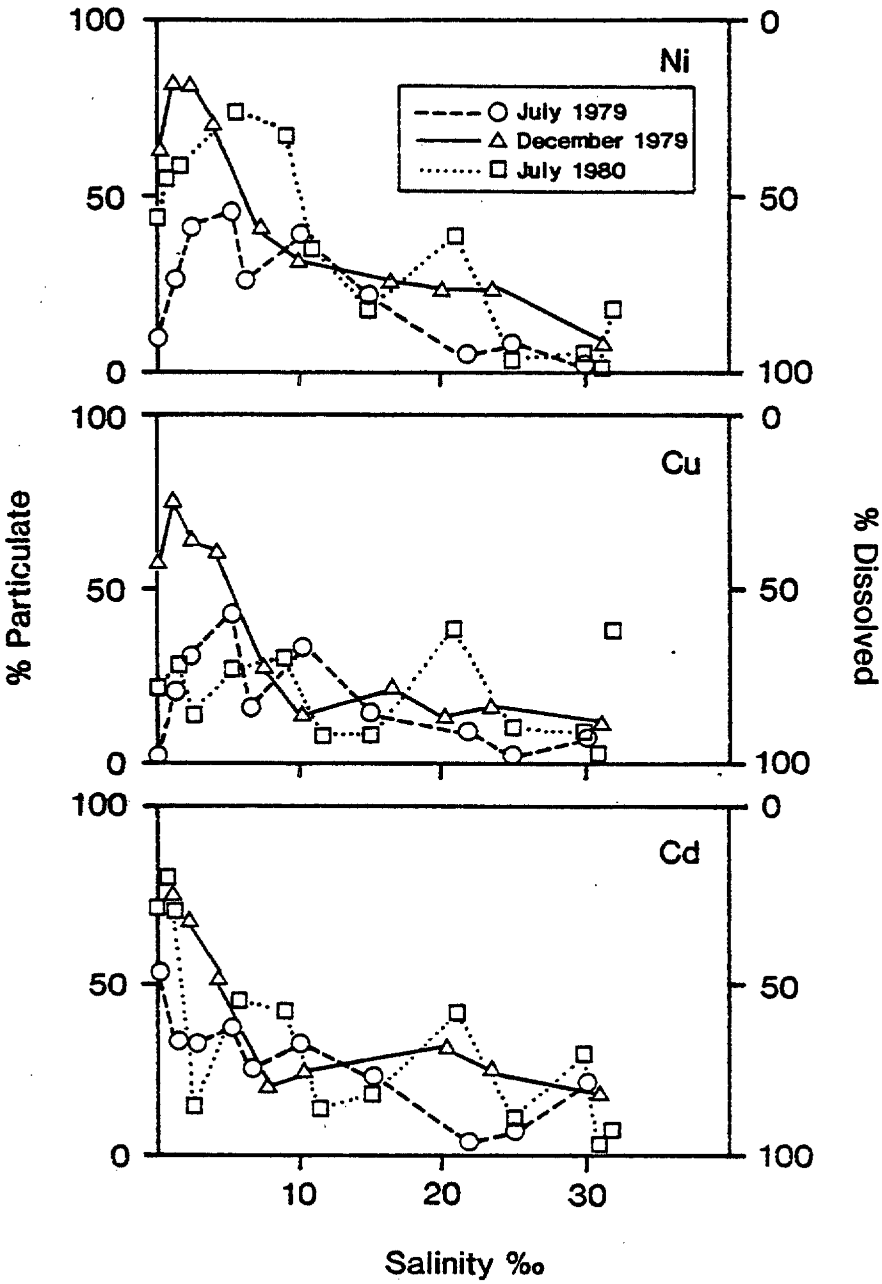


Figure 9-2B. Nutrient-type trace metals as percent dissolved and particulate vs. salinity.

end, associated with industrial activity. In the lower estuary, individual shells of microscopic algae, as well as iron sulfide particles, were observed. Colloidal particulates of the lower estuary include flocculated aluminosilicate material containing potassium, iron, and titanium as accessory elements. This suggests sites of dissolved metal removal in the lower estuary as shown in the water column data.

The dissolved trace metal data for the Delaware can be compared to neighboring major East Coast estuaries. Comparison with the Chesapeake Estuary (Church et al. unpublished) shows the Delaware with generally comparable but higher trace metal concentrations near its river source. However, the reverse is true for Cu and Cd in the Chesapeake because of its downbay sources off the Potomac River and Norfolk areas. The Hudson River Estuary (Klinkhammer 1981) shows higher concentrations of trace metal introduced into the mid-salinity area of the Hudson off New York City. However both estuaries show comparable trace metal concentrations at their saltwater ends.

TRACE METALS FROM TRIBUTARIES

During this study, trace metals were analyzed in waters bordering or entering the main stem of the Delaware Estuary. In shallow waters bordering Delaware Bay, dissolved Fe, Mn, and Cd often show higher concentrations than in the main channel, by a factor of two to four (Figure 9-3). The geochemical group of trace metals (Fe, Mn, and Co) as well as Cd show the greatest lateral increases, perhaps due to their release from bordering salt marshes. Pellenbarg and Church (1979) reported higher dissolved concentrations of Fe (10-fold) and Cu (3-fold), but similar concentrations for Zn in salt-marsh waters compared to the levels reported here in the lower bay. Subsequent studies on the lower Delaware salt marshes (Church et al. in preparation) show salt marshes to be significantly enriched relative to the lower estuary, in most of the dissolved trace metals reported in this study. However in salt marshes, maximum concentrations of trace metals are seen at middle rather than low salinities. The trend for salt-marsh enrichment relative to the lower estuary is Fe to Mn to Cu to Ni, in roughly decreasing order. Cd is more

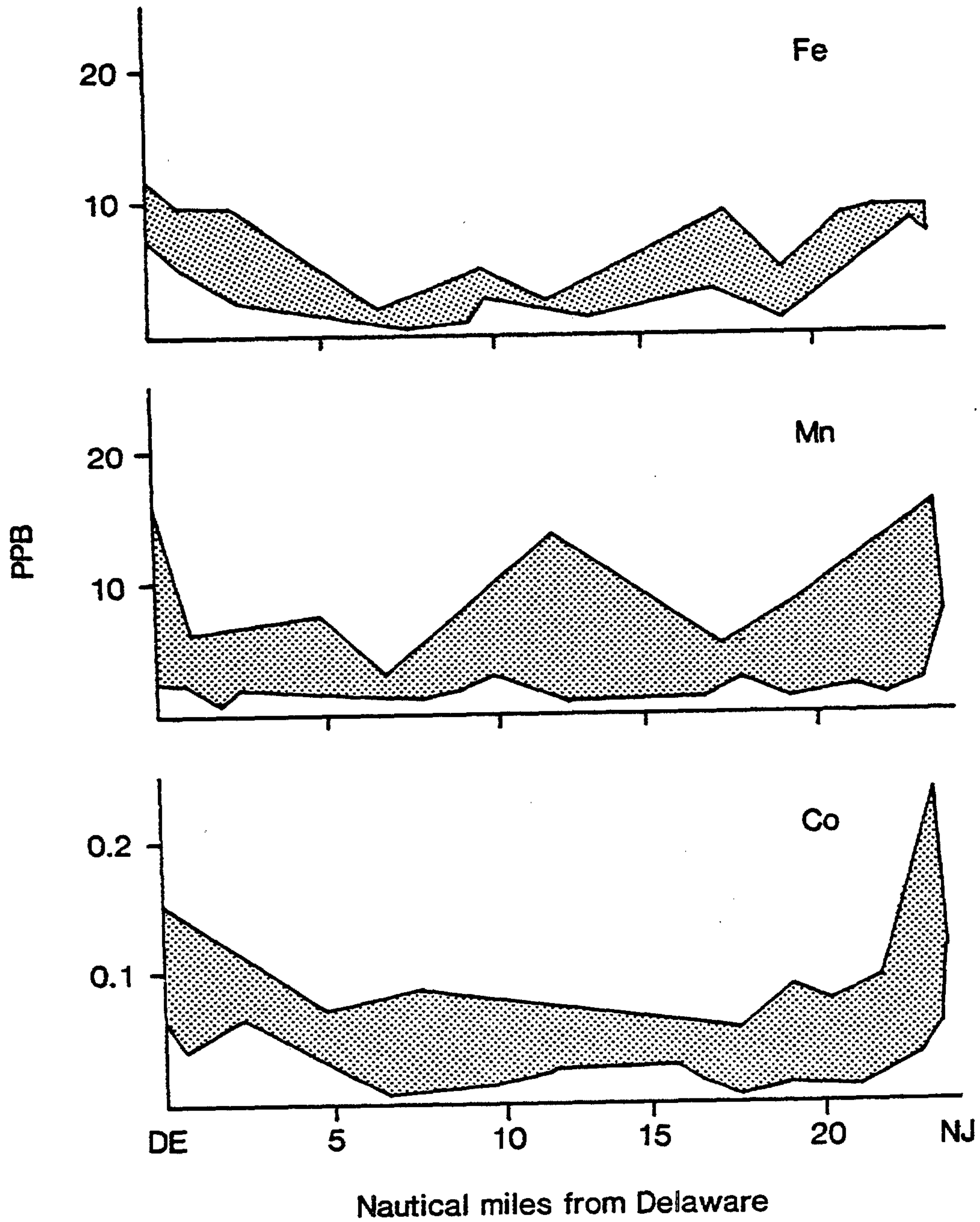


Figure 9-3A. Dissolved trace metal sections across lower Delaware Bay (same section as Figure 2-4) for geochemically reactive metals (iron, manganese, cobalt). Envelopes include values of all samples from several samplings.

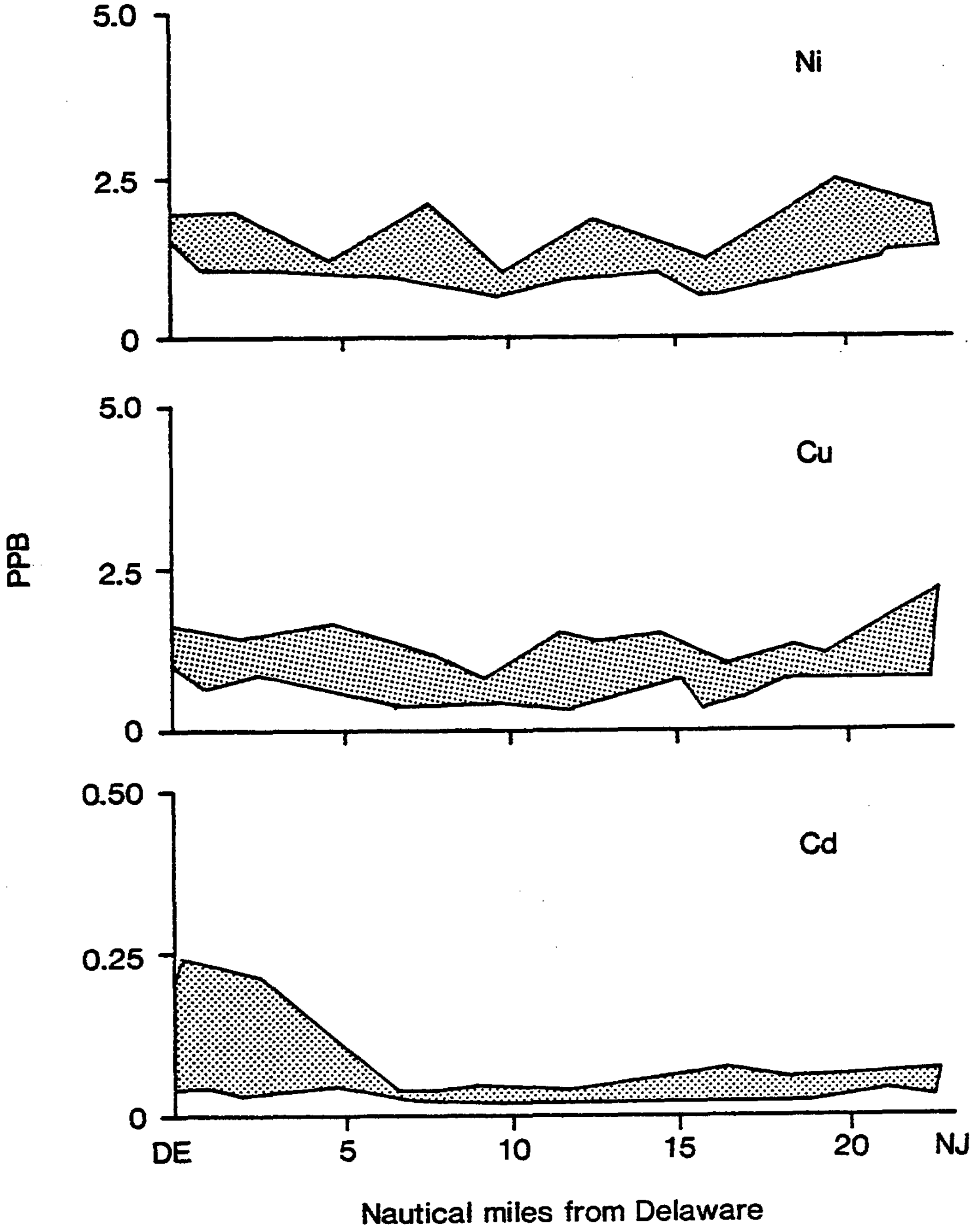


Figure 9-3B. Dissolved trace metal sections across lower Delaware Bay as in Figure 9-3A for nutrient type trace metals (nickel, copper, cadmium).

enriched in the estuary. The sources for these enriched trace metals dissolved in salt-marsh waters are attributed to the vigorous action of sulfate reduction in intertidal sediments.

Measurements of the dissolved trace metal concentrations in the waters of rivers entering Delaware Bay were monitored on at least two samplings. The dissolved trace-metal concentrations in most riverine sources, including the Chesapeake and Delaware Canal, are nearly equivalent to levels measured in corresponding waters in the main stem of the estuary with some exceptions. At times the concentrations of Fe, Mn, Co, Ni, Cu, and Cd can be as much as a factor of two higher at the mouths of Christiana, Cohansey, Smyrna, Leipsic, and Maurice Rivers than in the main stem of bay. This was during winter and summer and perhaps reflects characteristics of municipal or tide-marsh inputs. However, while the absolute concentrations of trace metals in tributary sources tend to be higher than in the bay, it is the Delaware River itself which probably dominates the absolute flux of trace metals to the lower bay.

TRACE METALS IN BOTTOM SEDIMENTS

An initial comprehensive study of trace-metal concentrations in the surface sediments of Delaware Bay was carried out by Bopp and Biggs (1972). As with suspended sediments in the present study, metals were extracted by a cold, weak, HCl acid leach and thus correspond to an "environmentally active" fraction. The metals Fe, Cu, Ni, Cd, and lead (Pb) were found most concentrated along the shores of the bay, particularly off lower bay tidal rivers, suggesting riverine sources. In addition, higher trace-metal concentrations in the center of the bay also point to fine particle deposition that appears to augment trace metal concentrations. Both Cu and Cd showed higher concentrations along the New Jersey shore in the upper bay suggesting, as does the water column data, that primary sources for these metals are from the Delaware River itself. In a subsequent synthesis of this data set, Bopp and Biggs (1981) performed a factor analysis on sources for the trace-metal concentrations in surface sediments of Delaware Bay. They found three groups of variance that they attributed to the following: riverine sources for Fe, Mn, potassium (K), lithium (Li), and aluminum (Al); marine sources for strontium (Sr), magnesium (Mg), sodium (Na), and calcium (Ca); and pollution sources for Cu, chromium (Cr), Pb, and organic carbon (Figure 9-4).

Included in the pollution source was mercury which had an average concentration of 0.73 ppm (Lepple 1973) with some values greater than 1 ppm in the central bay; this is attributed to concentration with the fine organic-rich sediment fraction. As part of this study, similar Hg concentrations (less than 2 ppm) have been found; with higher concentrations, about 5 ppm, in the upper bay near industrial sites; and 3 ppm in middle bay areas in accord with central-bay accumulation. Methyl mercury was found to be a minor fraction of the total (less than 2 ppm) for all samples.

Bopp (1980) also reported chemical separations of trace metals into adsorbed, oxide, organic, and weak hydrochloric-acid-leachable (environmentally active) fractions in Delaware Bay surface sediments. The adsorbed fraction of total metals showed minor (2%) amounts of Fe, Cu, and Zn with appreciably more Mn (20%). Adsorbed Mn was the most evident in fine particles while Fe, Cu, and Mn were the most evident on the oxide coatings of coarser fractions. The organic fraction showed appreciable amounts of Fe and Cu similar to the exchange fraction. The major portion of the particulate Fe, Cu, and Zn was found in the hydrochloric-acid-leachable (environmentally active) fraction. From bottom distributions of the environmentally active fraction, it was summarized that Fe, Mn, and Cd have major sources from the Delaware River.

In the present study two cores were analyzed from the middle bay region of the Delaware Estuary (near Artificial Island). The core from the bay showed no discernable pattern of trace metals; depth distribution in the core suggesting tidal resuspension, bioturbation, or disposed older material. However the core from an adjacent salt marsh showed higher concentations of Pb, Zn, and Cd in the upper layers of the core, indicating more recent atmospheric pollutant inputs. This corroborates the earlier findings of Dreier (1982) for three different salt-marsh core locations down the length of the estuary in which trace-metal concentrations were measured on the larger (plant-fragment) portions of the sediment as an indicator of biologically accumulated trace

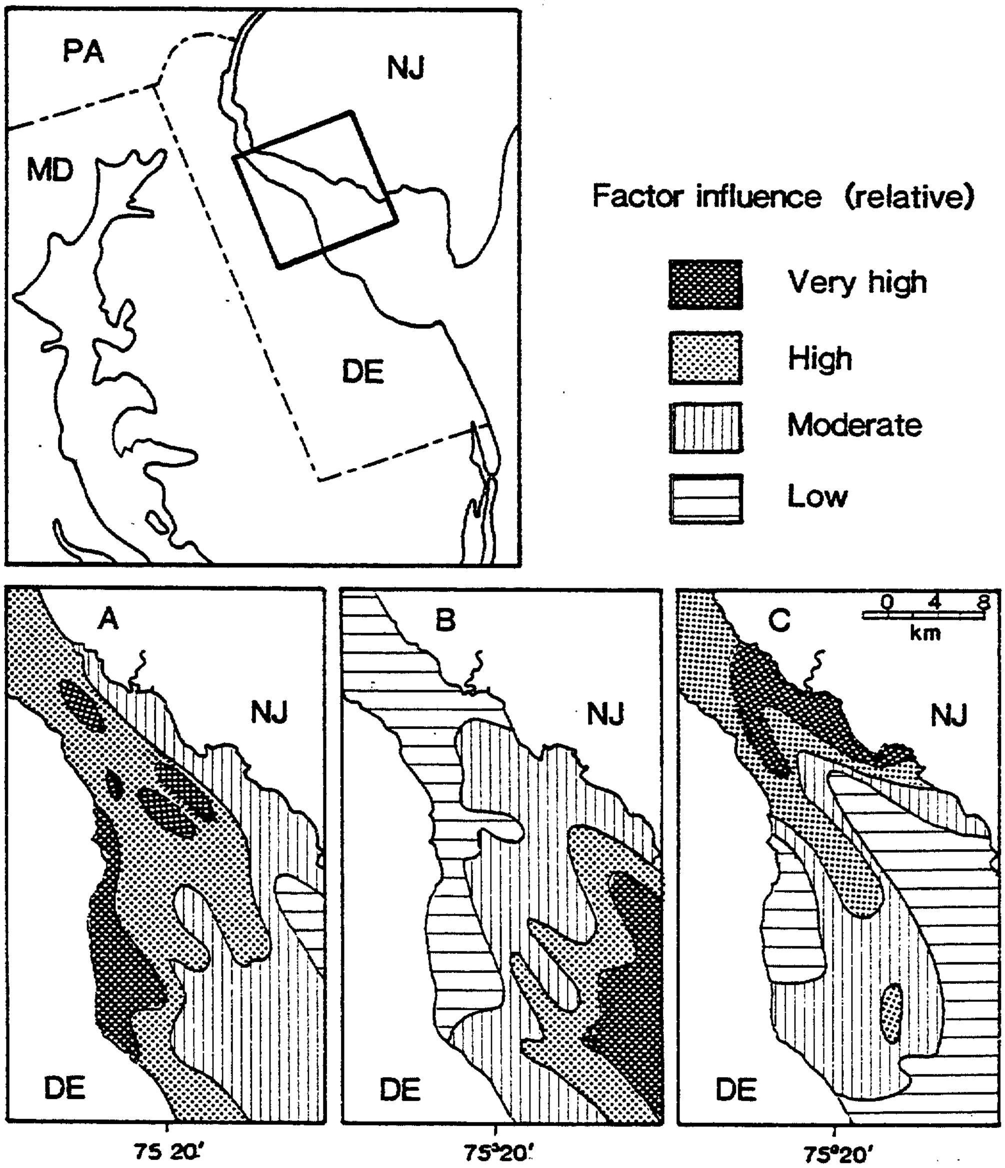


Figure 9-4. Distribution of trace metals in Delaware Bay sediments attributed to factors of (a) riverine sources (iron, magnesium, lithium, potassium, and aluminum), (b) marine sources (magnesium, strontium, calcium, and sodium), and (c) pollution sources (chromium, copper, lead, and mercury) sources (after Bopp and Biggs 1981).

metals. All three cores showed surface enrichment of Cu, Zn, and Pb indicative of recent industrial sources. Both Zn and Pb showed little variation between sites indicating atmospheric sources, while Cu decreased from the upper to lower bay salt-marsh sites indicating more riverine sources. However Ni and Cd showed little depth variation, suggesting less input or natural sources. In addition, Pb correlated negatively with changes of sea level rise in the upper 7-8 cm, supporting conclusions of intertidal atmospheric accumulations.

Another study of environmentally active trace-metal concentrations in surface sediments of tidal rivers entering lower Delaware Bay was carried out by Bopp et al. (1972) and Bopp (1980). The concentrations of Zn, Cr, Cu, Pb, Cd, Ni, and Hg were found to be comparable to the Delaware Bay and increased toward the upper ends in the St. Jones and Cohansey Rivers near their presumed sources from the industrialized towns of Dover and Bridgeton, respectively. Similarly, concentrations of Cd, Ni, and Pb increased downstream in the Murderkill River toward presumed sources of Bowers Beach and its recreational boating activities. Generally the Cohansey river sediments (Bopp 1980) had lower trace metal concentrations than did the bordering salt marshes, perhaps indicative of tidal transport of enriched fine particulates to intertidal surfaces.

CONCLUSIONS

Trace-metal distributions in the Delaware Estuary are reported for the water column and bottom sediments, and values from tributaries are discussed. Trace metals in the water column may be divided into two behavioral groups. The "geochemically reactive" group (iron, manganese, and cobalt) has riverine inputs as the dominant source; these metals are converted to particulate form by the action of seawater flocculation. This group appears to have largely natural sources. The "nutrient type" group (copper, nickel, and cadmium) has a more even distribution between dissolved and particulate forms and a distribution somewhat similar to nutrients (i.e. nitrogen, phosphorus, and silicon). Such apparent behavior suggests involvement in the living processes of the bay; this is important since this group is thought to have some sources from human activity in the tributary rivers.

Trace metals in bottom sediments show strong association with fine, organic-rich particles resulting in their bottom deposition near municipal sources, and in the central area of the bay where there is a tendency for net settling. Many of these sedimentary trace metals are found in metal oxide and biological shell debris which points to those chemical phases that can extract and transport trace metals in the Delaware Estuary.

Trace-metal levels in the water column of the Delaware Estuary are not exceptionally high compared to neighboring east coast estuaries. An indication in the water column of serious environmental deterioration from human inputs has not been clearly demonstrated at present. On the other hand, some elevations of metal concentrations in the sediments are definitely attributable to human activities.

Chapter 10

PHYTOPLANKTON

J.R. Pennock, J.H. Sharp, W.J. Canzonier

INTRODUCTION

The microscopic floating algae in estuaries or other bodies of water are called phytoplankton. Phytoplankton production provides the major source of organic matter to higher trophic levels in the Delaware Estuary. During photosynthesis, light energy is used to fix carbon dioxide into organic matter for growth. In conjunction with photosynthetic carbon fixation, phytoplankton require inorganic nutrients (nitrogen, phosphorus, silicon) and trace metals for growth. Phytoplankton photosynthesis thus serves two major functions: carbon fixation provides organic matter which supports finfish and shellfish populations in the estuary, and nutrient utilization removes nutrients from the water column which have been introduced from both natural (runoff, remineralization) and human sources (municipal and industrial inputs).

The pervading question behind our phytoplankton research in the Delaware Estuary is this: How do nutrients introduced in the metropolitan region of the upper estuary, and those regenerated naturally, influence growth of phytoplankton populations throughout the estuary? To approach this question we have examined several factors: (1) phytoplankton biomass (quantity of phytoplankton organic matter present) and phytoplankton taxonomy (species composition); (2) phytoplankton growth rate (the rate at which organic matter is being produced); and (3) phytoplankton nitrogen uptake rates. These measurements, which enable us to estimate the overall impact of nutrient enrichment on the health of the estuary, are discussed in the following sections.

PHYTOPLANKTON BIOMASS

Assessment of phytoplankton biomass involves chlorophyll analysis and taxonomic identification. Chlorophyll is a photosynthetic pigment that, in the water column, is unique to living phytoplankton thus giving a good estimate of their presence and quantity. Taxonomic analysis is used to identify major species of phytoplankton present. Significant shifts in species composition are often indicative of changes in the estuarine food web. Previously, few chlorophyll data have been obtained for the Delaware Estuary, particularly for open reaches of the lower bay. Chlorophyll data have been collected sporadically by the Delaware River Basin Commission (for the upper river to Ship John Light from 1967 to the present: EPA STORET data base) and Rutger's Oyster Research Lab (lower New Jersey shoal regions: 1979-80). Taxonomic data for the lower estuary have been summarized in Watling and Maurer (1976) and Watling et al. (1979). Taxonomy has also been enumerated for freshwater and upper estuarine regions (Schuyler 1977) and for the Murderkill tributary (Simek 1982).

Chlorophyll distributions in the estuary are the net result of both input and removal of phytoplankton from the system. Inputs of chlorophyll include phytoplankton delivery by river and tidal currents (from freshwater or marine populations) and in-situ growth. Losses of phytoplankton chlorophyll may be due to grazing by animals or flushing out of the estuary by currents or sinking. Each of these factors is important at different times of the year. In-situ increases in phytoplankton biomass (chlorophyll) in estuaries are often related to the total nutrient load to the system. In the Delaware Estuary, nutrient concentrations in the water column are almost always more than adequate and light appears to limit total biomass observed. Two parameters are critical for our understanding of observed phytoplankton concentrations: light energy (a function of daylength and turbidity) and mixed-layer depth (the depth to which waterborne compounds are mixed vertically). All other factors being similar (e.g. light, turbidity), a decrease in mixed-layer depth (mixing to a lesser depth) allows phytoplankton to spend a greater period of time in the photic zone, the upper portion of the water column where photosynthesis occurs. Under these conditions growth inputs are greater than losses and biomass levels increase in the water column.

Chlorophyll patterns in the Delaware Estuary fall into three characteristic seasons separated by transition periods which may vary temporally from year to year.

The spring season occurs from March to May and is characterized by a large middle-estuary phytoplankton "bloom", usually occurring in the area between Ship John Light and Miah Maull Shoal. Phytoplankton spring blooms are common phenomena in both estuarine and marine waters due to increasing light levels from longer days, and the presence of adequate nutrient concentrations. Chlorophyll concentrations along the main axis of the estuary reach levels as high as 60 micrograms of chlorophyll per liter (ug chl/L) in the bloom but decline significantly to concentrations less than 5 ug chl/L both upstream and downstream (Figure 10-1). Although we have observed late-spring chlorophyll levels in excess of 80 ug/L in inner shoal regions (Figure 10-2), the early bloom of Skeletonema costatum appears to be centered more towards the central channel. Our current hypothesis is that light limits phytoplankton growth during this period in both upper and lower estuary. Light limitation in the upper estuary is due to high turbidity while a deep mixed-layer is responsible in the lower estuary where there is little flow-induced stratification. In the middle estuary, vertical stratification due to high river flow maintains the phytoplankton in surface layers where they have enough light to grow. In addition to Skeletonema costatum, the diatoms Leptocylindrus sp. and Thalassiosira sp. are dominant species during the spring period; all are species characteristic of spring blooms in the Mid-Atlantic Bight and other systems.

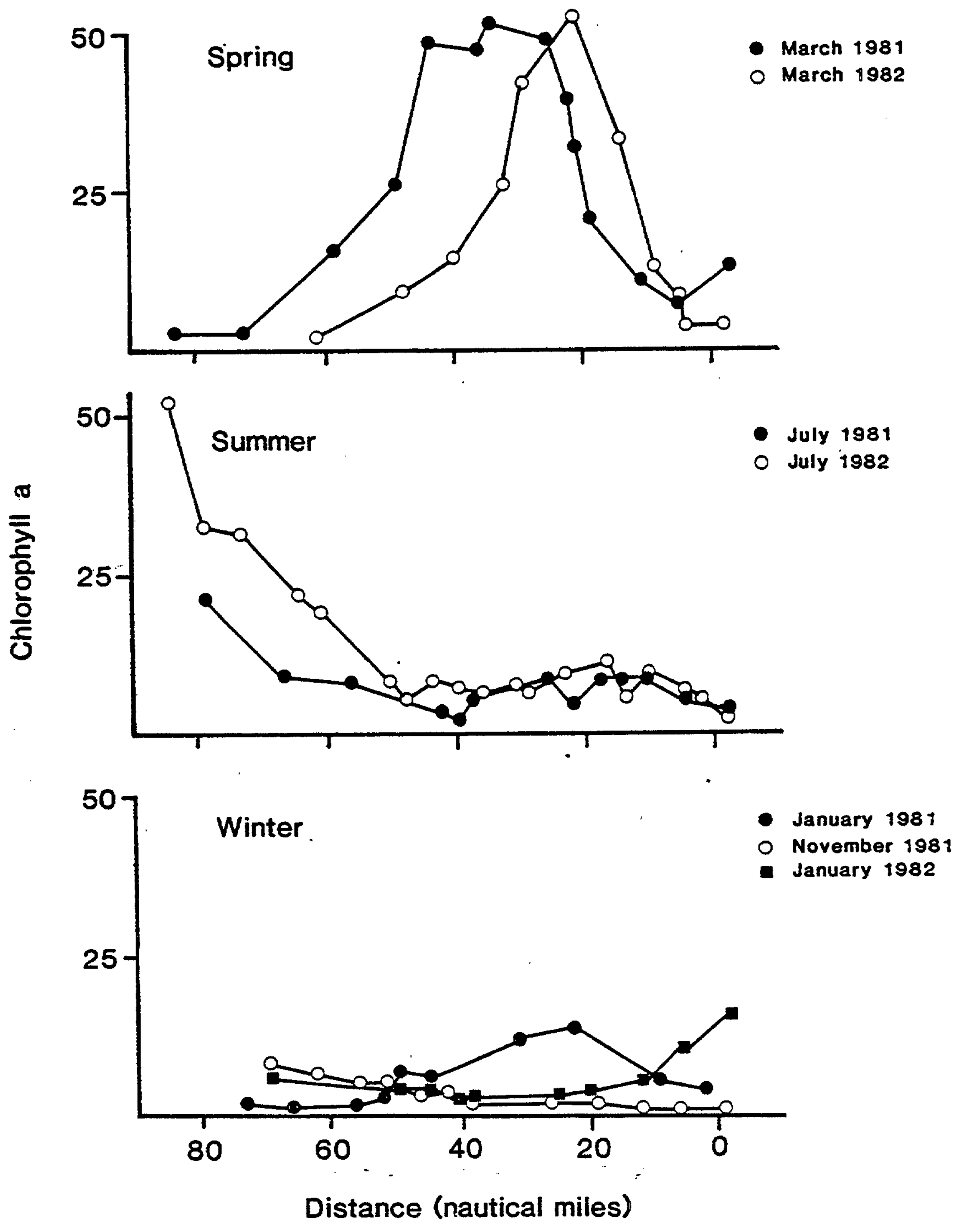


Figure 10-1. Chlorophyll concentrations (ug/L) vs. distance above mouth of the bay along main axis of the estuary. Data have been grouped into three seasons.

The transition from spring to summer (July-September) is significant for phytoplankton populations in the estuary. Chlorophyll levels generally increase at the freshwater end and decrease in the lower estuary during this transition (Figure 10-1). Chlorophyll concentrations at the freshwater end (south of Philadelphia) vary from 30 ug chl/L under high-flow conditions to 15 under low-flow conditions. Higher temperatures and increased light availability appear responsible for freshwater biomass increases during the transition from spring to summer. Data collected by the Delaware River

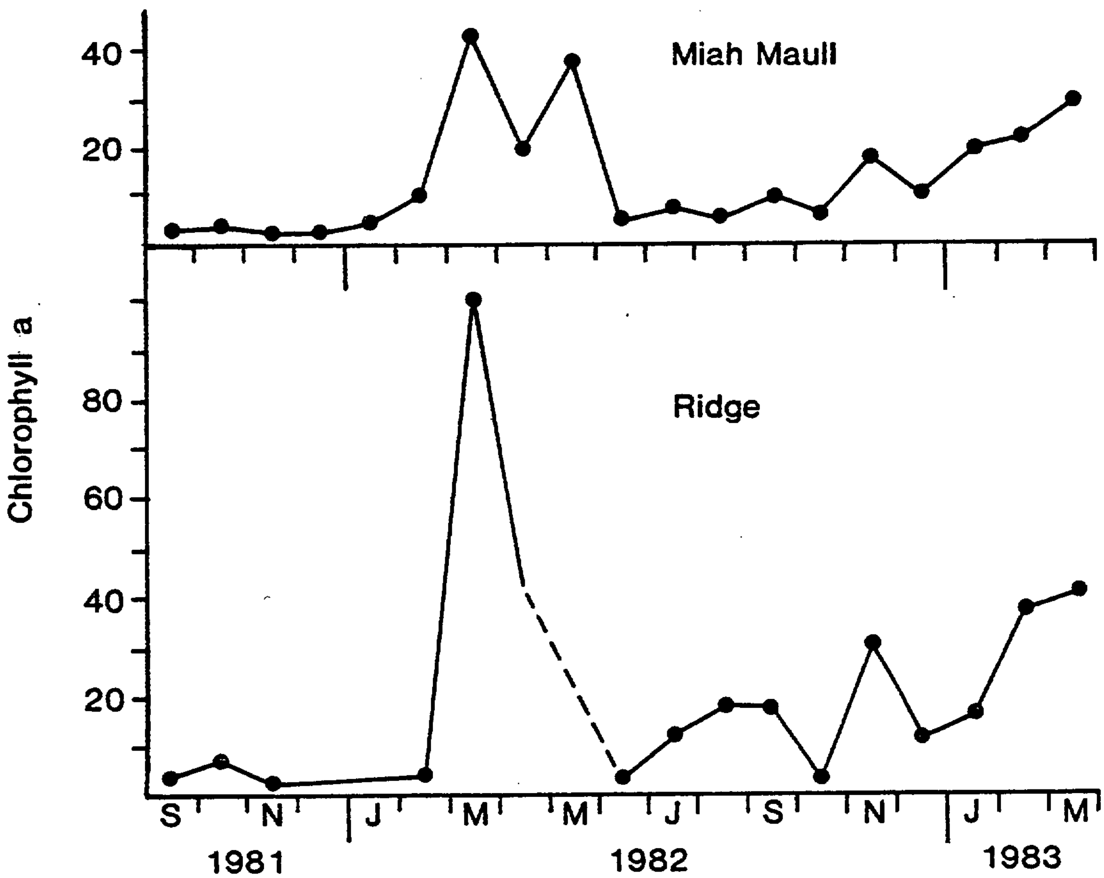


Figure 10-2. Seasonal distributions of chlorophyll (ug/L) for two stations in the lower estuary from September 1981 to March 1983. "Miah Maull" station is in deeper water; "Ridge" is in shallow water.

Basin Commission (DRBC) for freshwater regions from Trenton to Philadelphia record summer chlorophyll concentrations as high as 70 ug chl/L in the metropolitan area. These values are reduced below Philadelphia due to mixing with more turbid water incapable of supporting an increase in biomass (light limitation). The major freshwater forms observed are Closterium sp., Mesosira sp., and Asterionella formosa.

In summer, chlorophyll levels along the main axis of the lower estuary range from 1-10 ug chl/L, much lower than those found in the freshwater region. Although ambient light availability is greater in summer than other seasons, chlorophyll levels remain low. The deep central channel in the lower estuary appears to limit high chlorophyll accumulations because a large portion of the water column lies below the photic zone. In inner shoal regions of the lower estuary chlorophyll concentrations reach greater than 20 ug/L in summer due to the well-mixed shallow water column. Chlorophyll levels in the shoals have been examined intensively at select stations over a two-year period. These data show elevated shoal concentrations in summer when compared to the central channel (Figure 10-2).

Species dominance shifts from spring diatom populations to green flagellated algae and centrate diatoms during early summer. Pennate diatoms become more significant towards late summer. Although Watling et al. (1979) observed several species of dinoflagellates (Amphidinium sp., Gymnodinium sp., and Prorocentrum sp.), these species seem to have played a minor role over the last few years.

Winter (November-February) chlorophyll distributions in general are characterized by low chlorophyll levels (10 ug chl/L) throughout the estuary (Figure 10-1). This is due primarily to low light levels. Although upper-estuary distributions appear consistent from year to year (our data and DRBC data), the lower estuary shows significant variation. Relatively high flow in the fall of 1982 caused vertical stratification in the middle estuary and a subsequent minor bloom (17 ug chl/L) of the diatoms Coscinodiscus sp., Skeletonema costatum, and Asterionela japonica. Similar chlorophyll concentrations were observed in the shoals with the bloom reaching maximum concentrations in November. Under low-flow conditions in 1981 middle estuary chlorophyll levels were 3 ug chl/L during the same period but a minor bloom of 15 ug chl/L occurred at the estuary mouth.

Chlorophyll is a measure of phytoplankton biomass available to the food web of the estuary. Phytoplankton-produced organic matter is more available to filter-feeding shellfish and finfish that breakdown material (detritus) from marsh plants (Tenore and Hanson 1980). However, large increases in phytoplankton biomass have been shown to be detrimental in some estuarine systems because of high biological oxygen demand that can occur following large blooms.

The spring diatom bloom in the Delaware Estuary is comparable in magnitude and timing to those occurring in other major estuaries (Table 10-1). High chlorophyll concentrations in the upper estuary during summer result from inputs of freshwater phytoplankton populations. Although these concentrations are significant there is no indication that the Delaware Estuary suffers severe oxygen depletion due to degradation of phytoplankton organic matter after bloom events. This may be explained by turbulent mixing in the estuary, which serves to mix oxygen into bottom waters where unconsumed phytoplankton may settle, and natural grazing (consumption by planktonic animals) that removes organic matter, passing it on to higher trophic levels of the food chain.

Several important points emerge from this descriptive chlorophyll picture of the Delaware Estuary: (1) Chlorophyll levels reach maximum concentrations within the central estuary of 60 ug chl/L during the spring bloom and during summer in the upper estuary. Shallow inshore areas may have slightly higher concentrations; up to 80 ug chl/L. (2) Although high, these levels of phytoplankton biomass have not resulted in oxygen depletion and the resultant disruption of the estuarine food web. (3) Phytoplankton biomass in the estuary appears to be light-limited rather than nutrient-limited, except possibly at the termination of the spring bloom when nutrient concentrations reach low levels (see below).

Table 10-1. Concentrations of chlorophyll a, in micrograms per liter, are given as minimum to maximum and average values for several United States estuaries.

Estuary	Chlorophyll a Min-Max	Average	Reference
Barataria Bay, LA	5 - 16	10	Day (1973)
Pamlico River, NC	10- 25	18	Kuenzler et al. (1979)
Chesapeake Bay			
upper estuary	2 - 25	14	Boynton et al.
middle estuary	1 - 13	7	(1982)
Patuxent River, MD			
upper estuary	2 - 43	23	Flemer et al.
middle estuary	5 - 33	16	(1970)
Raritan Bay, NJ	2 - 45	16	Patten (1961)
Hudson River, NY	1 - 5	3	Boynton et al. (1982)
Long Island Sound	4 - 8	6	Bowman (1977)
Narragansett Bay, RI	2 - 12	6	Furnas et al. (1976)
Delaware Bay			
upper estuary	1 - 50		
lower estuary	3 - 65	17	this study
shoals	3 - 95		

PHYTOPLANKTON PRODUCTION

Phytoplankton production is measured using carbon-14 (radioactive isotope) uptake, oxygen evolution, and nitrogen-15 (heavy stable isotope) uptake. Carbon uptake and oxygen evolution methods are used to estimate photosynthetic rates occurring in the water column. Light-dark oxygen measurements that have been made periodically in the upper estuary provide the only previous record of productivity in the estuary. These, however, lack the necessary sensitivity to give a good estimate of phytoplankton production because they were designed specifically as long-term biological oxygen demand monitoring experiments (EPA STORET, Ichthyological Associates 1977). Because photosynthesis is light-dependent, optical measurements of attenuation coefficients (see Chapter 8) are used in conjunction with carbon-14 simulated in-situ incubations at six light levels to derive an integrated photosynthetic rate through depth in the water column. This measurement is the most useful estimate of total photosynthetic demand and growth rate in the estuary. Nitrogen uptake, indirectly coupled with carbon fixation is measured using nitogen-15-labeled ammonium and nitrate to determine the relative importance of these major nitrogen sources to the nitrogen requirement of phytoplankton.

Primary productivity measurements have been made for the entire estuary using carbon-14 incorporation techniques. Incubations were carried out for 24 hours; thus the results are considered to be a representative estimate of net primary production (gross uptake minus losses due to plant metabolism). Estimates have been obtained from P-max (the maximum uptake rate at saturating light intensity), areal production (production per square meter of estuary surface integrated over depth), and assimilation number (P-max/chlorophyll). These related measurements provide different types of information.

Areal production measurements provide the best estimate of total phytoplankton activity in the estuary on a temporal and spatial scale. As with chlorophyll, phytoplankton production in the Delaware Estuary can be divided into three seasons: spring, summer, and winter.

Spring levels of production are related to chlorophyll distributions, reaching a maximum of 1.4 gm C/m^2/day in the middle estuary (Figure 10-3). This spring diatom bloom is responsible for significant utilization of the inorganic nutrients ammonium, phosphate, and silicate in the middle estuary. Mass balance estimates suggest that phytoplankton production can account for observed losses of these nutrients from the water column of the lower estuary (see Chapter 5). During the secondary bloom in May, ammonium, phosphate, and silicate concentrations approach our analytical detection limits in the lower estuary, suggesting that they could limit phytoplankton growth at this time.

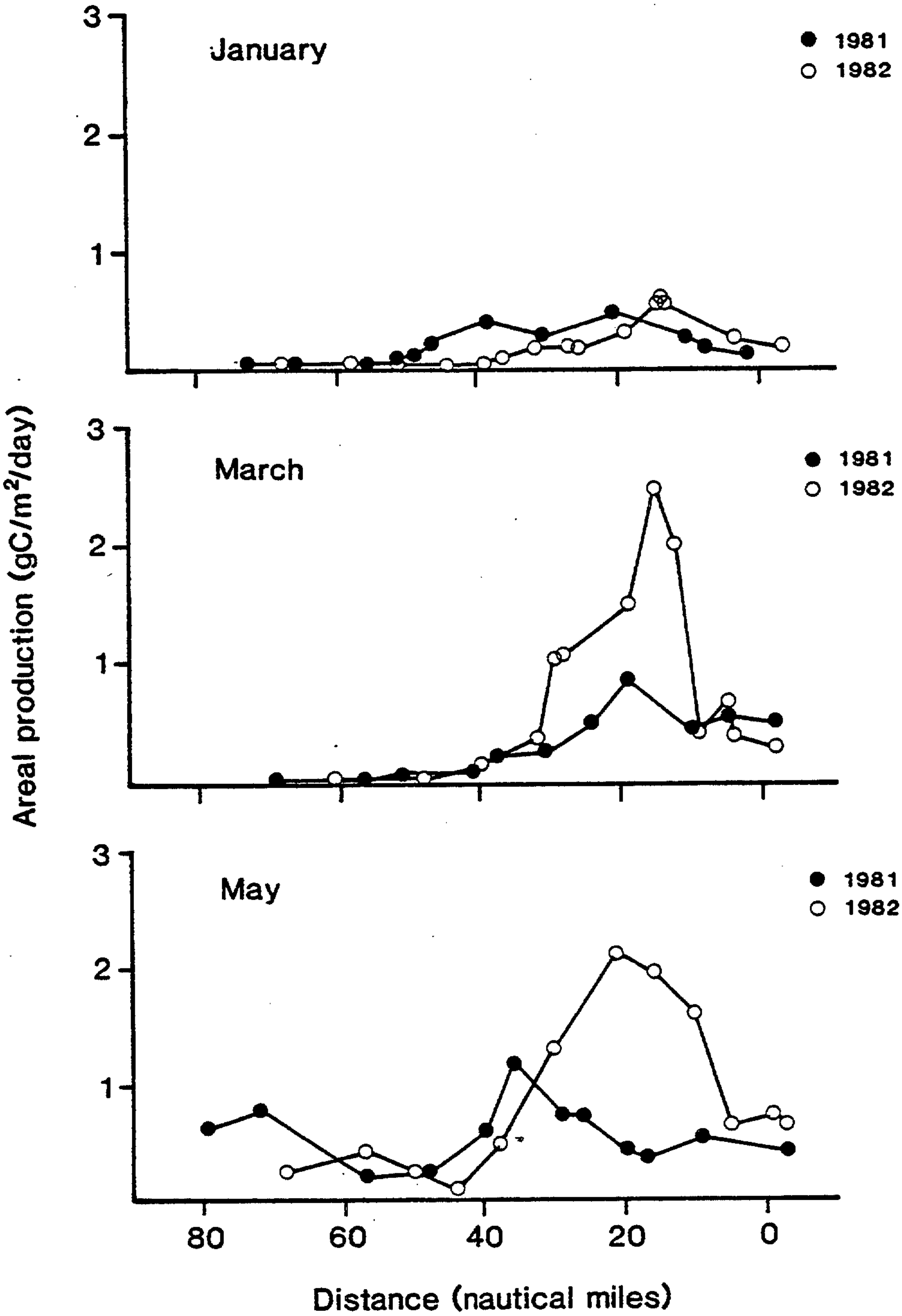


Figure 10-3. Phytoplankton areal production along the main axis of the estuary vs. distance from the bay mouth for January, March, and May.

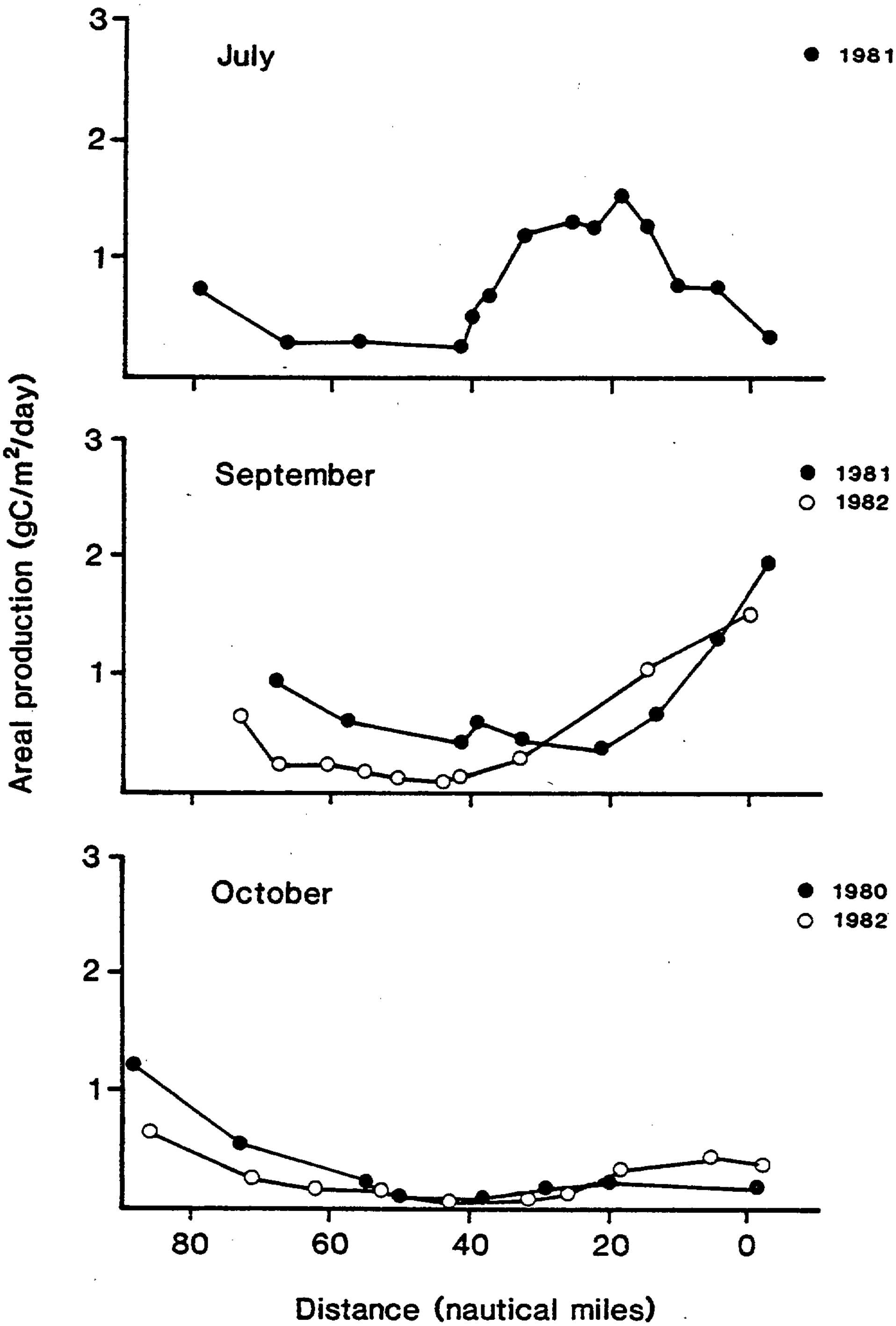


Figure 10-4. Phytoplankton areal production along the main axis of the estuary vs. distance from the bay mouth for July, September, and October.

Summer production in the estuary is high both upstream and downstream of the turbidity maximum (Figure 10-4). Rates as high as 1.1 gm C/m^2/day have been observed in the Philadelphia area while rates in the lower estuary in July have reached 2.7 gm C/m^2/day. These rates are comparable to rates found in coastal upwelling zones and other major estuaries (Table 10-2). Production in the lower estuary is not correlated with chlorophyll concentrations because small plankton (2-20 microns in size), which are low in chlorophyll, are the dominant producers in the summer.

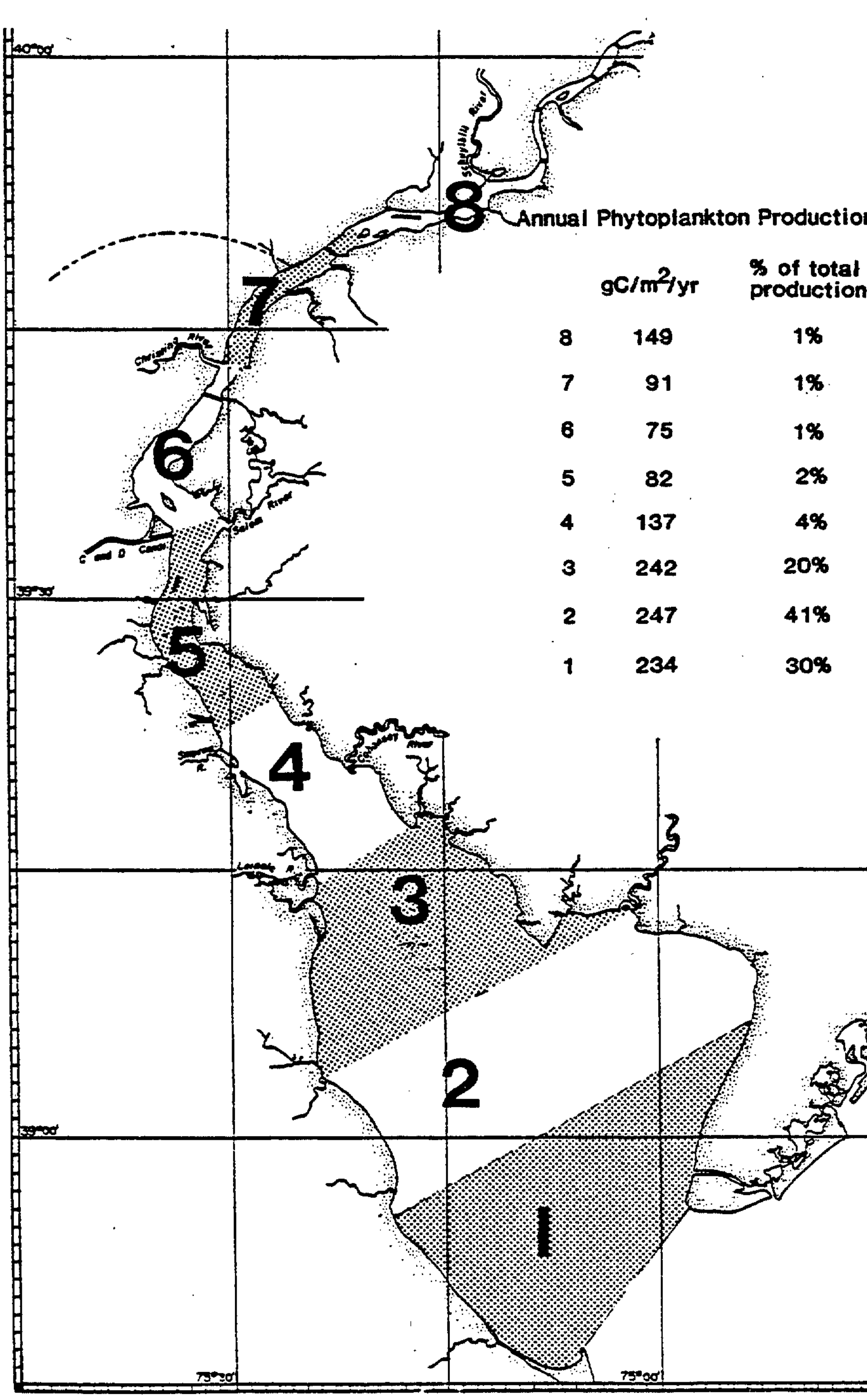
Winter production in the estuary is variable (Figure 10-3). It appears that production is positively related to river flow. During low flow in 1981, winter production rates reached a maximum of 0.12 gm C/m^2/day in the lower estuary, while during higher flow in 1982 values reached 0.65 gm C/m^2/day.

An integrated estimate of phytoplankton production for the entire estuary over the last 2 years gives an average production value of 228 gm C/m^2/year. This value lies above the average estimates made for estuarine and coastal systems over the last decade (Table 10-2). Estuaries often have greater phytoplankton production rates than coastal waters because of their increased nutrient levels and major differences in physical processes (stratification, two-layered flow found in estuaries). Production in marshes of the Delaware region averages 180 gm C/m^2/year (Morgan 1961), comparable to rates we measured for phytoplankton in the water column. However, several factors suggest that phytoplankton input to the estuarine food web is more important than marsh inputs: (1) The areal extent of open waters is five times the areal extent of marshes in the estuary. (2) Phytoplankton organic matter is known to be more available than marsh detrital matter to consumers. (3) Only a portion of the organic matter produced in the marshes is exported to the food webs of the open estuary (Roman 1981).

Ninety percent of phytoplankton production in the estuary lies in the middle and lower estuarine regions below Ship John Light (Figure 10-5). This suggests that a large percentage of phytoplankton organic input to the food web

Table 10-2. A comparison of phytoplankton production in several United States estuaries is shown with production in units of grams of carbon produced per square meter of estuary surface on a daily and annual basis.

Estuary	Production Daily	Production Annual	Reference
Wassaw Estuary, GA	0.9-2.2	90	Turner et al. (1979)
Pamlico River, NC	0.1-3.3	200	Kuenzler et al. (1979) Davis et al. (1978)
Chesapeake Bay	0.1-3.3		Flemer (1970)
Patuxent River, MD	0.1-1.5		Flemer et al. (1970)
Raritan Bay, NJ	0.1-1.5		Patten (1961)
Hudson Estuary			
lower bay	0.1-2.2		Malone (1977)
New York Bight Apex	0.1-6.0	370	Malone (1976)
Long Island Sound		166	Ryther and Yentsch (1958)
Narragansett Bay	0.2-3.2	220	Furnas et al. (1976) Smayda (1973)
San Francisco Bay			
lower bay	0.1-0.5		Cloern (1979)
upper bay	0.1-0.9		Peterson (1979)
Delaware Estuary			
upper estuary	0.1-1.3		
lower estuary	0.1-3.0	228	Pennock et al. (this study)



Annual Phytoplankton Production by Section

	gC/m²/yr	% of total estuary production
8	149	1%
7	91	1%
6	75	1%
5	82	2%
4	137	4%
3	242	20%
2	247	41%
1	234	30%

Figure 10-5. Average yearly areal production values for 8 sections along the salinity gradient of the estuary.

and nutrient uptake occurs in open waters of the lower estuary, the geographical region which has been studied least and is the most difficult to evaluate.

P-max values (maximum photosynthetic rates) are indicative of the photosynthetic potential of the estuarine phytoplankton population. This potential may or may not be realized in areal production. For example, high P-max values observed during the spring bloom are closely associated with high estimates of areal production. In contrast, summer P-max rates and chlorophyll concentrations in the upper estuary are greater than five times those found in late spring but areal production is about equal. The potential, indicated by P-max, is not realized due to upper-estuary high turbidity that restricts production to all but the surface water. We find that P-max is often at a minimum where the estuary's turbidity is greatest 40 to 60 nmi (nautical miles) upstream (Figure 10-6). We believe that this is due to two factors: Net growth of phytoplankton does not occur in this region due to light limitation (populations are thus diluted by simple mixing with saltwater); and freshwater phytoplankton populations which dominate in the Philadelphia region above the turbidity maximum are physiologically impaired in the low-salinity regime of the turbidity maximum. Other variations observed in P-max are due to variations in chlorophyll concentration (previous section) and seasonal variations in available light.

Assimilation number (P-max/Chl) is indicative of the photosynthetic efficiency of phytoplankton. Assimilation numbers vary from 1 during winter to 300 during summer (Figure 10-7). These values are comparable to values reported for other systems (Harrison and Platt 1980). Natural variation in assimilation number may be due to several factors, including temperature, ambient light, and species composition. Deviations in assimilation number may also be due to physiological stress to the phytoplankton, making assimilation number estimates valuable in determining the health of the phytoplankton population. High assimilation numbers found during summer in the lower estuary result from high temperature, increased light, and species composition dominated by small plankton (2-20 microns). Malone (1976, 1977) has shown that small plankton under a variety of environmental conditions, consistently have

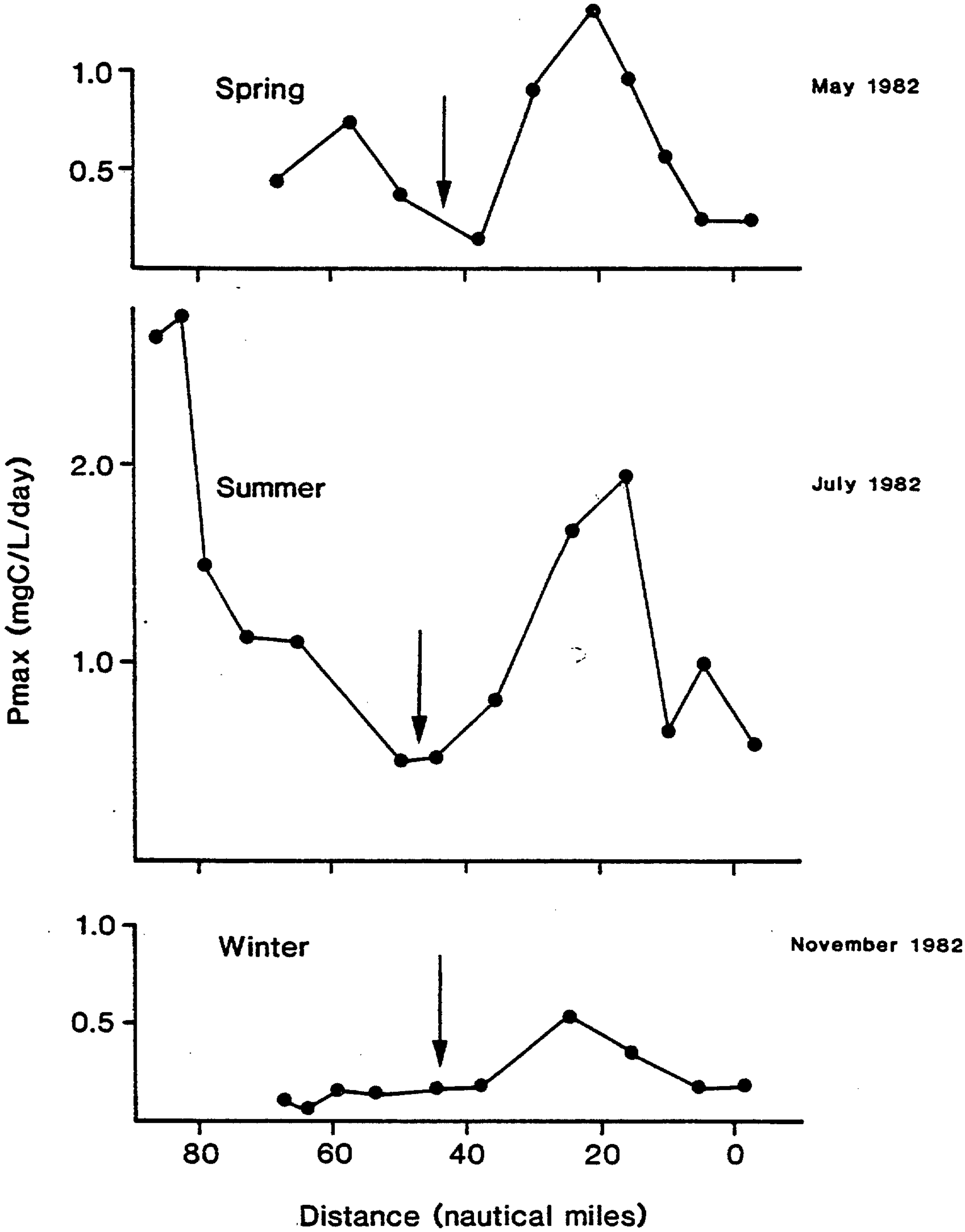


Figure 10-6. Maximum phytoplankton productivity rates (P-max) vs. distance upstream from mouth of the estuary. Arrow indicates turbidity maximum.

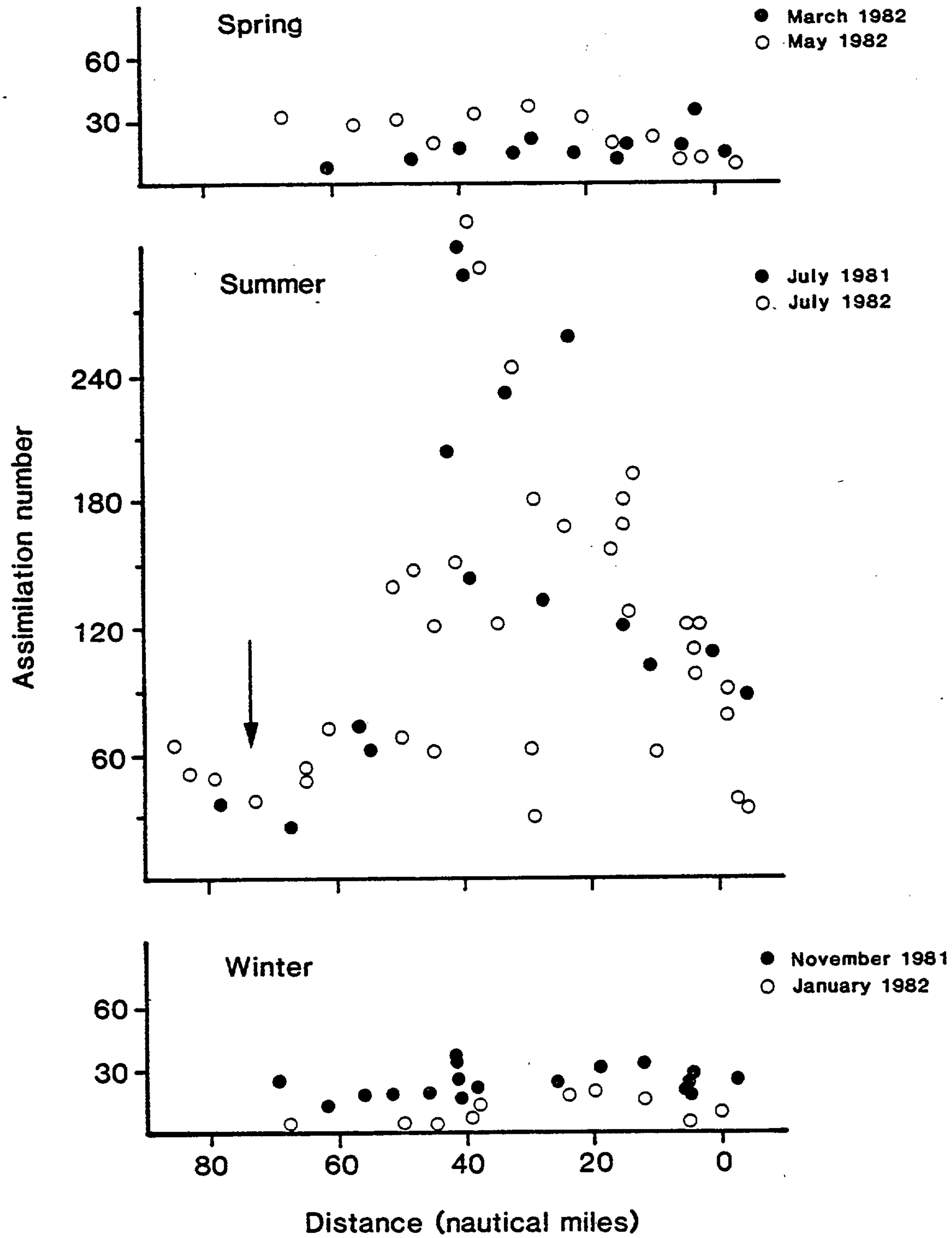


Figure 10-7. Assimilation number vs. distance. Depressed values below Philadelphia indicated by arrow. Units for assimilation number are ugC produced per day/ug chlor a.

assimilation numbers higher than larger ones. In contrast, assimilation numbers found in the upper estuary, near Philadelphia, do not rise above 60 even in summer. This indicates that riverine populations are stressed either by salinity, as previously mentioned, or potentially by some growth inhibitor or toxin in the water. This requires additional research.

Several important points evolve from an analysis of our phytoplankton production data: (1) Phytoplankton production is at a maximum during summer; highest rates occur in the lower estuary. Production rates during the spring bloom in the middle estuary are slightly lower. (2) Phytoplankton production in the Delaware Estuary is comparable to that found in other major estuaries previously studied. (3) Ninety percent of phytoplankton production occurs in the lower estuary below Ship John Light. (4) Assimilation numbers show natural variation in the lower estuary but are depressed in the Philadelphia region, suggesting that the phytoplankton may be physiologically impaired.

NITROGEN UPTAKE

Experiments have been made to determine specific uptake of ammonium, nitrate, and nitrite by phytoplankton in the estuary. Knowledge of the uptake of nitrogen is important to our understanding of the Delaware Estuary because nitrogen is the major biologically active human input to the estuary and, potentially, the controlling element for phytoplankton production (see Chapter 5 for nitrogen species and distribution). During spring, phosphate and silicate are also potentially limiting although we have little data available on phytoplankton uptake of these nutrients.

Phytoplankton usually take up ammonium-nitrogen in preference to nitrate-nitrogen. McCarthy et al. (1977) have suggested that ammonium concentrations in excess of 1 micromolar (uM) will inhibit uptake of nitrate; if this is correct, we would expect to see little uptake of nitrate in the Delaware Estuary because of ammonium concentrations higher than 1 uM found throughout the estuary.

Results of nitrogen uptake studies have clearly shown ammonium to be the major source of nitrogen for phytoplankton in the estuary (Figure 10-8). This occurs even though nitrate is usually present in concentrations several-fold higher than ammonium. When we compare phytoplankton nitrogen uptake with an estimate of nitrogen inputs from runoff, and effluent inputs at the freshwater end of the estuary (using a simple fluid dynamics model), we calculate that nitrogen uptake in the lower estuary is 10 to 20 times greater than total nitrogen input (nitrate + ammonium) during late spring and summer. This suggests that recycling of ammonium (in the water and bottom sediments by animals and bacteria) is occurring, and that this recycling is supplying a significant portion of the phytoplankton nitrogen demand in the summer. We as yet have inadequate data to be confident in the rates of recycling occurring in the estuary.

Although ammonium uptake dominates total nitrogen uptake by phytoplankton we have seen significant rates of nitrate uptake (Figure 10-8). Nitrate uptake appears to be most significant during the spring bloom and other periods of active growth when ammonium concentrations are reduced to 1.0 uM. However, we also observe nitrate uptake occurring at ammonium concentrations well in excess of 2-3 uM (Figure 10-9). This is an observation not previously stressed in reports for other estuaries and presumably is the result of the extremely high nitrate concentrations found in the Delaware. Much of the observed nitrate uptake at ammonium concentrations greater than 3 uM occurs in the lower estuary in conjunction with phytoplankton populations of coastal origin. We suspect that these populations are adapted to nitrate uptake in coastal regins where ammonium is scarce, and that they continue to utilize some nitrate when carried into the estuary because of preconditioning to nitrate offshore.

Interpretation of our data on phytoplankton nitrogen uptake yields several important observations: (1) Ammonium is the dominant source of nitrogen for phytoplankton in the Delaware Estuary although nitrate is the form present in highest concentration. (2) Ammonium uptake in summer is 10 to 20 times our best estimate for inputs from freshwater sources (runoff and input). This implies that recycling in the lower estuary is important during summer. (3) Although nitrate uptake is observed, phytoplankton are not capable of

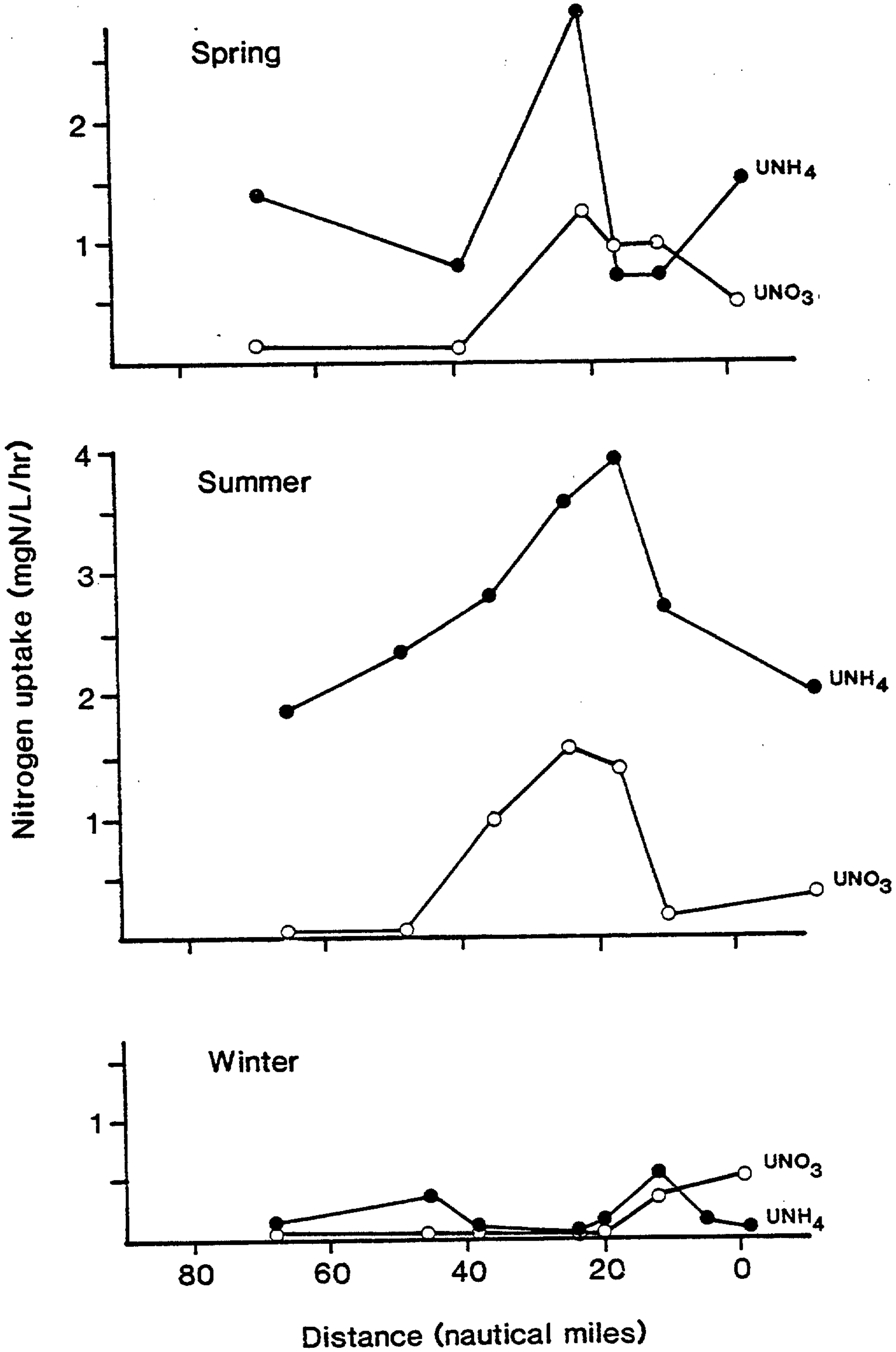


Figure 10-8. Nitrogen uptake vs. distance along main axis of the estuary. Nitrate (UNO_3) and ammonium (UNH_4) uptake plotted separately from equivalent stations.

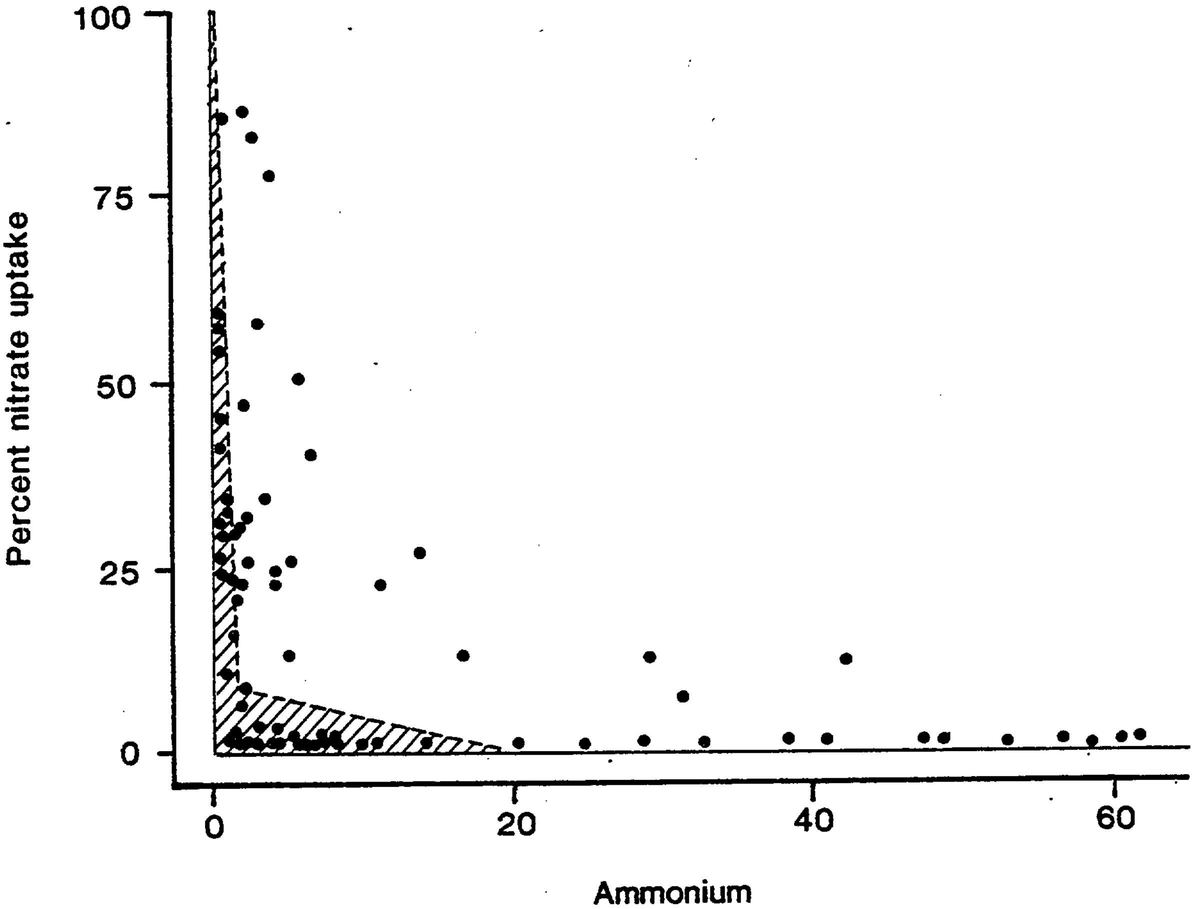


Figure 10-9. Nitrate uptake as percent of total nitrogen uptake vs. ammonium concentration (micromolar). Our data (dots) compared with data from McCarthy et al. (1975) for the Chesapeake Bay (stippled area).

processing the large input from freshwater sources. (4) We have observed significant nitrate uptake when ammonium concentrations were greater than 3 uM.

CONCLUSIONS

Phytoplankton populations in the Delaware Estuary appear relatively healthy compared to non-industrial estuaries despite high nutrient concentrations and turbidity which limits significant phytoplankton production in the upper estuary. Distribution of phytoplankton in the estuary appears to be controlled by light. Light limitation in the upper estuary may suppress formation of noxious blooms that have plagued other estuaries with elevated nutrient levels. Highest phytoplankton levels appear during spring when a large diatom bloom occurs in middle estuary. Some of this biomass presumably enters the estuarine food web through zooplankton grazing or bacterial processes. We do not observe oxygen depletion associated with degradation of this biomass in the middle estuary.

Annual phytoplankton production in the Delaware Estuary averages 228 gm C/m^2/year. This value is above average compared to other estuaries. High productivity can be attributed to high nutrient concentrations. The areal phytoplankton production is similar to estimates of marsh production in the Delaware region but the former is probably a far more important input to the estuarine food web.

Nitrogen uptake studies have shown that phytoplankton are capable of taking up more nitrogen than is carried into the lower estuary from runoff and human inputs. Thus, recycling of nutrients is important in maintaining phytoplankton in the lower estuary. Ammonium recycling appears to supply a large percentage of the nitrogen requirement for the phytoplankton in the summer. Much of the nitrate which is carried down the estuary is either utilized by microbial populations in the sediment or carried out into coastal waters where it may support elevated rates of phytoplankton production.

Decreased turbidity levels would undoubtedly lead to higher phytoplankton production because sufficient nutrients are available in this light-limited system. Increased production has often resulted in noxious phytoplankton growth in other eutrophic estuaries.

Production under low-flow conditions is decreased compared to high-flow conditions. This is because vertical stratification is important in a light-limited environment. Increased diversion of river water from the lower estuary, particularly under low-flow conditions, would be expected to decrease middle-estuary phytoplankton production.

Inputs of high concentrations of potential chemical toxins could have a severe impact on phytoplankton populations of the estuary. We have not examined the potential for toxic inhibition of phytoplankton populations in detail but examination of growth efficiencies suggests impairment of phytoplankton growth in the upper estuary below Philadelphia. This effect, which could be due to natural mixing dynamics or anthropogenic toxins, requires additional research.

A decrease in nutrient inputs from municipal and industrial sources could decrease the magnitude of the spring diatom bloom because nitrogen and phosphorus inputs during this period are significantly depleted. Since recycling appears to supply most of the nutrient requirements in the lower estuary in the summer, a decrease in nutrient input probably would not decrease summer production in the short term. However, a decrease in input in the long term would cause a decrease in the rates of remineralization which drive summer production. Since production in winter is light-limited, one would expect little effect from reduced nutrient loading. The potential impact of changed nutrient input on the overall annual production is difficult to assess at this time. This is an area requiring further research, especially through nutrient mass-balance modeling and laboratory research.

ZOOPLANKTON AND PARABENTHOS

S.S. Herman, B.R. Hargreaves, R.A. Lutz, L.W. Fritz, C.E. Epifanio

INTRODUCTION

One approach to investigating how the Delaware Estuary works is to identify the most important animal species and to study their population dynamics and the patterns and underlying forces that determine population size. Figure 11-1 represents a model food web for the Delaware Estuary showing biomass exchange. It attempts to show the predator-prey relationships between organisms and the various environmental parameters. The previous chapter dealt with the phytoplankton; this one deals with zooplankton and associated organisms that are directly or closely dependent on the phytoplankton for food.

Zooplankton are animals that float in the water column at the mercy of the ocean currents. By definition, they are incapable of strong horizontal swimming movements although they may swim vertically. In general the zooplankton may be divided into two major catagories, the macroplankton (organisms greater than 0.5 mm diameter) and the microplankton (those less than 0.5 mm). Each group requires different sampling gear and techniques. This report deals with three studies of the macroplankton including blue crab larvae, oyster larvae, and a survey of all major groups.

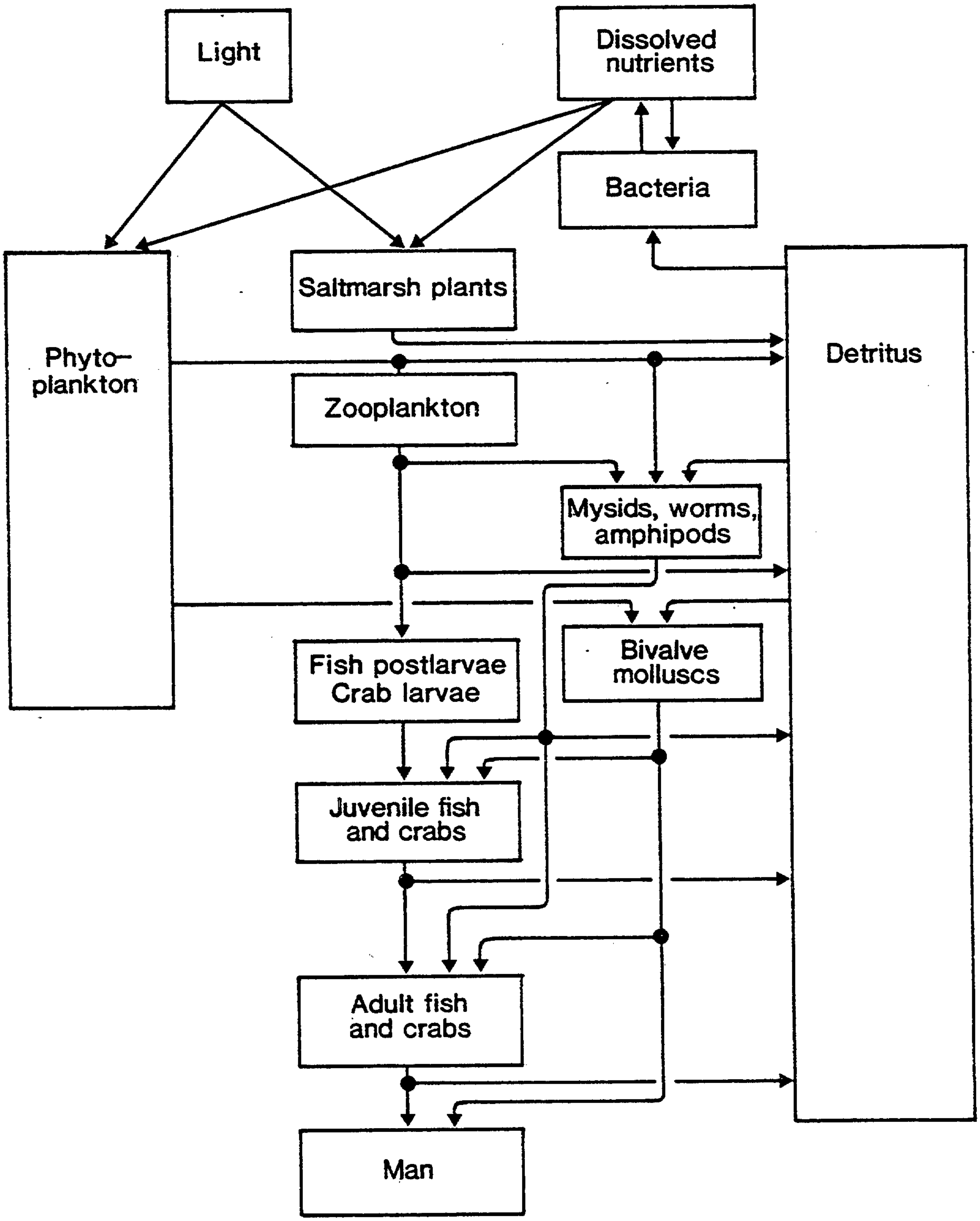


Figure 11-1. The Delaware Estuary food web. Arrows point from a component used by the component at the end of the arrow.

Finally, studies have been initiated on one component, the mysids (opossum shrimp), of the animals living on or near the bottom referred to as parabenthos or bottom plankton. Mysids and copepods are important food for many postlarval and juvenile fish. Oyster larvae in the macrozooplankton go through dispersal, growth, and development before settling on the bottom. The blue crab life cycle begins with planktonic forms hatched within the estuary; they are quickly carried out of the estuary but must return from the continental shelf to maintain adult populations. Each species has a unique combination of factors that determines population size, but the common biological factors are food availability and predation rate, while the common physical factors are temperature, salinity, oxygen, light, and water currents. We are reporting on studies of population dynamics of macrozooplankton and mysids, dispersal of blue crab larvae, and effects of food quality and quantity on feeding in oyster larvae.

GENERAL ZOOPLANKTON

The pattern of change in population size for mysid shrimp and macrozooplankton in the Delaware Estuary was studied 1982-83. The pattern should indicate when food is available for postlarval and juvenile fish and when there will be extensive grazing on phytoplankton (Figure 11-1). The Delaware Estuary is a major spawning and breeding ground for fish (Shuster 1959, Daiber and Smith 1969, Maurer and Wang 1973). Postlarval and juvenile fish feed on macrozooplankton, mysids, and small benthic invertebrates, and are themselves eaten by larger fish and crabs. The total numbers or species composition of macrozooplankton and mysids at any given time may determine the success of a year class of young fish, especially fish with specialized diets. Among such species in Delaware Bay is the juvenile weakfish which feeds primarily on copepods and mysids (Stickney et al. 1975, Allen et al. 1978).

In the present study, samples of plankton and mysids were taken approximately twice monthly for 11 months (beginning in May 1982) at 9 stations in the Delaware Estuary (Figure 11-2). These samples were analyzed for species composition, population densities, and total biomass. Numbers and biomass were

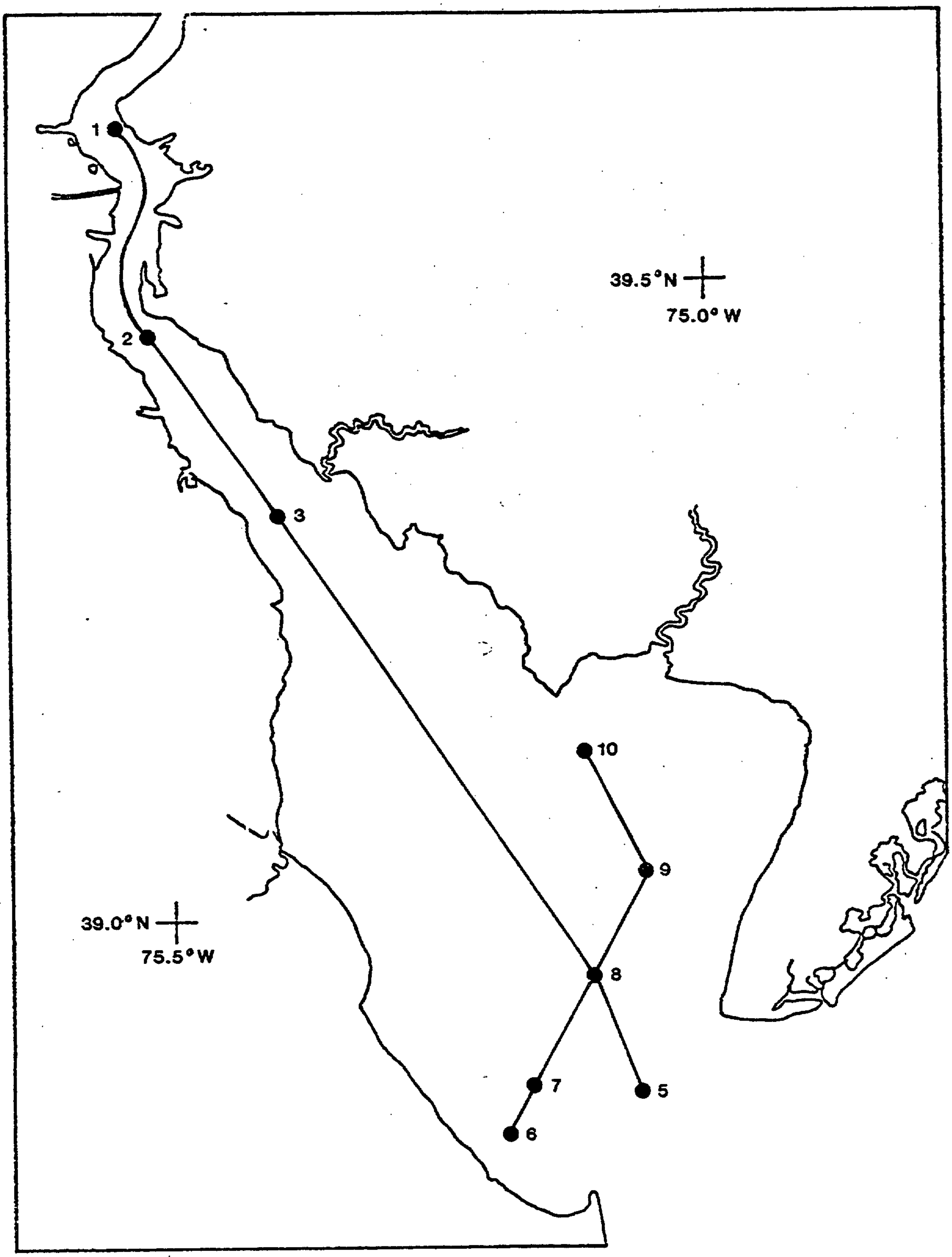


Figure 11-2. The Delaware Estuary showing locations of zooplankton sampling stations.

expressed per cubic meter of water for plankton and per square meter of water column for mysids because the former are distributed rather uniformly with depth while the latter are concentrated within one meter of the bottom during daylight hours.

Copepods were the most abundant organisms in the zooplankton, accounting for 94% by number in samples taken from May 1982 through February 1983. While more than 30 species of zooplankton were recorded in the present study, five species of copepods accounted for most of the recorded numbers. Two distinct regions of the estuary were evident, the upper low-salinity region (stations 1, 2, 3, 10 in Figure 11-2) and the lower high-salinity region (stations 5, 6, 7, 8, 9 in Figure 11-2). Acartia tonsa and Oithona sp. were the only abundant species distributed throughout the estuary; Temora longicornis, Pseudocalanus minutus, and Centropages hamatus were in the lower more saline region only. These latter three "marine" species were present only in winter and spring, while the other two were present most of the year. Overall, Acartia tonsa was the dominant copepod both geographically and seasonally. Maurer et al. (1978b) observed a similar pattern near our stations 6 and 7 but with less frequent sampling. Meredith (1982) observed strikingly similar population cycles with frequent sampling in a salt-marsh creek near our station 6.

Figure 11-3 shows seasonal abundance for all zooplankton as number per cubic meter and grams dry weight per cubic meter. There was general agreement between numbers and dry weight except in January when detritus levels rose and these materials, which included decaying plants, animals, etc., exceeded the amount of macrozooplankton. In the first summer peak (early May), increases in four species, Temora, Centropages, Pseudocalanus, and Oithona, plus copepodites (copepod larvae) accounted for 79% of the numbers observed, while Acartia tonsa and copepodites accounted for 79% of the peak in total numbers in late June and early July. Zooplankton numbers remained well below peak levels throughout summer and fall, rising only after December. In February, Centropages hamatus and copepodites accounted for over 70% of the total zooplankton in the water column. No previous studies from the Delaware Estuary have reported dry weights of zooplankton, nor did any have the spatial or temporal resolution to show these population cycles.

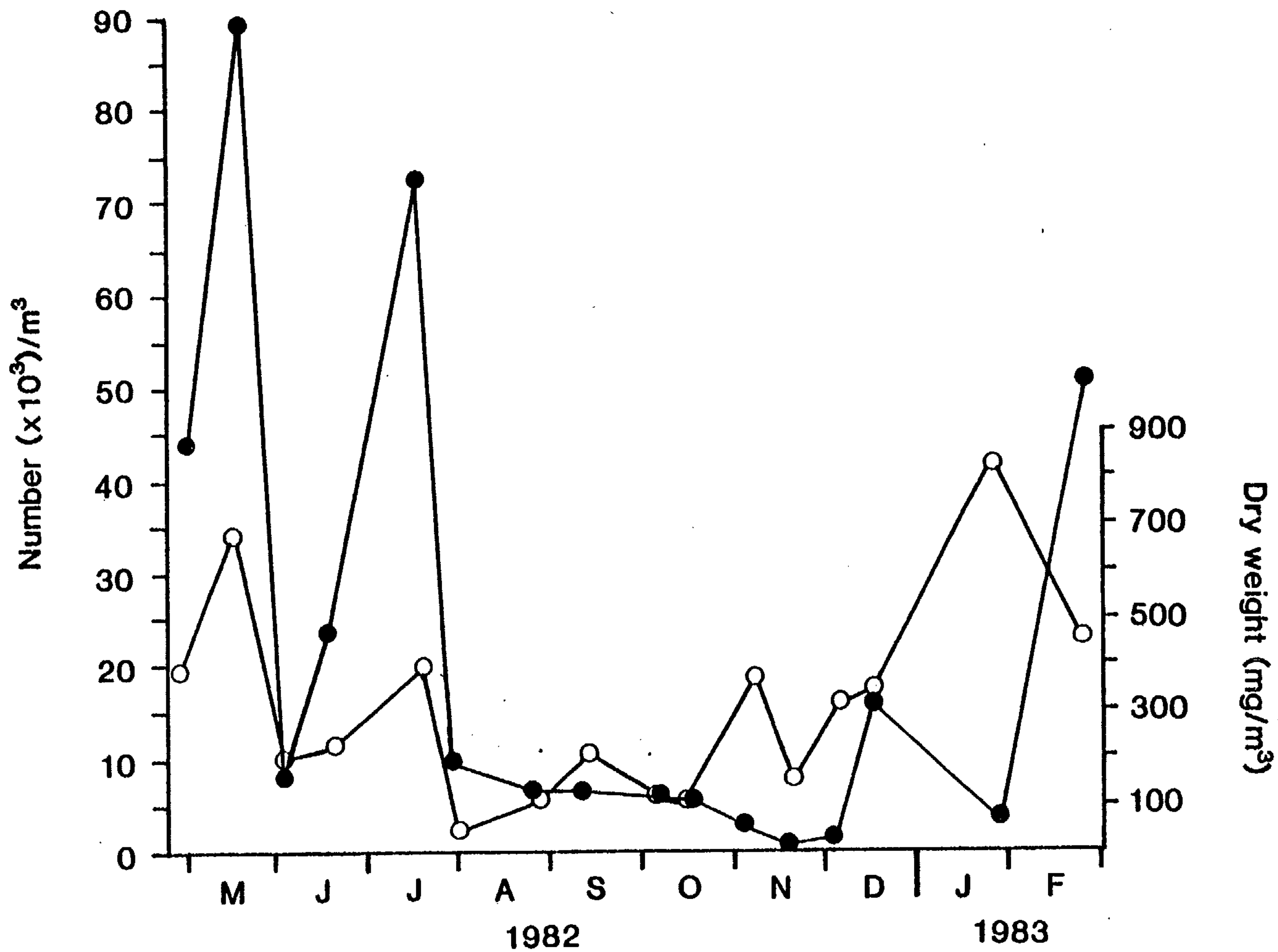


Figure 11-3. Abundance of macrozooplankton is shown over the annual cycle both as number of individuals (solid circles) and dry weight (open circles) per cubic meter.

Mysids typically make up a large percentage of the invertebrates that live near the bottom. They are omnivores, feeding on phytoplankton, zooplankton, and detritus (Figure 11-1). Two species of mysid shrimp were observed in the estuary, Neomysis americana and Mysidopsis bigelowi. Neomysis was the most abundant mysid although Mysidopsis was nearly as abundant during the winter months.

Mysid abundance was determined by combining data from replicate plankton tows and epibenthic sled tows taken at each site. The only previous study of mysid abundance (PSE&G 1980) did not include sled tows and thus probably greatly underestimated the mysid population size. Those earlier results did not show the striking seasonal changes in number and biomass that we observed. Apparent from the graph in Figure 11-4 are two major peaks of monthly means of mysid numbers and biomass (dry weight) per m^2.

The mean size of mysids changed seasonally. In spring, the peak consisted of large overwintered adults and their offspring; in late summer the peak consisted of small summer adults and their offspring. The mean size of individuals (Figure 11-5) remained low through the summer and fall, rising from November through February as the young, released in the fall, grew and matured in cold water. The winter rise in population biomass is probably attributable in part to an increase in mysid numbers (from reproduction and perhaps migration), but mainly to growth of the individual mysids. In warm temperatures mysids grow and reproduce rapidly (e.g. during late August of 1982), but never reach the size of the overwintering animals. In addition to growth and reproduction, another important factor in the size of the mysid population is predation. Two periods of heavy predation are apparent in Figure 11-4, from late May through August and from mid-September through November. The next step in modeling fish population dynamics should include a study of feeding selectivity of the dominant species of fish, and simultaneous measurements of prey and fish population size and distribution.

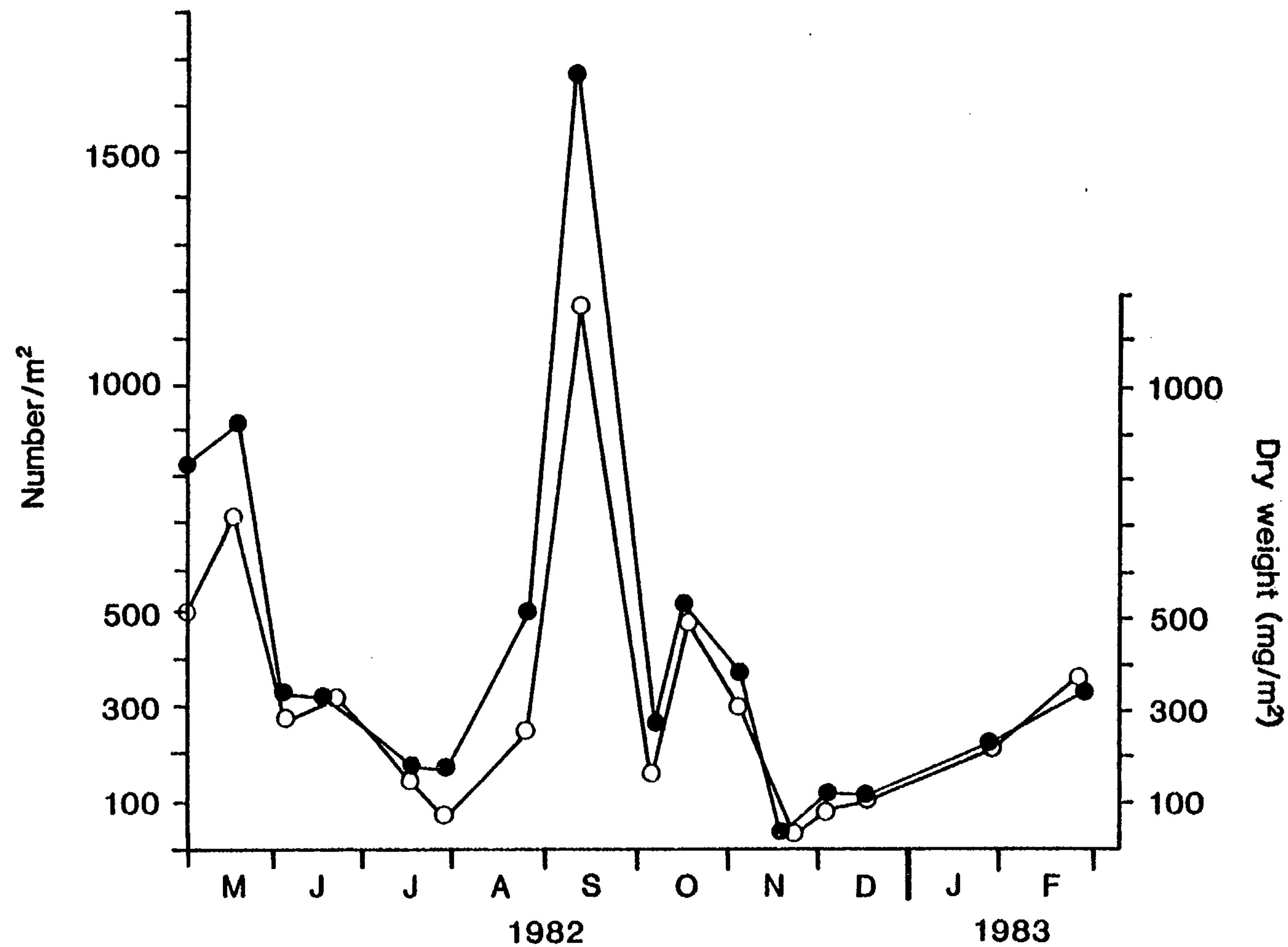


Figure 11-4. Abundance of mysids is shown over the annual cycle both as number of individuals (solid circles) and dry weight (open circles) per cubic meter.

BLUE CRAB LARVAE

The success of blue crab larvae in the zooplankton contributes to the fisheries yield of adult blue crabs. The past year's study has contributed to a dispersal model for these larvae that may explain variations in blue crab landings from year to year. Hatching of blue crab eggs occurs in the lower bay at salinities greater than $25^{o}/oo$. Hatching usually occurs around the time of high tide; larvae immediately migrate to the surface and are carried from the bay during the ensuing ebbing tide (Epifanio et al. 1983). The larvae are then dispersed in the waters over the inner continental shelf and it is in these waters that the larvae undergo their 5-6-week period of growth and development. While the exact mechanism is unknown, postlarval blue crabs appear to be transported back to the vicinity of the bay by wind-driven surface currents over the continental shelf (Sulkin et al. 1982). Once in the vicinity of the bay mouth, postlarvae appear to undergo vertical migration up into the water column during periods of flooding tidal currents and down to the bottom during periods of ebbing tidal currents. This pattern of vertical migration allows the postlarvae to move upstream in spite of the net seaward movement of the bay waters (Meredith 1982).

Our present understanding of the population dynamics of blue crabs in Delaware Bay suggests that the recruitment of new individuals is relatively independent of the size of the spawning population in the bay (Sulkin et al. 1982). This can be explained by the following: (1) Gravid females migrate to the lower bay for spawning. (2) Each female may produce as many as 3 million eggs. (3) Larvae are flushed to the waters of the continental shelf where mortality due to predation and food limitation are density-dependent. That is, the rate of mortality increases as the population of larvae increases. The result is that the number of larvae available for transport back to the bay does not vary much from year to year. (4) The number of larvae transported back to the vicinity of the bay varies with wind and current conditions in the Mid-Atlantic Bight. The effects of these variations upon larvae survival would be density-independent and, hence, it is the yearly variations in these

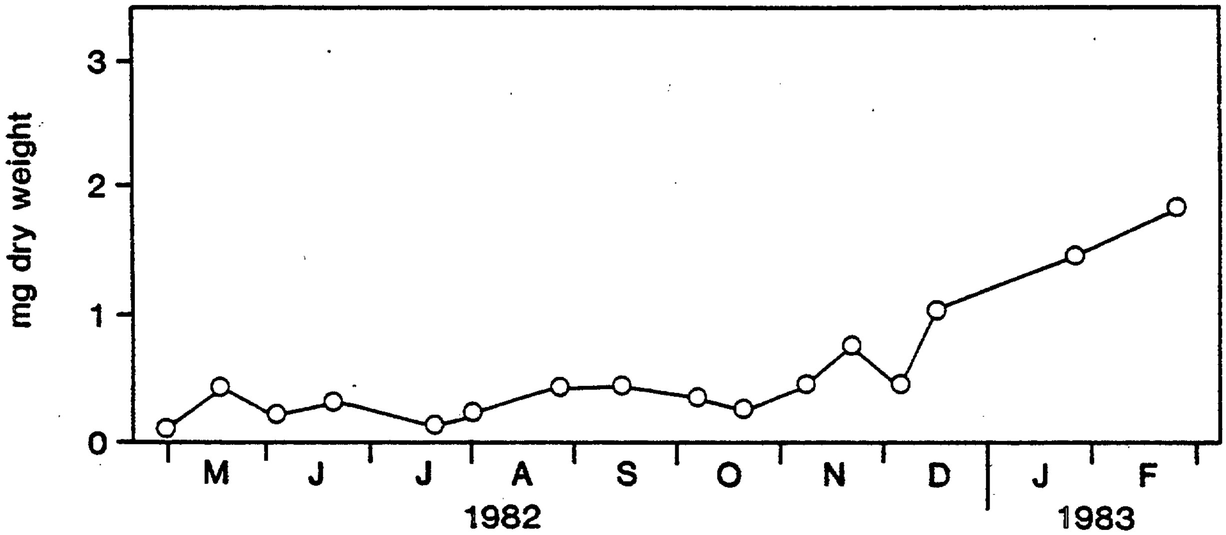


Figure 11-5. Mean weight of individual mysids is shown over the annual cycle.

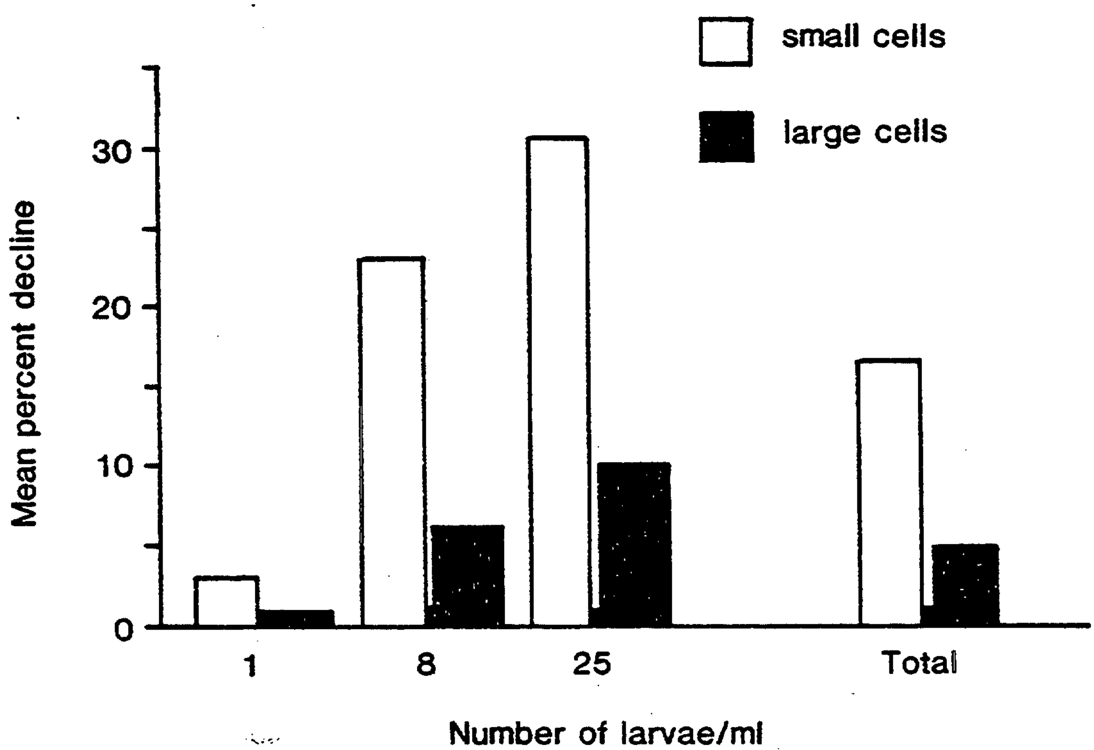


Figure 11-6. Feeding by oyster larvae on phytoplankton is shown as mean percent decline in density of phytoplankton before and after feeding trials. The small-celled phytoplankton were less than 10 microns and large cells were greater than that size. Experiments were done at 3 larval densities; total refers to the percent decline for all three larval densities.

physical factors that control recruitment of postlarvae into the bay. Thus we hypothesize that year-class strength in blue crabs in Delaware Bay is determined by variations in physical rather than biological conditions.

BIVALVE LARVAE

Bivalve larvae are members of the macrozooplankton community (part of the zooplankton in Figure 11-1). During the past year, we studied feeding habits of a commercially important bivalve species, the oyster Crassostrea virginica. These larvae have a 14-to-21 day planktonic phase during which they develop from fertilized eggs to eyed larvae (Galtsoff 1964). Most information about the natural phytoplankton diet of the larvae has been inferred from laboratory growth experiments with either pure or mixed cultures of various phytoplankton species (e.g. Davis and Guillard 1958). While these experiments provided necessary information on which species of phytoplankton are ingested and which promote rapid growth rates, they do not address which phytoplankton species the larvae feed on in nature. To investigate the phytoplankton component of the larval diet, feeding experiments were designed using natural assemblages and densities of phytoplankton.

Comparisons of phytoplankton cell counts before and after feeding trials showed that populations of small cells (less than 10 microns in the largest dimension) declined more rapidly than larger forms (Figure 11-6). The larvae used in the experiments are known to have mouth diameters of approximately 10 microns (Ukeles and Sweeney 1969). Larvae did not appear to be selecting particular cell types from the small phytoplankton fraction. The relative proportions of each of five small-cell types (coccoid cells, centrate diatoms, pennate diatoms, flagellates, and dinoflagellates) remained approximately the same during larval grazing after correction for changes in control trials where no oyster larvae were present. A difference in larval feeding rate was noted when long and short trials were compared. The lower rate during prolonged exposure suggests either that larvae became satiated within 6 hours and fed slowly thereafter or (more likely) that larvae ceased feeding actively when phytoplankton levels dropped below a threshold concentration. The lack of selectivity by oyster larvae, and the demonstration of active feeding on natural assemblages (at least at starting concentrations), suggest that growth and development of oyster larvae are not limited by food availability in the Delaware Estuary.

CONCLUSIONS

Macrozooplankton populations showed generally high levels in winter, spring, and early summer, with reduced levels in the late summer and fall; this is based on only one year's sampling. Copepods made up 94% of the samples with five different genera dominating. Mysid population peaks occurred in the spring and summer periods. Mean size of mysids changed seasonally with the largest mysids appearing in the spring.

Studies on blue crab larvae and postlarvae indicate that the year-class strength in Delaware Bay is dependent on physical conditions in the bay rather than the size of the spawning population. Investigations on oyster larvae suggest that growth and development in the Delaware Estuary are not limited by food availability.

Clearly the studies included are preliminary in nature. More sophisticated, in-depth investigations are necessary for further understanding. Different approaches that may be used to provide greater insight into the food web include: (1) examination of parts of the food web that have not been studied (e.g. microzooplankton) or (2) examination, in greater depth, of an area of the food web that has been shown to be significant to the productivity of the estuary. We feel that the more rational approach at this time is the latter and suggest concentrating on the interactions between mysid shrimp, certain zooplankton, and the most important sports and commercial fish in the Delaware Estuary, the weakfish.

Information on these interactions should be useful in the management of the Delaware Estuary. Eventually we should be able to develop modeling criteria to predict long-term effects of manmade and natural perturbations.

Chapter 12

NEKTON (FINFISH)

C.B. Grimes

INTRODUCTION

The swimming animals in an aquatic environment are referred to as the nekton in contrast to the plankton which are not able to move against the currents. For the most part, nekton are finfish. Marine mammals, such as whales and porpoises, and some molluscs, such as squid, are also nekton. The former are rarely fished today and the latter fall technically into the category of shellfish. The only nekton of present commercial interest in the Delaware Estuary can also be referred to as finfish.

The Delaware Estuary supports a large sport-fishing activity and moderate, but significant, commercial fisheries. Ultimately, much of the effort in the Delaware Estuary Project will be aimed at gaining more information for management of the Delaware Bay fisheries. At present, we have done no research directly on finfish and much of the information available comes from routine monitoring surveys.

The majority of finfish species are not harvested commercially. Called ichthyofauna, this group is treated in the first section of this chapter. The second section deals with the commercial and sport fisheries of the Delaware Estuary.

THE FAUNA

The ichthyofauna of the Mid-Atlantic Bight, including the Delaware Bay area, may be characterized largely as seasonal and migratory. The Delaware Bay area marks more or less the center of the geographic distribution of many fishes that range between Cape Cod and Cape Hatteras (June and Reintjes 1957). The region is the southern limit of several boreal forms such as the silver hake and Atlantic herring and the northern limit of many temperate species like Atlantic croaker, spot, and weakfish that migrate north in the summer.

As might be expected of a region characterized as a transition zone between warm- and cold-water fishes, temperature regimes are extremely variable year to year. For example, 21°C (70°F) surface water penetrates northward only to Virginia during cool years, but extends as far as Cape Cod in warm years. Similarly, in winter 6°C (42°F) surface water extends to Cape Hatteras during cold years, but in warm years only reaches Cape Cod (McHugh 1981). The highly variable water temperatures that characterize the region influence how far north the southern species will come in summer and how far south the northern species will move in winter. Under these oceanographic conditions it is not surprising that species composition and abundance are quite variable.

The fish fauna of Delaware Bay is diverse, but a relatively few species account for the preponderance of total fish abundance, or biomass. For example, Smith (1982) lists 76 species that have been collected during several trawling surveys in Delaware Bay (Table 12-1), however only 13 fishes accounted for about 90% of the numbers and biomass in 1979-81 (Table 12-2). Weakfish, hogchoker, and windowpane flounder were by far the most important species, collectively accounting for about 60 to 70% of the biomass and 50 to 60% of the numerical abundance (Table 12-2). The results of these trawling surveys (Daiber and Smith 1972, Smith 1981, Smith 1982) provide the basis for this description of the Delaware Bay fish fauna. Some fishes, such as pelagic, criptic, and predominantly marsh forms, are able to avoid the trawl or simply inhabit areas not sampled. However, the majority of the fauna are represented in the data from these surveys, almost certainly those most important from an ecological or fisheries point of view.

Table 12-1. Common and scientific names of fish that have been caught by otter trawl in Delaware Bay. Names taken from Robinson et al. (1980) (from Smith 1982).

Sand tiger shark	Odontaspis taurus
Sandbar shark	Carcharhinus milberti
Smooth dogfish	Mustelus canis
Spiny dogfish	Squalus acanthias
Atlantic angel shark	Squatina dumerili
Clearnose skate	Raja eglanteria
Little skate	Raja erinacea
Winter skate	Raja ocellata
Roughtail stingray	Dasyatis centroura
Bluntnose stingray	Dasyatis sayi
Smooth butterfly ray	Gymnura micrura
Spiny butterfly ray	Gymnura altavela
Bullnose ray	Myliobatis freminvillei
Cownose ray	Rhinoptera bonasus
Atlantic sturgeon	Acipenser oxyrhynchus
Conger eel	Conger oceanicus
American shad	Alosa sapidissima
Blueback herring	Alosa aestivalis
Hickory shad	Alosa mediocris
Alewife	Alosa pseudoharengus
Atlantic menhaden	Brevoortia tyrannus
Atlantic herring	Clupea harengus harengus
Gizzard shad	Dorosoma cepedianum
Striped anchovy	Anchoa hepsetus
Bay anchovy	Anchoa mitchilli
Inshore lizardfish	Synodus foetens
Oyster toadfish	Opsanus tau
Goosefish	Lophius americanus
Silver hake	Merluccius bilinearis
Red hake	Urophycis chuss
Spotted hake	Urophycis regius
Striped cusk-eel	Rissola marginata
Ocean pout	Macrozoarces americanus
Striped killifish	Fundulus majalis
Threespine stickleback	Gasterosteus aculeatus
White perch	Morone americana
Striped bass	Morone saxatilis
Black seabass	Centropristis striata
Snowy grouper	Epinephelus niveatus
Bluefish	Pomatomus saltatrix
Florida pompano	Trachinotus carolinus
Crevalle jack	Caranx hippos
Blue runner	Caranx crysos
Lookdown	Selene vomer
Atlantic moonfish	Vomer setapinnis
Pigfish	Orthopristis chrysoptera
Scup	Stenotomus chrysops

Table 12-1 (Continued)

Silver perch	Bairdiella chrysoura
Weakfish	Cynoscion regalis
Northern kingfish	Menticirrhus saxatilis
Spot	Leiostomus xanthurus
Black drum	Pogonias cromis
Atlantic croaker	Micropogonias undulatus
Atlantic spadefish	Chaetodipterus faber
Tautog	Tautoga onitis
Striped mullet	Mugil cephalus
Northern stargazer	Astroscopus guttatus
Harvestfish	Peprilus alepidotus
Butterfish	Peprilus triacanthus
Northern searobin	Prionotus carolinus
Striped searobin	Prionotus evolans
Sea raven	Hemitripterus americanus
Grubby	Myoxocephalus aenaeus
Longhorn sculpin	Myoxocephalus octodecemspinosus
Seasnail	Liparis atlanticus
Fringed flounder	Etropus crossotus
Smallmouth flounder	Etropus microstomus
Summer flounder	Paralichthys dentatus
Fourspot flounder	Paralichthys oblongus
Windowpane flounder	Scophthalmus aquosus
Winter flounder	Pseudopleuronectes americanus
Hogchoker	Trinectes maculatus
Orange filefish	Aluterus schoepfi
Planehead filefish	Monacanthus hispidus
Northern puffer	Sphoeroides maculatus
Striped burrfish	Chilomycterus schoepfi

Seasonal species composition was variable, the warm months dominated by species such as weakfish, summer flounder, spot, butterfish, and smooth dogfish, while the cool months were dominated by white perch, windowpane, and red and silver hake (Table 12-3). Total fish biomass and numerical abundance is much greater during warmer months (June-October) (Tables 12-2 and 12-3), therefore warm-season species account for the preponderance of numbers and biomass.

Since 1966 there have been some notable fluctuations in the abundance of several of the dominant species, as shown in Table 12-4. Weakfish numerical abundance declined from 29% in 1966-71 to 13% in 1981. Weakfish biomass

Table 12-2. Comparison of species dominance (in numbers and biomass) between the years 1979, 1980, 1981 for those species comprising 90% of the research trawl catch in Delaware Bay (from Smith 1982).

% of Total Catch by Number			Species	% of Total Catch by Weight		
1979	1980	1981		1979	1980	1981
29.5	29.4	13.1	Weakfish	46.5	46.4	37.1
14.9	9.8	29.0	Hogchoker	4.3	3.0	13.2
19.0	11.8	7.3	Windowpane flounder	17.8	10.8	11.2
3.8	10.4	15.3	Spot	1.2	3.7	6.0
3.2	4.9	10.9	Smooth dogfish			
4.8	5.9	5.2	White perch	5.8	6.7	4.6
4.6	4.4	0.7	Red hake	2.5	6.0	0.8
2.4	2.6	2.9	Oyster toadfish	1.7	3.8	6.5
2.0	1.8	3.0	Summer Flounder	4.8	4.7	7.5
1.1	4.8	1.8	Butterfish	0.3	1.0	0.7
3.1	1.3	0.6	Silver hake	1.7	1.5	0.1
1.5	1.3	1.6	Alewife	0.6	0.6	1.0
1.3	1.5	0.8	Striped searobin	1.8	1.6	2.6
91.2	89.9	92.2	Totals	89.0	89.8	91.3

also declined from 47% in 1979 to 37% in 1981. However the decrease in biomass was not as marked as the decrease in numbers, presumably due to increased size (growth) of individual fish (see following discussion of weakfish fisheries). Scup appear to have declined sharply in abundance. In 1966 scup accounted for 12% of the trawl catch (by number), in 1979-80 only about 1%, and in 1981 the species was not collected. Hogchoker and windowpane abundance has varied inconsistently. Spot and smooth dogfish showed increasing abundance for the three periods surveyed.

Trawl survey results also show a decline in overall fish numerical abundance from a high of 60 fish/0.1 nautical mile (nmi) in 1966 to a low of 8 fish/0.1 nmi in 1979. As noted by Smith (1982) this is mostly due to the conspicuous decline in numbers of weakfish, scup, hogchokers, spot, longhorn sculpin, northern sea robin, and black drum. However, the decline in total

Table 12-3. Seasonal representation (percent by number) of dominant species (accounting for 90% of numbers and biomass) in trawl catches during 1966-74 and 1979-81 Delaware Bay surveys (compiled from Smith 1982).

	Feb.		April		June		Aug.		Oct.		Dec.	
	66-74	79-81	66-74	79-81	66-74	79-81	66-74	79-81	66-74	79-81	66-74	79-81
Weakfish	0	0	0.08	0.77	29.3	26.2	35.1	40.9	29.3	46.7	0.57	0.51
Hogchoker	0.34	0	2.6	8.9	28.2	34.9	14.4	9.06	42.1	18.2	7.1	14.9
Windowpane	8.1	40.5	56.5	40.6	2.9	1.5	2.8	1.3	2.7	4.9	4.8	8.3
Spot	0	0	0	0	0	0	8.4	13.9	7.6	9.0	0	11.6
Smooth dogfish	0	0	0	0	6.1	15.4	2.1	8.2	1.9	7.8	0	0
White perch	17.6	51.4	0	0	0	0	0	0	0.3	0	0.1	44.2
Red hake	1.0	0	6.5	21.9	0.04	0	0.01	0	0	0	0.3	5.3
Oyster toadfish	0.34	0	0.23	4.5	0.16	1.8	1.2	0.58	1.6	5.5	0.49	0.4
Summer flounder	0	0	0.15	1.2	0.46	2.9	0.69	2.2	0.01	0.6	0	0.23
Butterfish	0	0	0	0.13	4.3	5.5	1.4	4.1	4.0	1.2	0	0
Silver hake	0	0	1.2	8.5	1.2	0	0.02	0	0.2	0	6.2	6.3
Alewife	0	0	2.5	5.2	0	0	0	0	0.04	0	1.4	1.5
Striped searobin	0	0	0	0.07	1.9	0.65	0.66	2.5	0.95	2.9	0.03	0

Table 12-4. Comparison of the most numerically abundant species of the Delaware Bay research trawl catches between 1966 and 71 survey (Daiber and Smith 1972), 1979 and 80 (Smith 1981), and 1981 (Smith 1982). Blank values indicate that the species was not caught.

	% of total catch		
Species of Fish	1966-1971	1979-1980	1981
Weakfish	32.4	29.4	13.1
Hogchoker	20.4	12.4	29.0
Scup	11.8	0.7	0.0
Spot	4.9	7.1	15.3
Windowpane flounder	4.3	15.4	7.3
Northern searobin	4.0	0.4	0.1
Smooth dogfish	2.7	4.0	10.9
Butterfish	1.8	3.0	1.8
Longhorn sculpin	1.8	0.0	
Northern puffer	1.7	0.1	0.0
Oyster toadfish	1.6	2.5	2.9
Clearnose skate	1.6	0.8	0.5
Spotted hake	1.5	0.4	1.0
Black drum	1.4	0.0	
White perch	1.1	5.4	5.2
Atlantic herring	1.0	1.0	0.2
Red hake	0.8	4.6	0.7
Striped searobin	0.8	1.4	0.8
Silver hake	0.8	2.2	0.6
Silver perch	0.6		
Summer flounder	0.5	1.9	3.0
Roughtail stingray	0.4	0.7	0.8
Winter flounder	0.4	0.2	0.1
Bullnose ray	0.3	2.0	3.0
Northern kingfish	0.3		0.0
Bony dogfish	0.3	0.2	0.1
Bluntnose stingray	0.2	0.4	0.3
Little skate	0.1	0.0	0.2
Alewife	0.1	1.4	1.6
Total fish caught	157,196	16,911	12,222

fish biomass is probably not nearly as marked because, although weakfish (the dominant species) declined from 30% to 13% in numerical abundance, biomass only decreased from 47% to 37%.

FIN FISHERIES

Not unlike most areas of the United States, the fisheries of the Mid-Atlantic Bight in general, and the Delaware Bay region in particular, have declined very substantially since in late 19th century. Another prominent characteristic of the fisheries of this region has been their variability. As noted previously, the Delaware Bay is approximately the center of a geographic region with markedly variable water temperatures. Consequently, the ichthyofauna supporting the fisheries is largely seasonal and migratory, and quite variable. For the discussion of historical and recent trends in commercial and recreational catches I will include not only fishes that are harvested solely in Delaware Bay, but also several estuarine-dependent fishes that are harvested in nearshore marine zones as well (e.g. weakfish, bluefish, and Atlantic menhaden). These all rely on Delaware Bay as essential spawning, feeding, and/or nursery grounds.

As shown by Seagraves (1982), the fish that are important components of current recreational and commercial fisheries are weakfish, bluefish, American shad, white perch, striped bass, windowpane flounder, spot, sharks, summer flounder, black drum, Atlantic sturgeon, and butterfish (Table 12-5). Based on historical information, alewives, Atlantic croaker, and Atlantic menhaden should be added to the species list (McHugh 1981). The catch of most of these species has declined steadily since the end of the 19th century, although there have been periods of temporary increase.

Industrial fin fisheries, those used for nonedible fish products such as fish meal, oil, and fertilizer, are exclusively Atlantic menhaden. This fishery, was not well developed until the mid-1940s. The east coast fishery developed rapidly until the early 1960s, then quickly collapsed. From the early 1950s until about 1960 New Jersey and Delaware were the foremost menhaden landing states along the Atlantic coast. The last menhaden processing plant in Delaware closed in 1966 and only one presently operates in New Jersey. The deterioration of the menhaden fishery in the mid-Atlantic resulted in general from overfishing. Truncation of the size composition of the population that naturally statified

Table 12-5. Estimated catch in weight and value of the inshore gill net fishery for the State of Delaware during 1981 (from Seagraves 1982).

Species	Estimated Landing (Metric tons)	Estimated Value (Dollars)
Weakfish	477	462,748
Bluefish	89	39,200
American shad	88	87,030
White perch	22	28,740
Striped bass	10	19,125
Windowpane flounder	5.4	2,400
Spot	5.0	2,750
Shark	3.4	1,875
Summer flounder	3.0	4,355
Black drum	1.1	250
Atlantic sturgeon	1.1	1,250
Butterfish	0.9	400
Tautog	0.05	10
Totals	769	650,058

by size along the Atlantic coast removed larger (older) fish. Because the larger fish were in the mid-Atlantic area, their removal by fishing disproportionately damaged the fishery in the mid-Atlantic (Broadhead et al. 1980).

Among food finfish, those first to show sharp declines in catches were anadromous species, those using the river as spawning and nursery area. Degraded water quality and habitat destruction in the river and upper bay, in particular in the Philadelphia-Camden area, presumably made passage to upriver spawning areas difficult or impossible, and eliminated or reduced nursery grounds. According to McHugh (1981), the sturgeon fishery was first to decline. In 1887, 1300 metric tons (t) were landed in Delaware alone, but by 1908 only 15 t were caught (one metric ton = 1000 kilograms = 2204.6 pounds).

American shad followed soon after, landings decreasing from 800 t in 1890 to 18 t in 1931. However, the shad population may have recovered slightly in recent years. They ranked third in weight and second in value in the 1981 gill net landings in Delaware. The gill net harvest in 1981 of 88 t represented an increase over 1980 when 43 t were caught (Seagreaves 1982). Also, recent abundance estimates made by the New Jersey Division of Fish, Game, and Shellfisheries suggest abandance is increasing (A. Lupine, personal communication). Despite their decline in commercial importance, shad are highly sought recreational fish during their spring spawning run up the Delaware River.

Alewife catches peaked in Delaware in 1930 at 1450 t, but eight years later had declined to 21 t (McHugh 1981). They do not appear now in appreciable amounts in current fisheries in Delaware Bay (Seagraves 1982), however they are landed by recreational anglers along with American shad.

White perch, another anadromous species, had peak landings in the estuary in 1897 at 180 t but declined to 7 t in 1940 (McHugh 1981). In 1981 an estimated 22 t of white perch were caught in the Delaware gill net fishery (Seagraves 1982), showing a slight improvement in landings.

Historically the Delaware River supported a substantial striped bass commercial fishery, as did major tributaries such as the Maurice River. In the early 1900s commercial landings totaled hundreds of thousands of pounds per year. By 1960 landings had declined to thousands of pounds per year, and today there is no commercial striped bass fishery in the Delaware River (Hemchak 1982). Several recent studies suggest that although Delaware Bay was once a major spawning and nursery area for Atlantic coast fish, it no longer produces eggs, larvae, or juveniles (Murawski 1969, Hemchak 1982). Chittenden (1971) reported no striped bass from extensive fish collections in the non-tidal Delaware River from 1960-67 and concluded that they were an insignificant part of the ichthyofauna from Chester, Pennsylvania upstream. Seagraves (1982) estimated striped bass gill-net landings for the upper bay at 10.2 t in 1981; apparently these fish were not of Delaware River origin.

Historically, weakfish were, and remain today, perhaps the most important edible species in the Delaware Bay region. Total landings of weakfish for Delaware in 1889 were 1500 t. Later landings fluctuated but attained a low of 2 t in 1968 (McHugh 1981). The same trends were evident in mid-Atlantic landings since 1940 with peak catches of about 11.5 t in 1945, then declining to a low of less than 1 t in 1967 (Wilk 1981). Weakfish landings began to increase in 1970 and continued through 1979 when about 3600 t were landed in the mid-Atlantic (Wilk 1981). In 1981, weakfish dominated the commercial gill-net landings in the Delaware Estuary, accounting for 71% of the total value of the fishery. Estimated landings for 1981 were 477 t compared to 89 t for bluefish, 88 t for shad, and 22 t for white perch (Table 12-5).

Weakfish are landed commercially by gill nets, haul seines, pound nets, and otter trawls, although trawls and haul seines cannot be operated legally within Delaware waters. The use of high-speed pelagic trawls (paired and mid-water) began during the mid-1970s and continues. This innovative methodology, centered off the mouth of Delaware Bay, concentrates on spawning adults entering and leaving the bay; young of the year leaving in the fall are taken in otter trawls (Shepherd 1982). Pelagic trawls annually land in excess of 700 t (Wilk 1981).

National Marine Fisheries Service recreational fishing surveys suggest that recreational catches of weakfish followed the same trends as commercial catches, low during the 1960s followed by increases in the 1970s. According to these surveys recreational and commercial landings were about equal in 1960, (1815 and 1725 t respectively) and in 1974-75 (8850 and 9990 t respectively). Sport catches reportedly were double commercial landings in 1970 (7264 and 3632 t respectively) but in 1979 (4990 and 12,700 t respectively) and 1965 commercial catches predominated (1040 and 2720 t respectively) (Wilk 1981). Wilk (1981) reported that 95% of the total 1979 recreational catch of weakfish (4990 t) was taken in the mid-Atlantic region, and 65% of that amount in Delaware and New Jersey alone. About seven times more weakfish than the nearest rival, summer flounder, were landed in Delaware in 1980 and 1981 (Seagraves 1982), however due to a rather sharp decline in 1982 catches, weakfish dropped to third behind summer flounder and bluefish (Seagraves, personnal communication). Both Wilk (1981) and Seagraves (1982) noted an increase in average size of recreational weakfish and a concomitant decrease in catch per unit effort. Nationally, average size increased from just over 0.5 kg (1 lb) in 1960 to more than 1.4 kg (3 lb) in 1974-75 and 1979 (Wilk 1981).

Historically bluefish were less important in Delaware Bay commercial fisheries than they have been in recent years. About 1970, bluefish landings increased dramatically nationwide and regionally. Since 1973, total U.S. landings have averaged in excess of 4500 t and the mid-Atlantic landings over 900 t (Wilk 1977). Not surprisingly, bluefish were the second ranking species in the Delaware inshore gill-net fishery landings in 1981 (Table 12-5). Bluefish have become an increasing important recreational fish as well. An estimated 55,000 t were caught nationwide in 1970, many in the mid-Atlantic region (Wilk 1977). Recreational catch rates in Delaware have remained relatively stable in recent years, 0.5 and 0.3 fish per angler-day in 1980 and 1981, respectively (Seagraves 1982). However, in recreational landings they have increased from third, behind weakfish and summer flounder in 1980 and 1981, to second behind summer flounder in 1982, presumably due to a rather sharp decline in 1982 weakfish catches (Seagraves, personal communication).

At times, Atlantic croaker have been important commercial fish in Delaware Bay. About 500 t were landed in Delaware in 1930, but landings fell off irregularly, producing no catches from 1960 to 1975 (McHugh 1981). Croaker are not currently important in gill-net landings in the bay (Seagraves 1982) and they accounted for only 0.4% by number in 1979-81 research trawls in the bay (Smith 1982). Croaker, primarily a southern species, comes north of Chesapeake Bay only when conditions are particularly favorable and populations high.

Commercial landings of spot in the bay were reportedly 295 t in 1880, but catches were not reported again until 1904 (McHugh 1981). Peak landings of about 100 t were recorded in 1931 and 1955, with landings averaging around 40 t in between. Since 1958 never more than 10-15 t were landed (McHugh 1981). Seagraves (1982) estimated the 1981 gill-net catch in Delaware at 5 t. Spot, like croaker, is a southern species near the northern limit of its range.

Windowpane flounder, summer flounder, black drum, butterfish, and tautog are less important commercial species in Delaware Bay (Table 12-5). Another species of recreational importance in the bay is summer flounder. In 1980 and 1981, flounder ranked a poor second behind weakfish with 5.3 weakfish and 0.8 flounder per angler-day in 1980, and 2.8 and 0.4, respectively in 1981 (Seagraves 1982). However, in 1982 summer flounder became the number one-ranking recreational species in Delaware; bluefish ranked second and weakfish declined to third (Seagraves, personnal communication). Summer flounder is also a predominantly southern species, which visits Delaware Bay only during summer.

CONCLUSIONS

The most abundant species of fish caught year round in research trawls on the Delaware Bay are the weakfish, hogchokers, windowpane flounder, and spot. The weakfish is also the fish of greatest abundance in commercial fishing and was until the past year (1982) the most often caught sport fish. The weakfish is undoubtedly the species of greatest significance in the Delaware Estuary.

Most fisheries in the Delaware Estuary, as is generally true for the entire east coast of the United States, have declined markedly in the past 75 years. Some of this decrease was probably due to estuarine pollution; this is especially critical for anadromous (river-spawning) species like shad and striped bass. However, the major cause of the decline was overfishing. The environmental status of the Delaware Estuary today is sufficiently healthy to maintain major fisheries.

Since the weakfish is so important, thorough knowledge of its life cycle and populations dynamics is essential. For any future management activity, an understanding is necessary of larval and juvenile feeding, growth, and survival. This must be done over and above any surveys of adult population size.

Chapter 13

BENTHOS (SHELLFISH)

H.H. Haskin, R.A. Lutz, C.E Epifanio

INTRODUCTION

Often aquatic organisms are divided into three groups, plankton (free-floating), nekton (swimming), and benthos (bottom-dwelling). Plankton and nekton are discussed elsewhere in this report as are the planktonic larvae of benthic animals and the parabenthos which swim just above the bottom. The subject of this chapter is the true bottom-dwelling animals that live in or on top of the sediment. Most animals called shellfish fit into the category of benthos.

By far the most important shellfish resource in Delaware Bay is the oyster. Second in importance is the blue crab. A small but interesting lobster fishery is pursued at the Delaware Breakwater. The hard clam, which seasonally provided a living for a number of baymen a generation or two ago in the lower bay, no longer supports a significant fishery in the bay. The discussion here therefore will primarily address the status of the oyster and crab fisheries. A general discussion of benthos is followed by a discussion of the oyster industry, then oyster quality and the role of the oyster in the overall benthos, and last, the blue crab industry.

THE BENTHOS

In an extensive bay-wide study the benthos of Delaware Bay has been found to be very low in density by "one or two orders of magnitude" when compared with "temperate estuaries in North America and other parts of the world" (Maurer et al. 1978a). These investigators, with a 0.1 m^2-grab sample at each of 207 stations, collected 169 different species with an average density of 722 individuals per square meter, with density per square meter written here as m^{-2}. They compare this density with figures ranging from 1300 for Moriches Bay in Long Island, 4000 to 9000 for Buzzards Bay, Massachusetts, up to 30,000 for a salt pond in Rhode Island. Maurer et al. support their finding of low densities in Delaware Bay in citing the earlier work of Kinner and Leathem (1974) who report average densities of 100 m^{-2} in 277 benthic samples at the mouth of Delaware Bay. In discussion of low secondary production of the bay Maurer et al. strongly suggest that a major causal influence is the heavy input in the upper estuary of industrial and municipal pollution. Sediment transport, predation, and hydrography are also cited as "natural mechanisms" that may explain low secondary production in the lower bay.

These "natural mechanisms" are highlighted in another report on the benthic community composition of the lower bay (Haskin et al. 1978). In this two-year study on the biota of lower Delaware Bay (contracted with the Delaware River and Bay Authority) of the effects of overboard spoil disposal from the Cape May Ferry terminal, it was apparent that the area selected for disposal was characterized by low density and diversity of organisms. There is also a strong seasonal influence on density, lowest in winter (November 1971) at 77 organisms m^{-2} mean density and highest in spring (June 1972) at 2972 m^{-2}. Summer and fall densities were 272 and 380 m^{-2} respectively. This seasonal pattern in density largely reflected the reproductive activity of two dominant bivalve species, an active small clam Tellina agilis and the razor clam Ensis directus. At 24 stations sampled in the disposal site in June, the mean density for the juvenile razor clams alone was 2627 m^{-2} and the range in station counts for all species was from 32 to 26,340 m^{-2}. Like many other bivalves with pelagic larvae, the populations of Ensis and Tellina are subject

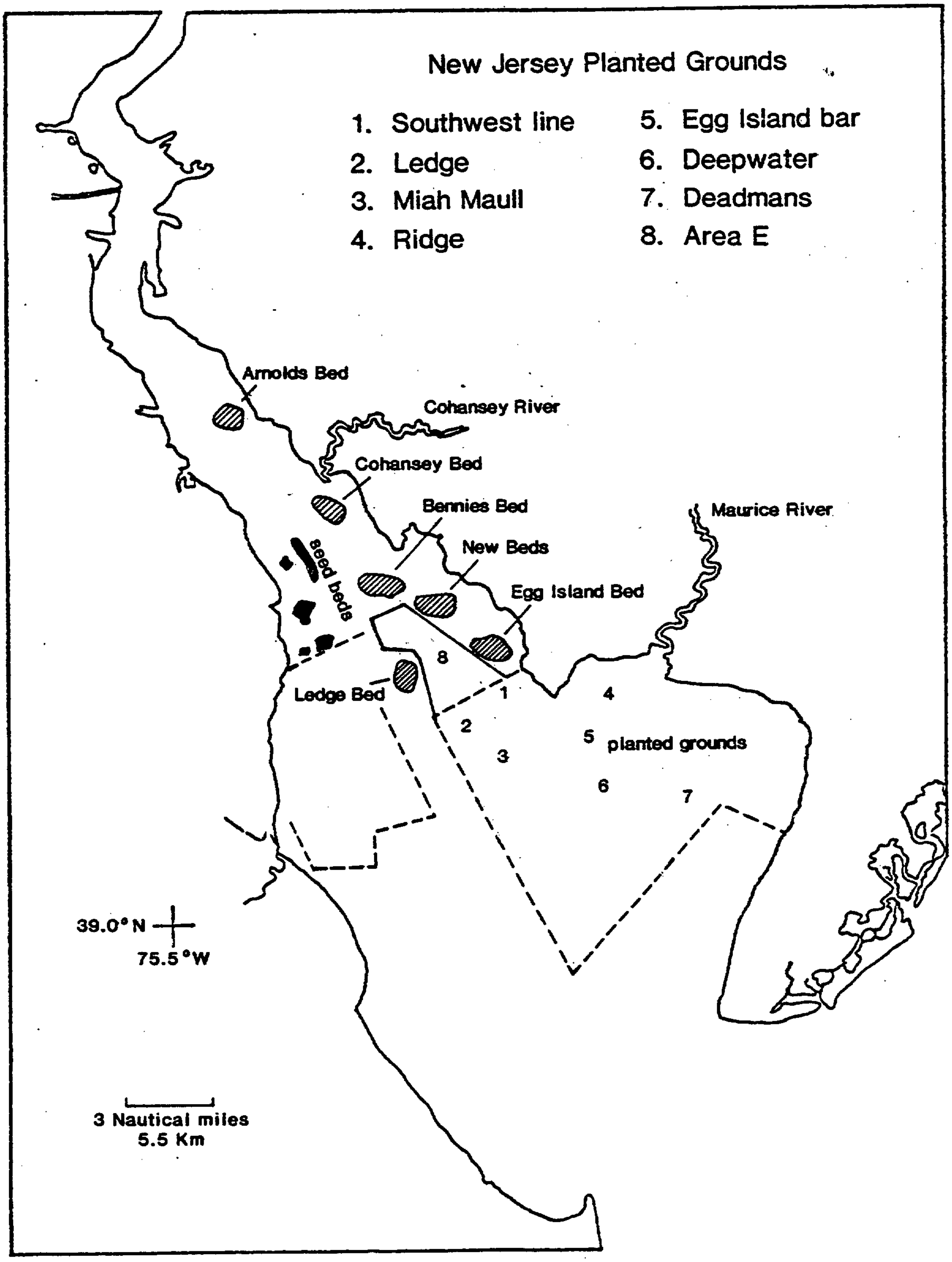


Figure 13-1. Oyster seed beds in New Jersey (cross hatched) and Delaware (solid) are shown as well as areas of planted beds for the two states (delineated by dashed lines).

each larval species. In lower Delaware Bay, brood stocks are not well established, as evidenced by the faunal densities reported here. But, because of the length of pelagic life of many species, and the presence of tidal currents which can carry larvae long distances, the entire benthic population in the bay and in adjoining coastal areas, may serve as the brood stock for the individuals which chance to set in the study area.

There is ample evidence that the lower bay is a rigorous natural environment for the benthic fauna. One need not look to pollution inputs in the upper estuary as a cause for the low faunal density in the lower bay. It also seems illogical to do so since the lowest faunal densities are in the parts of the bay farthest removed from the major sources of pollution and most generously flushed by ocean waters. The importance of a stabilized substrate for the development of a relatively high-density community is dramatically illustrated by comparing the densities reported by Maurer et al. (1978a) with those found by Ismail (1980) on three oyster grounds in the Ridge and Deepwater sections of the bay (Figure 13-1).

Ismail was examining the effect on the oyster community of using a hydraulic dredge. He quantitatively sampled the three oyster grounds before dredging and successively during the period of recovering the faunal assemblages. He sampled five control and five dredged-area stations on each of the three grounds and reported average densities of 9,122, 4,763, and 1,739 m^{-2} for ground 515 in deepwater, lab ground, and ground 154 in the Ridge section respectively. Maximum densities on the three grounds were 17,947, 30,700, and 4,860 m^{-2} respectively. Ismail noted that the paucity of organisms on ground 154 is probably due to a layer of shifting mud on three stations of the control plot. It should also be noted that ground 154 was sampled by use of a Petersen grab. On the other two grounds, because of the presence of large volumes of shell, a quantitative suction sampler was used, which may have drawn in some materials from the surrounding bottom.

to random fluctuations in recruitment due to variations in the environment (temperature, storms, hydrography, etc.) with the subsequent appearance of strong and weak year classes.

Following their dramatic appearance in June the densities of the two small clam species had an equally dramatic decrease, due largely to predation by a variety of crabs in the area, including the calico crab Ovalipes ocellatus, the spider crab Libinia emarginata, and the hermit crab Pagurus pollicaris, etc. One small calico crab had fragments of 50 Tellina in its gut and nearly 400 Ensis were found inside a single large spider crab.

In evaluating the faunal densities of the lower Delaware Bay area, several factors must be considered. (1) The shoreline, in contrast to many areas with which it has been compared, is open and exposed. The Delaware shore is battered by easterly storms; the New Jersey shore is battered by wind-driven waves of northwest and southeast storms. (2) The sediments of the shallow areas bordering these shores are unstable and almost continually shifting. (3) The sediments shift in response not only to storms but also to strong tidal currents.

As pointed out by Haskin et al. (1978):

> for the most part benthic infauna and epifauna of this region are maintained by recruitment from the plankton. Larvae released from brood stocks spend a variable amount of time in the water column and are dispersed by currents. Some control on distribution is effected by larval behavior as demonstrated by oyster larvae (Haskin 1964), cyprid barnacle larvae (Knight-Jones and Morgan 1966), and mussel larvae (Bayne 1963). After large losses from predation and other hazards of planktonic life, the larvae settle with the possibility of colonizing any suitable substrate. Larval recruitment within a defined area thus depends upon the presence of brood stocks, a current system which can carry larvae to or trap larvae in the area, and a favorable combination of environmental conditions for survival of

Table 13-1. New Jersey oyster production.

Year	Seed * Planted (Bushels)	Oysters** Marketed (Bushels)
1930	4,255,138	1,406,064
1931	2,690,182	1,456,210
1932	1,128,337	953,634
1933	937,000	874,904
1934		
1935	852,880	949,741
1936		
1937	1,072,550	754,165
1938	1,549,610	1,006,563
1939		
1940	785,970	893,504
1941		
1942	612,700	711,533
1943	487,500	860,614
1944	253,600	846,892
1945		973,409
1946		
1947		836,143
1948		855,471
1949		1,012,243
1950		1,206,967
1951		960,217
1952		1,065,840
1953		1,060,562
1954		916,113
1955	Beds closed	650,563
1956	512,000	687,725
1957	Beds closed	453,333
1958	450,850	138,167
1959	Beds closed	34,333
1960	Beds closed	23,829
1961	166,000	137,513
1962	172,000	194,175
1963	Beds closed	64,425
1964	170,700	137,213
1965	Beds closed	87,183
1966	221,300	115,733
1967	142,100	171,200
1968	145,100	220,000
1969	82,000	176,500
1970	123,000	112,833

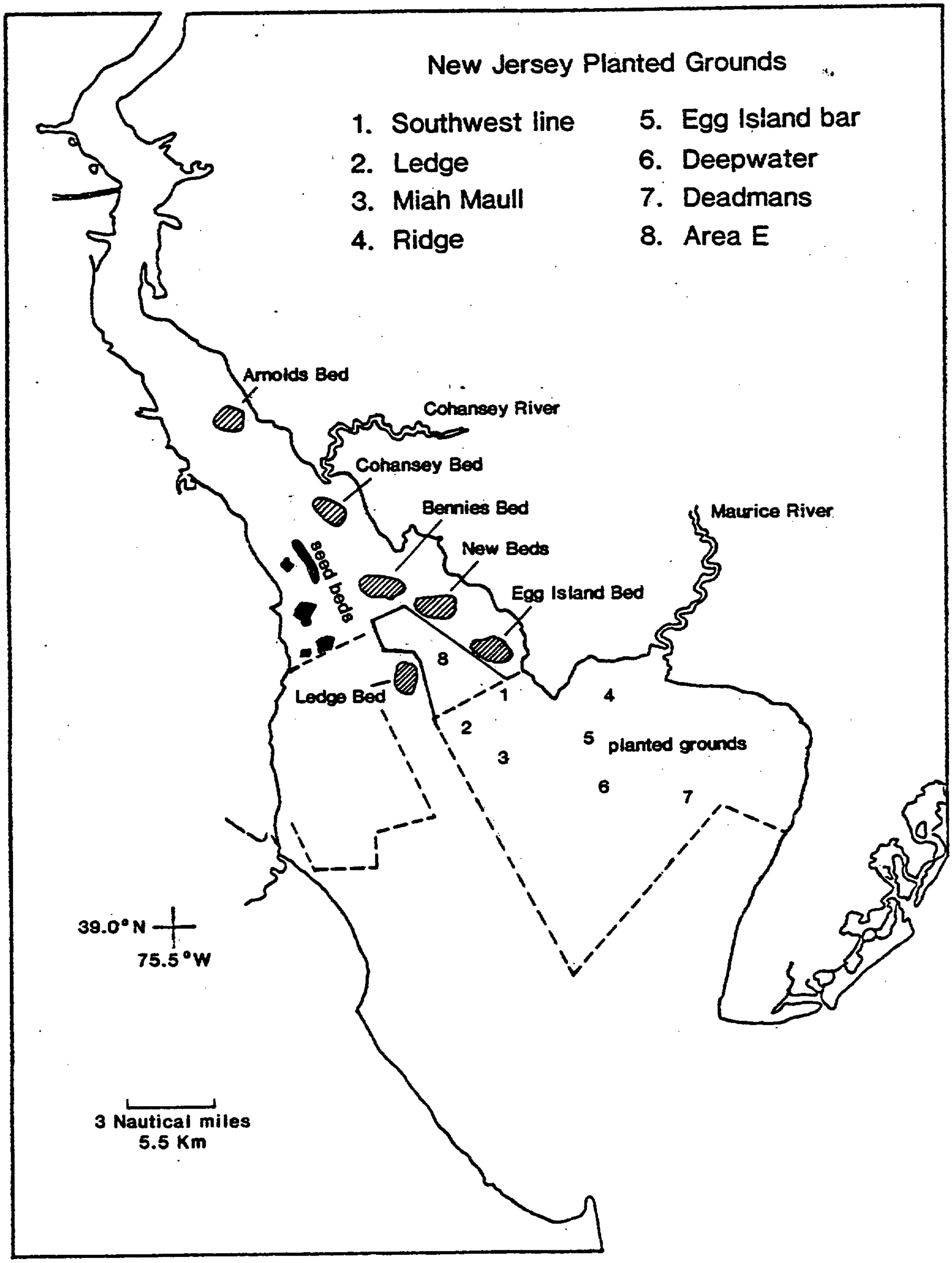


Figure 13-1. Oyster seed beds in New Jersey (cross hatched) and Delaware (solid) are shown as well as areas of planted beds for the two states (delineated by dashed lines).

THE OYSTER INDUSTRY

The oyster industry is based on the native oyster populations that extend from the Hope Creek beds, below Artificial Island, to the vicinity of Brandywine Shoals in the lower bay (Figure 13-1). The populations thus range over 33 nautical miles measured along the central axis of the bay. At mean river flow, salinities at the upper edge of this range vary around 5^{o}/oo and at the lower edge are about 30^{o}/oo. The oyster is quite tolerant of salinity over a broad range, although, as discussed below, it does not grow, reproduce, and condition equally well over its entire salinity range.

In addition to favorable salinities oysters require a stable substrate. They grow naturally in discrete beds, the most prominent of which comprise the natural seed beds in the upper bay. Over a century ago oystermen began the practice of oyster culture in which they transplanted small oysters from natural beds to growing and fattening grounds. Frequently, they first established a layer of shells to stabilize the bottom and to prevent the young seed oysters from settling into the softer sandy and muddy sediments. About the turn of the century, by act of the legislature, the New Jersey portion of the bay was divided into two general areas: the natural seed beds and the planting grounds (Figure 13-1). The Southwest Line was established as the boundary between the two areas. The planting grounds are available for lease by the state to individual citizens of the state. The seed beds are held under state management and traditionally are open in the spring of each year when planters may dredge seed oysters for planting on their individually leased grounds.

Approximately 28,500 acres are under lease in the New Jersey planting area and the major producing seed beds total about 13,000 acres. The State of Delaware oyster bottoms are similarly divided, though the producing seed beds and leased planting areas are smaller at 900 and 8,950 acres, respectively.

The planting and harvesting practices have been developed empirically by the oystermen and result from several generations of experience. Two ecological principles underlie this empirical system: (1) Although the oyster

Table 13-1 (Continued)

Year	Seed * Planted (Bushels)	Oysters** Marketed (Bushels)
1971	172,000	145,167
1972	165,825	285,500
1973	227,840	232,667
1974	395,755	168,167
1975	370,425	162,000
1976	335,975	233,767
1977	298,000	204,167
1978	385,140	194,038
1979	460,175	209,413
1980	434,270	145,577
1981	458,800	

*Figures from 1930-56, federal statistics; from 1956-81, N.J. Oyster Research Laboratory.

**All harvest data from federal statistics.

These densities place the Delaware Bay benthos, on stabilized bottom, within the same order of magnitude as the benthos in most productive estuaries around the world. They also negate the speculation that upper-estuary pollution inputs have seriously damaged lower-bay populations. Also, it is interesting to note that at all three locations Ismail reported a total of 148 species, compared with the bay-wide total of 169 species taken at 207 stations by Maurer et al. (1978a). Other information specifically comparing oyster production in Delaware Bay with that in other estuarine systems will be presented below. Of special interest among the benthos are the oyster (*Crassostrea virginica*) and the blue crab (*Callinectes sapidus*) which provide the base for important commercial fisheries.

For the first 46 years (1883-1929) for which oyster landing statistics are available, harvests in New Jersey were highly variable, ranging from 1 to 3 million bushels and averaging approximately 2 million bushels annually. For the next two decades (1930-50) landings were relatively steady, averaging about 1 million bushels annually (Table 13-1). The cause or causes of the 50% reduction in production starting in 1930 are unknown. With a sharp decline in oyster seed production in the early 1950s, planters imported seed from the Chesapeake Bay. Even with these imports harvest production dropped to a little over half a million bushels by the mid 1950s. Then with the advent of a new oyster pest called MSX (Haplosporidium nelsoni, Haskin, Stauber, and Mackin) production plummeted to a record low of approximately 24,000 bushels in 1960. The earlier decline, starting about 1950, was not caused by MSX but was most probably the direct result of overfishing of the natural seed beds.

When setting of larvae on major lower beds (New Beds and Bennies) became irregular and scant, a serious shortage of seed developed (Figure 13-1). In 1953, the New Jersey Oyster Research Laboratory made its first recommendation for restriction of seed-bed dredging to permit rebuilding of upper bay brood stocks. Brood stocks were seriously depleted further by the MSX kill starting in 1957. We estimate that in three years 90 to 95% of all oysters on the planted grounds and about 60% of the stocks on the seed beds, up to and including Cohansey Bed, were killed by this disease (Figures 13-2 and 13-3).

Two major developments over the intervening years now shape the industry: the seed beds have been brought back into more regular production; and native bay stocks, under continuing disease selection, have developed a level of resistance to kill that enables the industry to maintain production of market oysters though at a level seriously reduced compared to the pre-1950 period. Oyster production data for New Jersey from 1960 to the present are also shown in Table 13-1; production data for Delaware from 1970 to the present are shown in Table 13-2. Seed-bed production figures and the official harvest data (Table 13-3) highlight some questions on current status of the industry.

can exist over a broad range of salinities (in Delaware Bay from approximately 5 to 30°/oo), at the lower salinities it grows more slowly, does not condition well, and fails to reproduce as abundantly. (2) The second principle is that over time most of the animal species inhabiting the estuary have invaded from the sea and they differ in their abilities to withstand the lower salinities as they penetrate the inner reaches of the estuary. Consequently, the number of animal species associated with the oyster declines with the decreasing salinity or increasing distance from the sea. We find for example about 150 species of animals in the oyster community on the planted grounds below Egg Island Point, while on the uppermost seed beds, the species list drops to about 40. Similar species distributions along the salinity gradient are reported on Delaware oyster beds (Maurer and Watling 1973). Among the species in the oyster community that drop out at the lower salinities of the upper beds are, most importantly, the oyster drill which is the principal oyster predator, some of the mud crabs which prey on smaller oysters, and in addition several species that compete with the oyster for food and space.

The result is that at the upper end of its salinity range, the oyster is in a natural sanctuary where it is free from several of its major enemies as well as many competitors for space and food. This means that, although the oyster does not reproduce as freely here, those that settle here from the plankton generally have much higher survival rates than those settling downbay. Here, beyond reach of drills and some of the mud crabs, they grow slowly over several years until they reach a size less vulnerable to the oyster drills and crabs. They are then moved downbay and, after one or two growing seasons on the planted grounds, are ready for harvest.

The Delaware Bay oyster industry is slowly recovering from a low point of about 20 years ago after a series of misfortunes, some of which are not yet completely understood. Using the available statistics of the New Jersey industry for reference, these misfortunes will be discussed briefly. The history of the Delaware industry roughly parallels that of New Jersey. This would be expected since both industries are based on the same oyster population although they have not always been managed in exactly the same way.

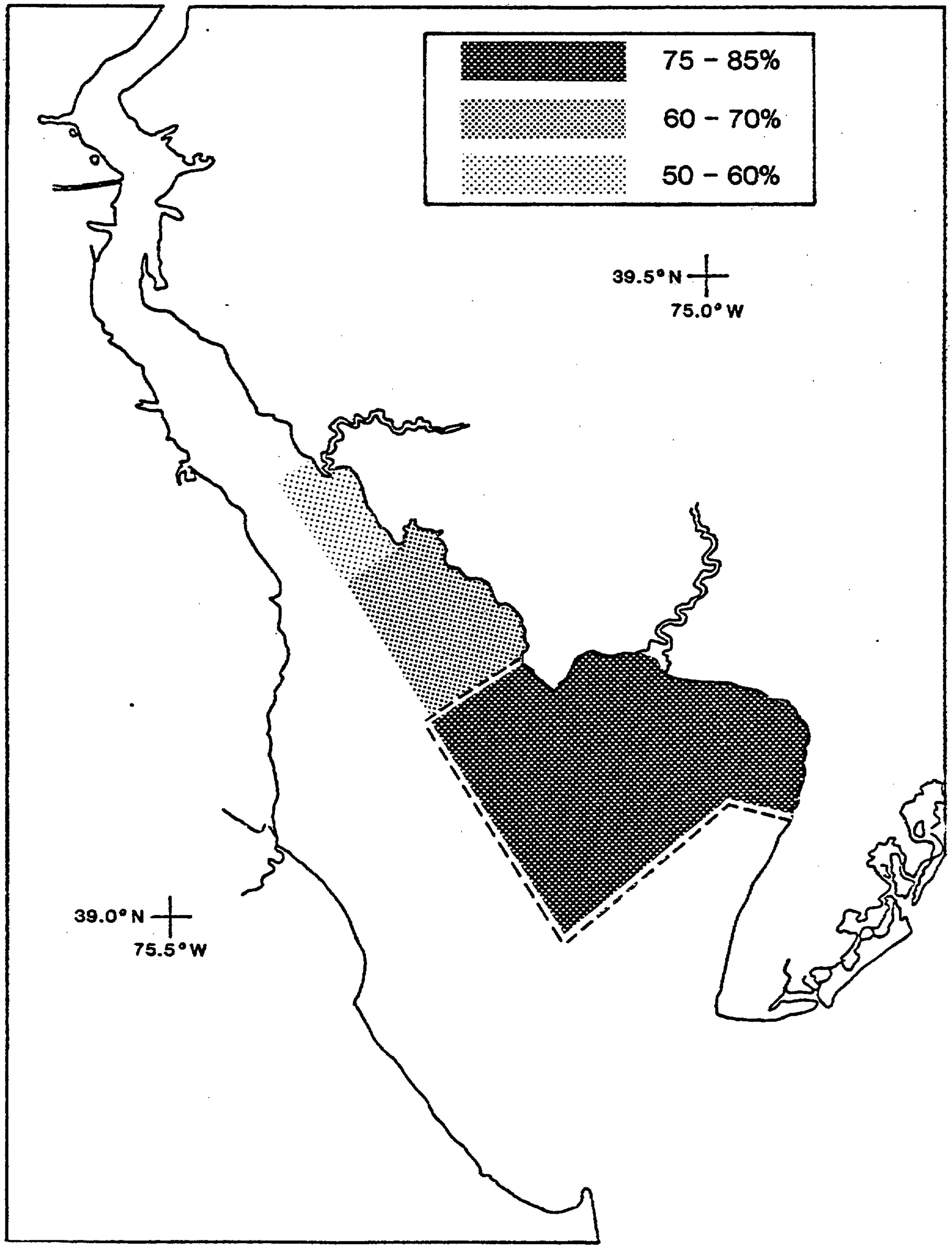


Figure 13-3. Oyster mortalities in 1958-59 are shown with 75-85%, 60-70%, and 50-60% mortality. The dashed line outlines the planted oyster grounds.

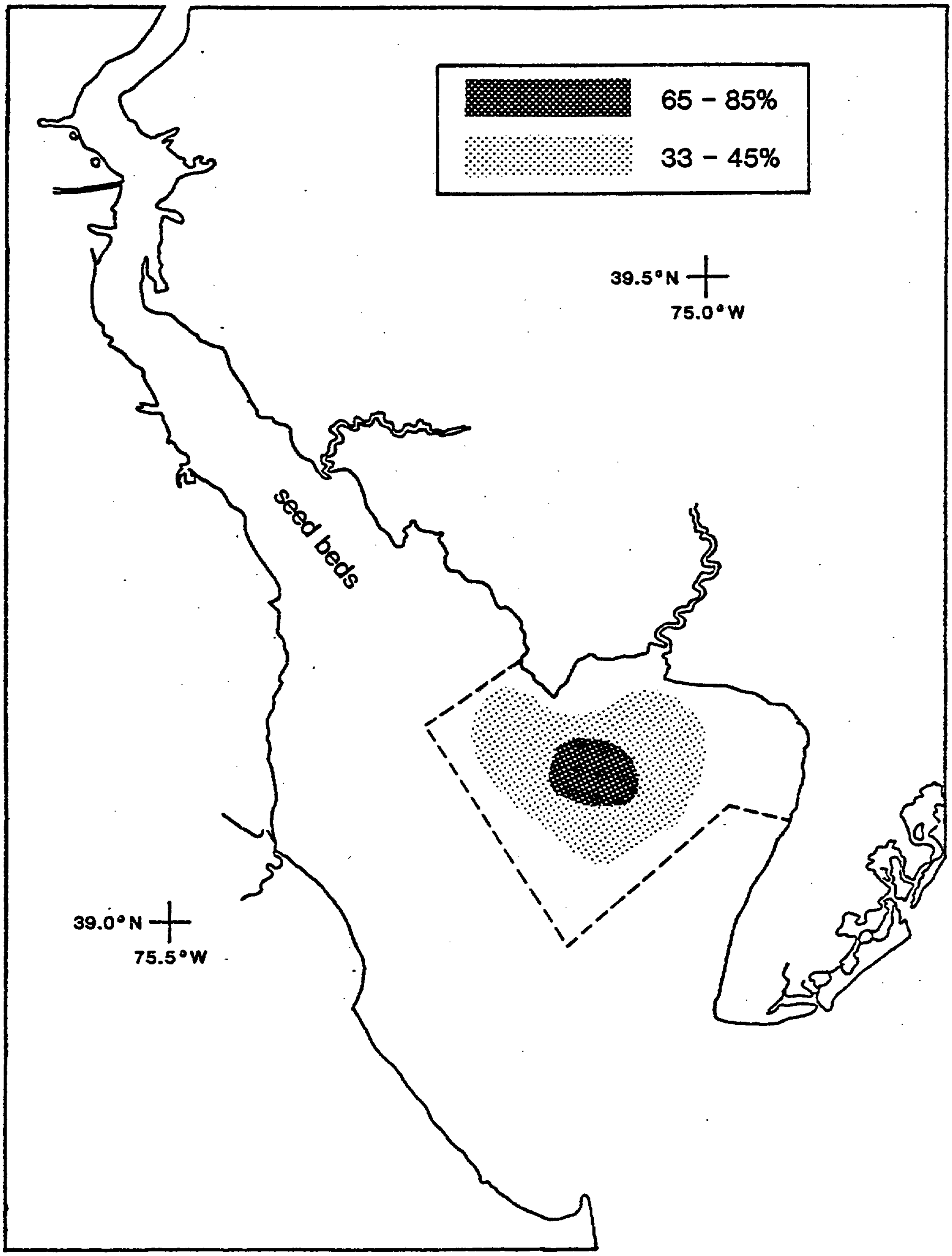


Figure 13-2. Oyster mortalities in spring of 1957 are shown with areas of 65-80% and of 33-45% mortality. The dashed line outlines the planted oyster grounds.

Table 13-3. Ratio of oysters harvested to seed planted over selected periods.

Year	Seed (Bushels)	Harvest (Bushels)	
1956	512,000	687,725	
1957		453,333	
1958	450,850	138,167	
1959		34,333	
1960		23,829	
1961	166,000	137,513	H/S = 1.33
1962	172,000	194,175	
1963		64,425	
1964	170,700	137,213	
1965		87,183	
1966	221,300	115,733	
1967	142,100	171,200	
1968	145,100	220,000	
1969	82,000	176,500	
1970	123,000	112,833	H/S = 1.14
1971	172,000	145,167	
1972	165,825	285,500	
1973	227,840	232,667	
1974	395,755	168,167	
1975	370,425	162,000	
1976	335,975	233,767	
1977	298,000	204,167	H/S = 0.49
1978	385,140	194,038	
1979	460,175	209,413	
1980	434,270	145,577	
1981	458,800		

reduces disease loss as well as loss to predators. Careful study of disease-related mortality for more than 20 years enables us to draw firm conclusions on mortality levels. On average, in the first year after planting 17% of the oysters will be killed by predators and 37% will die of other causes. Since MSX began to kill oysters in 1957 two-thirds of the 37% dying of other causes, or approximately 25% of all oysters planted, have died with MSX within their first year. If oysters are held a second year, the nonpredation kill increases to 50% and by the end of the third year to 56%.

Table 13-2. Delaware oyster production.

Year	Seed Planted (Bushels)	Oysters Marketed (Bushels)
1970	18,600	30,857
1971	43,000	45,000
1972	77,975	72,000
1973	41,095	56,114
1974	52,060	25,128
1975	16,625	27,857
1976	24,425	37,471
1977	21,725	18,214
1978	14,280	9,751
1979		1,263
1980	112,395	91,350
1981	70,015	

Data from Delaware Department of Natural Resources (personal communication from Richard Cole).

In the pre-MSX years the long-term experience in the Delaware Bay industry was to get one bushel yield of market oysters for every bushel of seed planted, given 600-800 seed oysters per bushel and an average of 250-300 market oysters per bushel. This means that, on average, half to two-thirds or more of the seed oysters died before harvest. Oyster-drill predation was recognized as a principal cause of this mortality. From more recent experience a background mortality death from unrecognized causes, of about 1% monthly could be expected. With planting cycles of two to three or four years, such background mortality would account for a substantial portion of the total mortality experienced.

MSX has changed the traditional planting practice. Oysters on the lower-salinity seed beds are under substantially less disease pressure than those on the planting grounds. The present practice is to allow, whenever possible, oysters on the seed beds to grow almost to marketable size, and then plant for one growing and fattening season before harvest. This only exposes the oysters to a single MSX infection period in the lower bay and substantially current annual seed production, thus equaling the pre-1950 production. What yield of market oysters can we reasonably expect from such an increased seed production?

Assuming that the seed is similar in size and quality to that currently available we could expect that doubling the planting, on the average, would double the harvest. Based on official current landing figures this would mean a harvest of about 400,000 bushels annually. As indicated above, however, actual present landings are probably substantially higher than reported, and the 400,000-bushel estimate would then be increased proportionately.

Obviously the present utilization of small seed is wasteful and costly, and shifts in management will be explored. In the spring of 1981, areas immediately above the Southwest Line were leased for planting for the first time in our history. Expansion of this above-the-line area will probably provide an opportunity to grow small "plants" for a year or two in relative safety from heavy MSX kill. Then, in a second transfer, the larger oysters resulting may be moved for a brief period, perhaps from late summer to early fall, downbay for rapid market conditioning with little or no risk of loss to MSX. If with such a system the 1:1 seed to yield ratio (obtained as recently as in the 1966-73 period) is realized, an annual harvest of about three fourths of a million bushels would be obtained. This is our current management objective. We think that it is realistic barring unforeseen catastrophes.

OYSTER QUALITY AND ROLE OF OYSTERS IN THE BAY

Another avenue of attack directed toward improving oyster production is to understand what controls differences in oyster quality (oyster meat content) from year to year and from place to place within the bay. Oyster planters and packers have long known that in good years Delaware Bay oysters will produce up to 9 to 10 pints of oyster meat per bushel. In poor years the meat yield may be less than half of this. Furthermore in any one season meat quality will vary from ground to ground in any one area of the bay. The Rutgers Shellfish Research Laboratory is now examining this problem on the premise that oyster

One would expect that, with the MSX mortality of planted oysters added to all the other mortalities that existed before MSX appeared, the ratio of harvest oysters to seed planted would be reduced sharply from the traditional 1:1. However, for the first eight years (1966-73 inclusive) of consistent improved seed production after MSX was well entrenched, a total of 1,279,165 bushels of seed yielded 1,459,600 bushels of market oysters for a ratio of 1:1.14. In contrast, for the next seven years (1974-80 inclusive), with a conspicuous increase in seed planted, 2,679,740 bushels of seed yielded only 1,317,129 bushels of market oysters for a ratio of 1:0.49 (Table 13-3). With no overall increase in MSX losses in those last 7 years, how can we account for the dramatic reduction in ratio of oysters harvested to seed planted?

Some of this reduction may be the result of planting smaller oysters. With a record heavy set in 1972 followed by a series of good general setting years, smaller, younger oysters have been mixed with the larger seed. Although they add to the bulk of the seed planting, they are too small to be marketed in the first harvest season following planting. If culled and returned to the planted ground a higher proportion dies before the next year's market season. Examination of shucking-house shell piles indicates that as many as one third of the oysters run were too small to shuck and were passed through and died on the piles. There is also reason to believe that landings are underreported, and that this practice has increased in late years.

This belief is stengthened by the Delaware landing data (Table 13-2) for 1972-80, which yielded a harvest to seed ratio of 1:1. The Delaware harvest figures are estimated by observation of deck loads by Department of Natural Resources personnel, rather than by reports of the oystermen.

Given the history of the New Jersey-Delaware Bay industry over the past 25-30 years as reviewed above, it is very encouraging that the seed beds have made a strong recovery and have produced an average of slightly over 380,000 bushels of seed annually since 1974. Since MSX has not caused substantial mortalities on the seed beds except in drier years, we know of no reason why the seed beds should not continue to improve to approximately double the

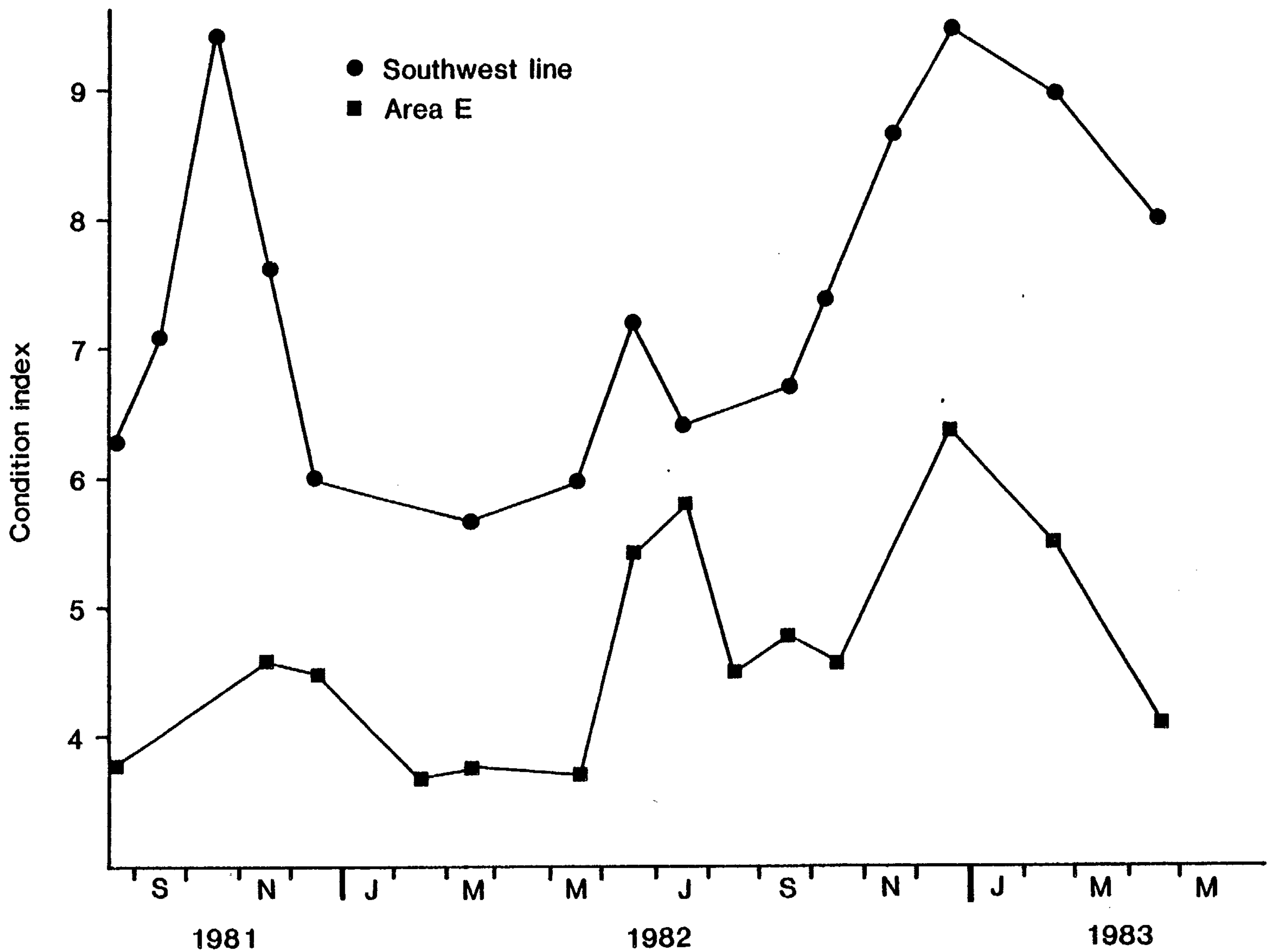


Figure 13-4. Oyster meat quality for two locations in Delaware Bay. See text for explanation of condition index.

meat content is related to measurable environmental parameters. Seven oyster-producing areas are being monitored weekly for phytoplankton, phytoplankton nutrients, total particulate materials, etc., and are sampled at least monthly for oyster meat content. Some of the results to date for two of these areas are illustrated in Figures 13-4 and 13-5. One oyster ground is just below the Southwest Line and the other is approximately four miles above the line in Area "E" (Figure 13-1). Figure 13-4 shows the oyster meat conditions for these two grounds from the fall of 1981 to the present. The condition index is approximately the percentage of the oyster shell cavity that would be occupied by dried oyster meat. It is apparent that the oysters on the Southwest Line ground have a meat content usually about double that of oysters on the Area "E" ground. Both groups build to a peak of condition immediately before spawning in June and again in late fall before the period of winter dormancy. The warm fall and early winter of 1982, compared with 1981, is reflected by displacement of the condition peak to December and generally better condition through the early winter. This also correlates nicely with the increased phytoplankton abundance in the second winter as shown by the chlorophyll values in Figure 13-5B.

Reasons for the difference in meat condition in the two grounds are not yet evident. This is no real difference in the total phytoplankton populations over the two grounds (Figure 13-5B). There is a consistent difference in the total organic particulates over the two grounds but the greater concentration is at the Section "E" ground where the oyster condition is relatively poor. It is clear that more work will be required to define parameter differences in the two areas.

It is of interest to estimate what portion of the total primary production of the bay may be utilized by the oyster and to compare this with similar estimates in other estuaries. Ryther (1969) pointed out that Chesapeake Bay had an annual production of approximately 15,000 metric tons (t) of oyster meats compared with Japan's Inland Sea annual production of about 25,000 t. Divided by the area of the respective estuaries these production values reduced in both cases to approximately 100 kilograms per hectare

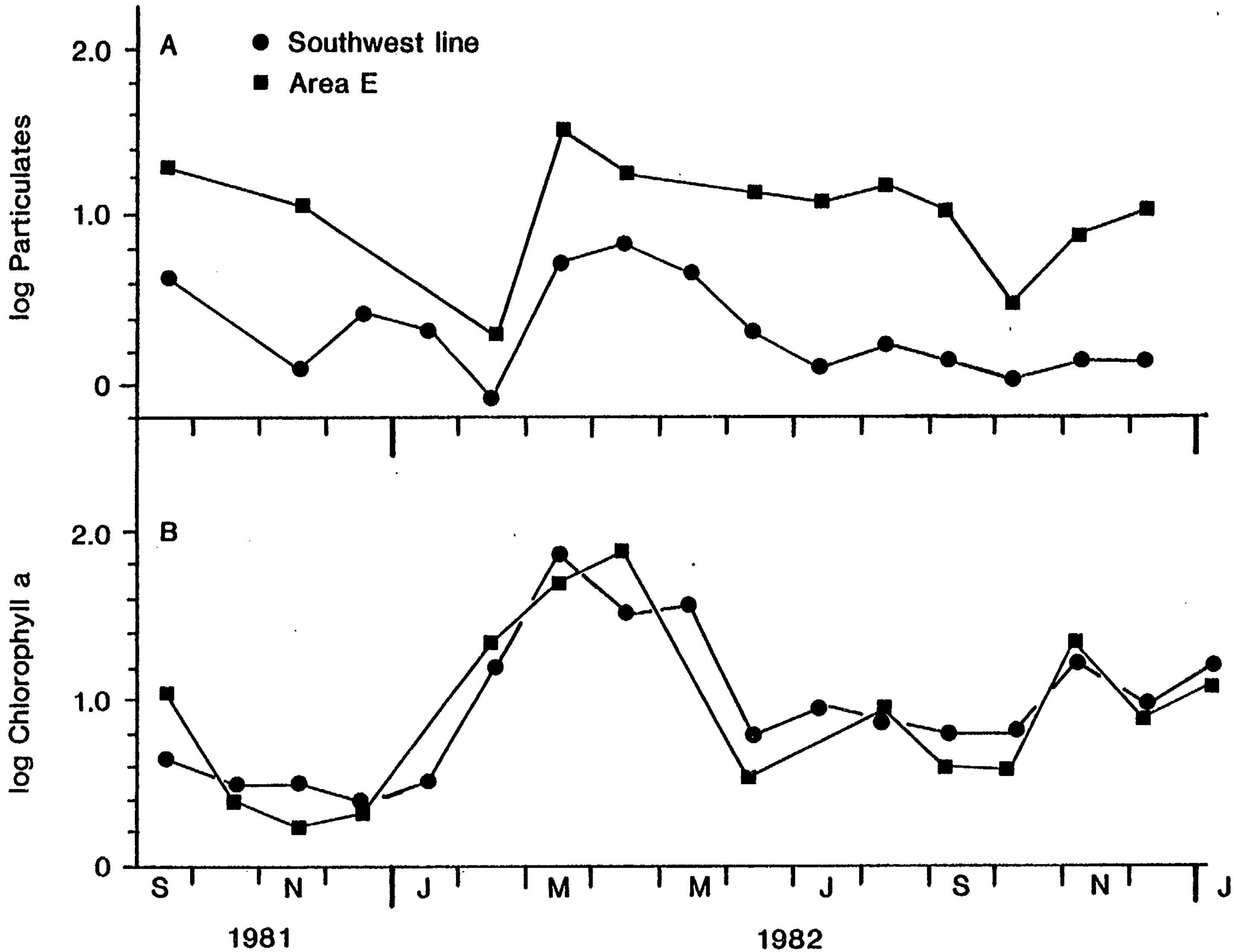


Figure 13-5. Particulate organic matter (13-5A) and chlorophyll a (13-5B) for bottom water samples from the same locations as in Figure 13-4. Organic matter (log scale) in units of mg/L; chlorophyll (log scale) in units of ug/L.

(kg/ha), or about 100 pounds per acre. At 7 pounds of oyster meat to the bushel, these values would reduce to about 15 bushels of oysters per acre per year.

The best oyster bottom in conventional culture, however, will produce 500-1000 bushels per acre (about 5000 kg of meat/ha). This is the density at which oysters are planted in the Delaware Bay. The Japanese oyster rafts in the Inland Sea produce 10 times this value or 50,000 kg/ha per year! In both cases, the oysters are obviously harvesting the phytoplankton (food) carried to them from surrounding areas by the estuarine currents and the rafted animals are harvesting from a larger volume of water.

Ryther also notes that the average estuary produces organic matter at the annual rate of 3 metric tons (dry) per hectare (primary production). Assuming a plant-food-to-animal-tissue conversion efficiency (secondary production) of about 10%, the 3 dry metric tons (3,000 kg) could produce 300 kg of oyster meat (dry weight), or, at 20% solids, 1500 kg wet weight. This is equivalent to about 200 bushels of whole oysters per acre per year. Such a production in an "average estuary" would imply that the oysters are getting the entire primary production of the water column above them. With competition in the food web this could easily drop to the average values cited above (15 bushels/year) for the Chesapeake Bay and the Inland Sea of Japan.

In our work on oyster quality in Delaware Bay we are finding values for carbon fixation over the various oyster grounds that extrapolate to 235 to 329 grams (g) of carbon fixed per square meter per year ($gC/m^2/yr$). Assuming a mean value for carbon fixation of 280 $gC/m^2/y$ and that dry organic matter produced by the phytoplankton is 40% carbon, this would calculate to 700 g dry matter/m^2/yr. This will mean that, for Delaware Bay, if all primary production over the beds were available to the oysters, at 10% conversion efficiency, 470 bushels of oysters per acre per year would result. This compares with the 200 bushels for Ryther's "average estuary."

What is the actual record of production for Delaware Bay oyster beds and how does this compare with the production estimated if all phytoplankton produced in overlying water were converted to oysters? To avoid the problems involved in dealing with planted grounds, three of the natural seed beds have been selected to provide an answer to this question. The basic data have been developed from the Rutgers Shellfish Laboratory yearly surveys of the natural seed beds and daily estimates of seed-oyster catch by individual boats during the spring planting season. New Beds and Bennies have been in continuous production since the early 1970s, for 11 years and 8 years respectively. Cohansey Bed was a major producer of seed for 9 years between 1956 and 1970, excepting the years when either Cohansey and/or the entire bay was closed for conservation reasons (Figure 13-1). The production figures may be summarized as follows:

New Beds: Productive area 800 acres; in 11 years, 1971-81, produced 1,133,720 bushels of seed oysters. Yield of 129 bushels/acre/year.

Bennies Bed: Productive area 450 acres; in 8 years, 1974-81, produced 731,435 bushels of seed oysters. Yield of 203 bushels/acre/year.

Cohansey: Productive area 300 acres; in 9 years, 1956-70, produced 771,400 bushels of seed oysters. Yield of 286 bushels/acre/year.

The above values of natural seed-bed production (129, 203, and 286 bushels/acre/year) would indicate that somewhat less than half of the total production of the immediately overlying waters is being converted, at 10% efficiency, to oyster meat. If one includes in the estimate the areas surrounding the beds that appear to support a comparatively much less dense population of infauna and epifauna than do the beds themselves, the fraction of primary production utilized by the oyster drops proportionally.

Overall, it seems clear that the production of seed oysters on Delaware Bay beds compares very well with that of other estuaries and that the primary production of the surrounding water could be exploited further by expansion of the oyster-producing areas.

THE BLUE CRAB FISHERY

The status of the blue crab fishery of Delaware Bay is probably best represented by a consideration of landings in recent years (Tables 13-4 and 13-5). Landings from year to year are highly variable; no long-term trends are apparent.

From 1948 to 1982 the Delaware pot fishery has ranged from extremes of 62,000 lbs (1948) to 3,186,000 lbs (1975). From 1956 to 1982 the New Jersey total landings have ranged from 63,380 lbs (1968) to 1,913,470 lbs (1975). As one would expect, New Jersey and Delaware landings usually have risen and fallen together, but those of Delaware generally exceed those of New Jersey.

When one adds the trot line and dredge landings to the Delaware pot fishery, the disparity between the landings of the two states is increased. It is of interest that the apparent cessation of the winter dredge fishery in Delaware in the early 1960s was not followed by an increase in the landings of the pot fishery. This adds credence to the claim that the crabs taken in the lower-bay winter dredging are for the most part crabs in their last winter that would not, in any event, survive to enter the pot fishery of the following summer.

Except for winter-kill, as evidenced by the decline in landings in years following unusually long, cold winters, there seems to be no predictable relationship with environmental or other known parameters to size of the blue crab population.

Table 13-4. State of Delaware commercial blue crab landings from Delaware Bay.

Year	Pots		Trot Line		Dredge		Total	
	Pounds	Dollars	Pounds	Dollars	Pounds	Dollars	Pounds	Dollars
1948	62	16	406	49	900	90	1,368	156
1949	504	47	1,582	147	147	14	2,233	207
1950	536	37	232	19	3,652	162	4,420	218
1951	642	45	151	12	3,853	271	4,646	329
1952	950	127	–	–	300	15	1,250	142
1953	1,300	174	–	–	421	50	1,721	224
1954	2,572	224	–	–	338	29	2,911	253
1955	2,149	289	60	8	600	52	2,809	249
1956	2,221	256	38	6	1,321	161	3,580	423
1957	3,164	281	49	5	1,711	131	4,924	416
1958	1,260	113	118	2	1,176	71	2,554	186
1959	1,114	90	4	?	533	35	1,650	125
1960	2,601	187	6	?	542	43	2,149	231
1961	682	61	–	–	131	4	813	66
1962	1,701	121	–	–	209	8	1,910	129
1963	260	21	–	–	266	14	526	34
1964	275	31	–	–	40	2	316	33
1965	558	47	–	–	–	–	558	47
1966	–	–	–	–	–	–	–	–
1967	–	–	–	–	–	–	–	–
1968	223	40	–	–	–	–	223	40
1969	510	62	–	–	–	–	510	62
1970	608	107	–	–	–	–	608	107
1971	1,014	203	–	–	–	–	1,014	203
1972	2,504	657	–	–	–	–	2,504	657
1973	1,682	642	–	–	–	–	1,682	642
1974	1,962	736	–	–	–	–	1,962	736
1975	3,186	1,195	–	–	731	–	3,917	1,195
1976	2,833	–	–	–	465	–	3,298	–
1977	439	227	–	–	–	–	439	227
1978	333	145	–	–	227	50	560	195
1979	551	168	–	–	–	–	551	168
1980	1,823	594	–	–	–	–	1,823	594
1981	877	308	–	–	105	23	982	331
1982	815	281	–	–	10	–	825	281

Data from State of Delaware, Divison of Fish and Wildlife (personal communication from Richard Cole). Pounds and Dollars are in thousands.

Table 13-5. State of New Jersey commercial blue crab landings from Delaware Bay.

Year	Landings (Pounds)	Landings (Dollars)
1956	332,074	33,614
1957	733,160	82,431
1958	584,680	58,035
1959	706,360	80,870
1960	947,681	111,017
1961	418,120	48,419
1962	833,560	88,060
1963	243,440	29,891
1964	414,330	59,118
1965	380,321	53,695
1966	302,395	42,066
1967	384,090	49,710
1968	63,380	11,126
1969	469,920	61,787
1970	478,140	73,327
1971	585,718	101,947
1972	886,480	102,466
1973	1,528,658	407,033
1974	1,849,400	466,392
1975	1,913,470	424,305
1976	1,736,480	547,791
1977	111,645	40,047
1978	503,821	217,590
1979	463,825	186,974
1980	1,183,760	
1981	1,162,120	
1982	601,960	

All figures from National Marine Fisheries Service, U.S. Dept. of Commerce.

It is generally encouraging that the blue crab fishery, though unpredictable in its extremes of abundance, seems as viable as ever. Its tolerance of widely ranging salinities and gross pollution levels in other east coast estuaries, coupled with its record of production over the last 30 years or so, leads one to predict that this species will continue to thrive in the Delaware Estuary.

CONCLUSIONS

Although the Delaware Bay benthos has been considered by earlier investigators to be of low density and impoverished in comparison with other estuaries, evidence is presented here that the benthic assemblages on stablized bottom are diverse and the population density compares with that in other highly productive temperate estuaries. In particular the assemblage of species, generally recognized as the oyster community, is highly diverse and the production of oysters per unit area compares favorably with other oyster areas around the world. As evidenced by its shellfisheries, Delaware Bay is "healthy" and its benthic populations demonstrate a more than respectable secondary production.

The oyster industry is recovering from a period of low production resulting from mismanagement and the advent of a serious new disease (MSX) in the 1950s. The continued pressure of MSX on the oyster population has required some changes in industry operations. Better understanding of requirements for consistent seed production and for consistent high meat quality on planted grounds will increase the production of market oysters. It is reasonable to expect that the current oyster production in Delaware Bay can be approximately doubled.

Although highly variable in its annual production, the blue crab industry of Delaware Bay is no less predictable than that of the Chesapeake or other producing areas.

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MANAGEMENT SECTION

INTRODUCTION TO MANAGEMENT CHAPTERS

G.J. Mangone, J.H. Sharp

A PRESENT ROLE OF THE DELAWARE RIVER AND BAY AUTHORITY

The Delaware River and Bay Authority (DRBA) is a bistate agency, sanctioned by the United States Congress, that has statutory authority granted by the legislation of New Jersey and Delaware for the planning, development, and operation of crossings of the Delaware Estuary. It also has latent authority, indicated in the compact that created the DRBA (Delaware-New Jersey Compact 1962), for planning, development, and operation of any transportation or terminal facility at the shoreline and in areas adjacent to the shoreline of the Delaware Estuary when provided with enabling legislation by New Jersey and Delaware. The DRBA could also perform any other functions that are approved by the two states.

In supporting the Delaware Estuary Project (see Chapter 1), the DRBA has already established itself as a major research sponsor and potential resource manager in the lower Delaware Estuary. The lower estuary is the focus of the scientific research supported by the DRBA and is also the area of most immediate interest for potential management roles for the DRBA.

There are not many examples of regional agencies with strong direct roles in research support designed for management of aquatic resources. However, one very good example is the Southern California Coastal Water Research Project

(SCCWRP). SCCWRP is governed and sponsored by an authority consisting of representatives from five municipal and county entities. Their sole activity is supporting research in the Southern California coastal waters with respect to the impact from sewage outfalls (Bascom 1982). The SCCWRP research is directed by its scientific staff with the objective of obtaining a broad understanding of how those waters function physically, chemically, and biologically. However, the research program is responsive to the needs of the managers of sewage effluents for this very densely populated area. The research is designed by the researchers and is broad and interdisciplinary, yet it is responsive to the needs of regional managers and provides them with appropriate information for decisions. There is thus a similarity between the DRBA sponsorship of the Delaware Estuary Project and SCCWRP.

In the contract between the DRBA and the University of Delaware/New Jersey Marine Sciences Consortium (DRBA 1982), questions were addressed concerning specific actions that the DRBA could take to improve the management of the estuary. These questions and chapters of this report containing appropriate recommendations on them (in parentheses) are:

(1) Functions related to commercial fishing and aquaculture (Chapter 17) and to bistate planning and development (Chapter 15).

(2) Methods to use predictive models and results produced by the Delaware Estuary Project (Chapters 2-13, and also 17 and 19).

(3) Regulatory roles appropriate in light of existing responsibilities, differing statutes of the two states, and hazardous activities (Chapter 16).

(4) Establishment of a division within DRBA for investigation and oversight of environmental and development activities (Chapters 1, 14, and 15).

(5) Roles related to transportation (Chapter 18).

(6) The planning and development of a deepwater port (Chapter 19).

(7) Any other matter to improve management of environmental and economic resources of the estuary (Chapters 1, 14, 15, and 16).

The following chapters deal with these suggestions in detail. Some, because of previous study, are closer to realization than others; some are closer to the latent authority of the DRBA than others; but all require a bistate approach, a bistate planning and development agency, and a bold initiative from the DRBA to invigorate maritime transportation, improve environmental regulation, and assist the fishing industry for the benefit of the people in both New Jersey and Delaware.

POTENTIAL ROLES FOR THE DELAWARE RIVER AND BAY AUTHORITY

A wide range of problems presently confronts the people who depend on activities in the Delaware Estuary area for their economic welfare and personal satisfaction. First, there is no truly bistate planning and development agency for the area served by the DRBA. Second, there is considerable need for re-examination of the fisheries development strategies of both New Jersey and Delaware. Third, environmental regulations, necessary for the safety and pleasure of the community, have become burdened with procedures, often overlapping and repetitive and always time-consuming in administration or litigation. Fourth, the pulse of the estuarine system, with its ports and trade is slowing and requires expensive dredging for maintenance which with intense competition for marginal commerce brings about limited vision of the future. Important background information on the development of the Delaware Estuary Region was discussed in a report commissioned by the DRBA (URS 1980).

None of these problems can be confronted adequately without some bistate coordinating agency that would obtain the cooperation of the several commissions, councils, boards, or departments in both states that presently have fragmented responsibilities for dealing with activities in the Delaware Estuary region. It is our judgment that the DRBA could serve as the nucleus of such a bistate agency simply by regularly convening interested parties, by providing a forum for the discussion of various issues, and by maintaining minutes. If such meetings should prove fruitful and require a permanent agency with power to recommend, delegate, contract, acquire, or otherwise exercise authority, then a sound basis for legislation, if necessary, by New Jersey and Delaware will have been provided.

In the following five chapters the need is indicated for general planning and development and an overview of the economic and environmental picture of the Delaware Estuary. Our specific recommendations in a priority order are the following:

(1) The DRBA should continue support of research to fully understand the estuary and serve as background should future development take place. For this agency to be granted an enlarged role suggested here, the citizens of Delaware and New Jersey will need to feel confident that the DRBA possesses a thorough understanding of the physical, chemical, and biological characteristics of the estuary and that it could adequately predict the consequences of any alteration of the estuary brought about in the future development.

(2) The DRBA should serve the role as a bistate planning and development agency. This is a large function and it also encompasses minor roles suggested in several of the chapters, some of which are direct roles and some of which are more indirect. As the bistate planning and development agency, the DRBA would become a major force in determining the future economic growth and environmental safety of the lower Delaware Estuary. Minor roles envisioned as part of this function are to serve in an advisory and guidance capacity for environmental regulation, to give advice in fishery management, and to advocate sport fishing reef and pier projects. In a more direct way, the DRBA should establish itself as a Maritime Planning and Development Agency for coordinating port activities.

(3) The DRBA should seek concurrent legislation to establish itself in an overview and permitting role for cargo transfer in the waters of the lower Delaware Bay. This should be done with the recommendation from the DRBA that any regulation of these transfer activities rest with the respective states.

(4) The DRBA should explore advantages and disadvantages of a deepwater port in the lower Delaware Bay.

References cited in the texts of all the chapters are listed together in a master reference list at the end of the report (after Chapter 19).

Chapter 15

BISTATE PLANNING AND DEVELOPMENT

G.N. Lawrence

INTRODUCTION

Future planning and development of the lower Delaware Estuary should be carried out on a bistate level. To discuss this potential role, this chapter first establishes the demographic and economic settings and examines the needs for planning and development. A review of planning and development agencies in Delaware, in New Jersey, and on a regional scope helps one to understand the role and activities at the state and regional levels. Finally, the chapter concludes with a discussion of possible future roles for the Delaware River and Bay Authority (DRBA).

DEMOGRAPHIC SETTING

The DRBA has authority in an area that includes portions of the three counties of Delaware (New Castle, Kent, and Sussex) and five counties in southern New Jersey (Cape May, Atlantic, Cumberland, Salem, and Gloucester). This region comprises about 3,620 square miles of land (mostly flat coastal plains) and contains a population of more than one million people. Three subregions can be identified within the area: (a) the industrialized metropolitan section in the northeast encompassing Wilmington and Newark, Delaware, and Pennsville, New Jersey; (b) a coastal recreation section in the southeast encompassing Atlantic City to Cape May, New Jersey, and Lewes and Rehoboth Beach, Delaware; and (c) and agricultural and manufacturing midsection encompassing Milford and Dover, Delaware, and Bridgeton, Vineland, and Millville, New Jersey.

The northwest subregion, the industrialized and urbanized section of New Castle and Salem Counties, has the best access to the mid-Atlantic region and to ports on the Delaware Estuary. Since 1970, however, population growth in this area, including Wilmington and the shoreline of the Delaware River where industrial development is permitted, has slowed to about 0.4% per year, the lowest among the DRBA regions. It is anticipated that growth rates in this section will increase only modestly in the future.

The southeast coastal recreational section is the fastest-growing area in the DRBA region. Since 1970, the population here has increased about 2% per year and may exceed 3% per year in the next decade. At present this area contains about one-third of the region's total population. About 55% of the total population growth in the entire DRBA region, estimated at about 200,000, will occur in this coastal zone. The rapid expansion of the New Jersey hinterlands with its revenue-generating Atlantic City casinos, the prospective expansion of commercial fishing based in Lewes and Cape May, and the possible development of the Baltimore Canyon off the coast of New Jersey and Delaware for oil and gas deposits may further accelerate population growth. Rapid economic and population expansion in this coastal recreational zone will place additional burdens on planning and local government efforts to balance economic development with environmental protection.

Agriculture and fishery resources (poultry in Delaware, truck farming in New Jersey, oyster farming in the Delaware Bay), special military developments affiliated with the Air Force base in Dover, and the glass industry in Millville and Bridgeton have developed the agricultural and less urbanized midsection of the midregion served by the DRBA. This section, including Cumberland and Kent Counties, has no cross-bay link as do the other two locations, but will probably grow steadily in population in the next decade.

Delaware had a 1980 estimated population of 612,940. Within the next two decades its population is projected to grow by 19.4% to 760,555. New Jersey had a 1981 estimated population of 7,404,000 people. Within the next two decades its population is estimated to grow by 15% to 8,958,000 (U.S. Department of Commerce 1979a).

ECONOMIC SETTING

New Castle County contains almost all the companies for chemicals, petrochemicals, oil refining, pharmaceuticals, auto production, electric generation, metal fabrication, and plastics in Delaware. The county provides about 76% of Delaware's jobs. It is the major industrialized, metropolitan subregion in the area served by the DRBA.

In the Delmarva Peninsula, the poultry industry accounts for income of some $300 to $500 million a year (D.F. Crossan, personal communication). Agriculture in Cumberland and Atlantic counties generates another $225 million a year, so that a total of from $500 to $750 million of income annually comes from major farm pursuits. To this should be added the income from truck farming, sand pit excavations, the glass industry, and oyster culture that sustain the region's economy.

In the coastal recreational subregion the DRBA serves, tourism and recreational fishing are the paramount stimulants to economic vitality. The beaches of Sussex County generate an appreciable portion in Delaware's $202-million-a-year travel industry. Added with revenue from New Jersey's tourism and that generated by the Atlantic City casinos, this subregion's annual revenue may well exceed $1 billion.

NEEDS FOR PLANNING AND DEVELOPMENT

The following deficiencies in the current planning and development for the region are apparent: (1) lack of coordination between county and state planning and development agencies on one hand, and regulatory agencies on the other, in both New Jersey and Delaware; (2) lack of coordinated planning and development between Delaware and New Jersey for the region as a whole; (3) lack of initiative and leadership in promoting the region as a whole; (4) lack of a coherent and consistent planning and development strategy for marinas, marine terminals, and their ancillary transportation facilities in the region; (5) lack of a formal bistate planning and development agency to promote the lower Delaware Bay; (6) lack of a regional bistate agency to serve as both regional development advocate and liaison with the federal regulatory agencies; (7) fragmented and inconsistent federal, state, and local jurisdiction over planning, development, and environmental protection; (8) short-sighted planning and limited revenue sources for the revitalization and development of coastal zone industries and marine transportation facilities in the region as a whole; (9) uncertainty concerning the jurisdictions and regulations of reorganized state and local planning, development, and environmental agencies in both Delaware and New Jersey; and (10) lack of a regional information service to be a clearinghouse for data concerning the jurisdictions, regulations, and permit processes of the appropriate federal, state, and local agencies, and developments affecting planning, development, and transportation in both New Jersey and Delaware.

STATE PLANNING AND DEVELOPMENT AGENCIES

In 1972, Congress passed the Coastal Zone Management Act (also see Chapter 16 for more on this act and state institutions responding to it). Section 303 anticipated that the implementation and enforcement of a state's approved coastal management programs would result in consistent processes for siting major facilities related to national defense, energy, fisheries development, recreation, ports, transportation and the location, to the maximum extent practicable, of new commercial and industrial developments in or adjacent to areas where such development already exists. Moreover, the act foresaw assistance in the redevelopment of deteriorating urban waterfronts and ports, and sensitive preservation and restoration of historic, cultural, and aesthetic coastal features; and opportunities for the public and local government to participate in coastal management decision-making with regard to conservation and management of living marine resources, pollution control, and aquaculture facilities (U.S. Department of Commerce 1979b).

State of Delaware

The Coastal Management Program of Delaware approved by the federal government is the state's land use plan. Nearly all lands in Delaware are in close proximity to coastal waters, with no part of the state more than 35 miles from these waters; thus, the entire state is subject to the Coastal Management Program. For management and control, Delaware's Coastal Management Program (DCMP) has divided the state into (1) the coastal strip and (2) the remainder of the state. The coastal strip averages four miles in width along Delaware's inshore coast where state laws regulate development. The Underwater Lands Act regulates uses in state water bottoms from mean high tide to the limits of state jurisdiction. The Beach Preservation Act controls uses on beaches and dunes with no construction generally allowed on beaches or on primary dunes. The Wetlands Act regulates activities in both the saline and freshwater tidal wetlands. The Coastal Zone Act prohibits heavy industry and bulk-product transfer facilities from locating in the coastal strip and allows manufacturing by permit only to ensure protection of coastal resources.

Department of Natural Resources and Environmental Control (DNREC). In November 1981, the Planning Section of the Division of Environmental Control in the DNREC superseded the Office of Management, Budget and Planning (OMBP) as the lead agency in managing Delaware's coastal resources. The Secretary of the DNREC assumed the roles and responsibilities of the former State Planner in

OMBP. Most changes in Delaware's Coastal Zone Act have been procedural with refinements in administrative applications and the internal flow of documents as well as a broader review process.

In Delaware, most planning is done on the local level, especially through the county planning offices. In 1978, Delaware passed the Land Use Planning Act to ameliorate state and local coordination in reviewing new developments, providing for the publishing and sending of notices and comments to other local governments and state agencies affected by a major local planning decision, and establishing a procedure to resolve any intergovernmental disputes over a proposed development. Coordination between state and county planning and development agencies and state regulatory agencies nonetheless remains a persistent problem.

Delaware Development Office (DDO). The DDO greatly assists potential developers by preparing portfolios, apprising them of permit processes, initiating the applications for permits, and introducing them to permit agencies. The DDO also attempts to mediate conflicts between potential developers and the DNREC. In addition, it provides a revenue bond program that facilitates the financing of development projects. If shorefront sites for loading, unloading, processing, and storage are on the local real estate market, the DDO will solicit acreage when a private firm wants to remain anonymous and its intended uses would be permitted.

The DDO foresees an interest in developing these areas: (1) Big Stone Beach, (2) further development at the area north of the Chesapeake-Delaware Canal, and (3) Lewes, as well as at (4) the Port of Wilmington in cooperation with the Delaware Chamber of Commerce. The Economic Development Division of the DDO conducts a credit analysis on a prospective developer, as does the developer's bank. The maximum federal ceiling on one development project is $10 million. Through general revenue bonds provided by the federal government and issued through the DDO, a three-year ceiling is set on past and future expenditures by the developer. The total three period expenditures may not exceed $10 million. Serving as both a federal and state agent, the DDO through its Economic Development Authority may grant tax-exempt status to projects serving public purposes; that is, the interest on indebtedness is tax-free. Ports, docks, wharves, and pollution control may be excluded from the $10-million capital investment ceiling (E. Oliver, personal communication).

<u>City of Wilmington Development Division.</u> The Development Division of the City of Wilmington advises the Mayor, makes long-range growth projections, and seeks to create a climate for financial investments. It also helps the Port of Wilmington by guaranteeing revenue bonds. The port pays for itself; from its revenues, it pays both the principal and the interest to the Department of Commerce. Last year, the Department of Commerce provided $2 million to the Port of Wilmington for capital improvements, which the port repaid.

The Development Division of the City of Wilmington has rezoned its regional coastal zone: east of Interstate 95, state laws apply; west of Interstate 95, state laws do not apply, allowing Wilmington to create a mixed-use zone not covered by the Delaware Coastal Zone Act. The city promotes development in these mixed areas, but its interaction with the Delaware Development Office - the state-wide advocate of development - is not clear. The City of Wilmington's Development Division encourages more marina development, because only two mediocre marinas exist - East 7th Street and Fort Christiana Marina. Furthermore, the City of Wilmington is giving serious consideration to establishing a foreign trade zone in the Port of Wilmington to generate more jobs and revenues (L. Liggett, personal communication).

State of New Jersey

In New Jersey, the statewide document for future development is the New Jersey State Development Guide Plan. Three acts regulate planning and development in New Jersey: the Coastal Area Facilities Review Act (CAFRA), the Waterfront Development Act, and the Wetlands Act.

The CAFRA regulates the design and construction of major facilities -such as power-generating stations, public facilities, industries, marine terminals - in the coastal region encompassing portions of Salem, Atlantic, Cumberland, and Cape May Counties (also see Chapter 16).

The Waterfront Development Act regulates activities in the waterfront area comprising (a) any navigable waterway or stream of New Jersey and all submerged lands up to the mean high-water level; and (b) all areas landward from the mean high-water level to the first surveyable property line (public road, railroad, right-of-way) existing on the effective data of these rules, provided that the landward boundary of such area shall be at least 100 feet and no greater than 500 feet from the waterway, except where lands that were formerly covered by tides (i.e. tidelands) extend more than 500 feet from the mean high-water line. In such cases, the boundary of the upland fringe area is the upland boundary of such tidelands. The upland area this Waterfront Development Act excludes is any part of the coastal area that the CAFRA defines. Developments outside the waterfront area (that is, landward of the first surveyable property line more than 100 feet from the waterway) or in the wetlands area do not require permits under the Waterfront Development Act.

The Wetlands Act covers all coastal wetlands in the Raritan Basin, south along the Atlantic, and north along the Delaware Bay and River. The Waterfront Development Act covers all wetlands north of the Raritan Basin and all coastal wetlands along the Delaware River (not covered by Wetlands Act). Unless demonstrated otherwise, the New Jersey Department of Environmental Protection (DEP) will consider all lands within 500 feet of tidal waters to be within its jurisdiction as promulgated in the three acts (U.S. Department of Commerce 1980a).

The legislative intent of the CAFRA, Wetlands, and Waterfront and Riparian statutes is the foundation of the coastal resource and development policies which apply to the actions and decisions of the DEP on the use of coastal resources including: (1) coastal permits, (2) consistency determinations, (3) financial assistance, (4) DEP management actions affecting the coastal zone, and (5) DEP planning actions affecting the coastal zone.

Parts of Atlantic, Cumberland, and Cape May Counties are Pinelands Protection Areas; therefore, coastal developments must be consistent with the National Parks and Recreation Act of 1978.

For planning and development, the DEP has divided New Jersey into three regional growth areas: development regions, extension regions, and limited growth regions (see Figure 15-1). Development regions are already predominantly developed. Further development could possibly require the expansion of existing or the construction of new ports, docks, and marinas. After full development in the development region, the extension region (Cape May) is where development will be channeled. Finally, limited growth regions (in Salem, Atlantic, and Cumberland Counties) contain environmentally sensitive areas, but may be developed to a limited extent.

Under Section 305 of the Federal Coastal Zone Management Act of 1972, the Governor of New Jersey designated the Department of Environmental Protection as New Jersey's coastal planning agency. Figure 15-2 illustrates the new reorganization of the former Division of Marine Services into the new Division of Coastal Resources.

The Bureau of Coastal Project Review administers the CAFRA, Wetlands, and Waterfront Development Permit Programs in conformity with the rules on Coastal Resources and Development Policies. The Bureau of Coastal Planning and Development assumed the planning functions of the former Office of Coastal Zone Management, and serves as a single planning agency to assist in the development and refinement of a program to guide and regulate development and resource protection in the coastal zone. The Bureau of Tidelands assumed the functions of the former Office of Riparian Lands Management regarding the description and valuation of state-owned tidelands. It serves as staff to the Tidelands Resource Council which reviews applications for tidelands grants, leases, and licenses from the state.

The Bureau of Coastal Enforcement and Field Services assumed the inspection and enforcement activities of the former Offices of Coastal Zone Management, Wetlands, and Riparian Lands Management. The Bureau of Coastal

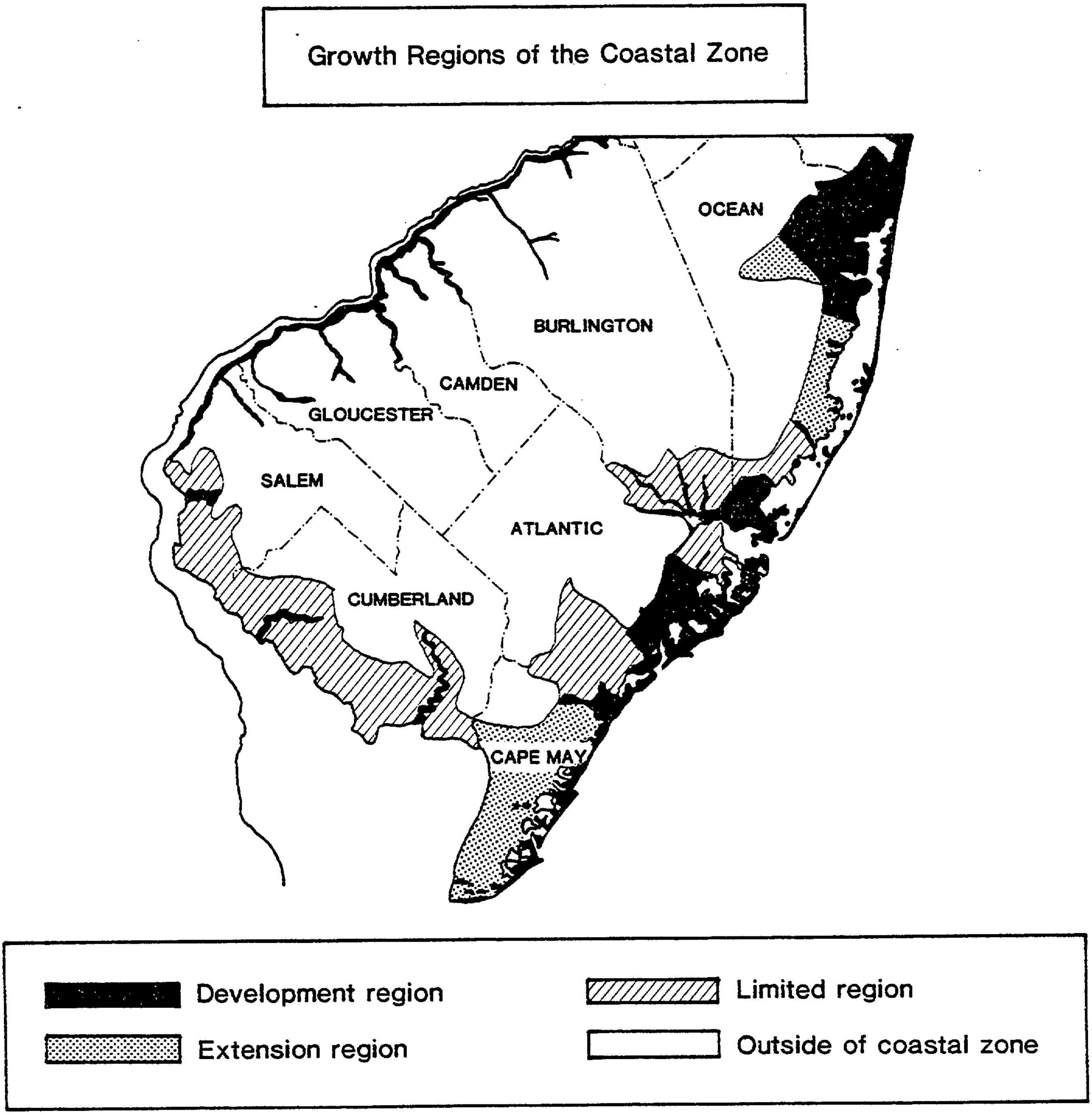

Figure 15-1. New Jersey regional growth regions shown for the coastal zone of the southern part of the state.

DIVISION OF COASTAL RESOURCES

Organizational Chart

April 1980

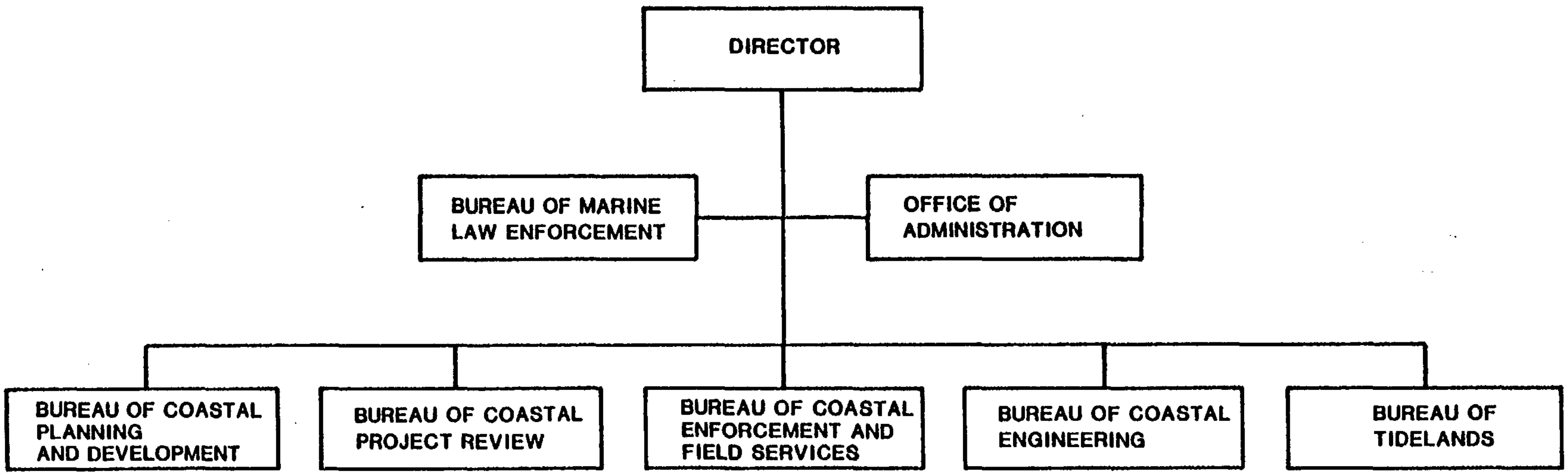

Figure 15-2. Reorganization of the former New Jersey Division of Marine Services into the Division of Coastal Resources.

Enforcement and Field Services provides an interdisciplinary inspection team to support the functions of the Bureaus of Tidelands and Coastal Project Review. The Bureau of Coastal Engineering administers New Jersey's shore protection and waterways maintenance programs, assuming the functions of the former Office of Shore Protection.

The Division of Water Resources in the reorganized New Jersey DEP is responsible for water quality planning and maintenance, water supply, and flood plain management. Under Section 208 of the Federal Clean Water Act, this division is the state's designated water quality planning agency, and under the New Jersey Water Pollution Control Act has the authority to administer the National Pollution Discharge Elimination System (NPDES) permits once the federal Environmental Protection Agency delegates this authority to the DEP. In 1980, the Division of Water Resources, four county planning boards, and the Delaware Valley Regional Planning Commission conducted area-wide water quality planning in four counties, four counties, and nine counties respectively.

The Division of New Jersey State and Regional Planning has been eliminated. Its mandate was to prepare and maintain a state plan (submitted by the DEP) to facilitate coordination among other New Jersey state agencies regarding the planning and development of land resources, and to provide booklets on technological assistance (R. Hoeh, personal communication). This division also served as liaison to the Wilmington Metropolitian Area Planning Coordination Council (Wilmapco) as a community representative, and maintained guide plans for transportation development.

REGIONAL PLANNING AGENCIES

Table 15-1 presents an outline of the regional planning agencies.

Table 15-1. Local governments functioning as regional and interstate agencies.

Government	Plan	Regulatory Authority
County of Atlantic	County Master Plan	Authority to review subdivisions of land within county and to approve subdivisions affecting county roads or drainage facilities
County of Cape May	County Master Plan	
County of Cumberland	County Master Plan	
County of Ocean	County Master Plan	
Delaware Valley Planning Commission	Land Use Plan Open Space Plan Housing Allocation Plan Water Supply Plan Transportations Plans	None
Wilmington Metropolitan Area Planning Coordination Council	Regional Land Use Plan	None
Delaware River Basin Commission	Comprehensive Plan for the Delaware River Basin	Intrastate allocation of Delaware River Basin waters Review authority over proposed facilities with the potential for significant impact on water quality in the basin Enforcement authority over effluent standards required to attain water quality standards described in the Comprehensive Plan

Delaware Valley Regional Planning Commission

The Delaware Valley Regional Planning Commission (DVRPC) was established between New Jersey and Pennsylvania to develop bistate plans for transportation and land use activities. Its jurisdiction extends as far south as Gloucester and Camden, and its membership includes the Chairman of Wilmapco, the Pennsylvania Metro Agency, the Pennsylvania Department of Transportation, and the New Jersey Department of Transportation. In the past, the DVRPC conducted some studies of the coastal zone, but has largely reverted to land transportation planning because federal aid has been severely cut (R. Hoch, personal communication).

Wilmington Metropolitan Area Planning Coordination Council

Wilmapco represents New Castle County and Salem County. It is the only regional planning agency in the area served by the DRBA. Recent federal reductions in funding regional planning activities have drastically cut back Wilmapco's activities. Cecil (Maryland), Salem (New Jersey), and New Castle (Delaware) County planning officials have been meeting every month with Wilmapco. Although some members have proposed that Wilmapco become involved in the planning and development of the coastal zone where both states are affected, such suggestions have been denied (C. Warren, personal communication). Through its original mandate, Wilmapco has the potential to plan coastal zone activities but has not taken the initiative. It is substantially limited in funds.

Delaware River Basin Commission

The Delaware River Basin Commission (DRBC) also has planning authority. A coordination project between the New Jersey DEP and the DRBC found no conflicts with plans of a regulatory nature. This project was the DEP's solicitation of comments from the DRBC in drawing up New Jersey's Coastal Management Program. Section 3 of the DRBC compact provides that the DRBC shall develop and effectuate plans, policies, and projects relating to the water resources of the basin, and that it shall adopt and promote uniform and coordinated policies for water conservation, control, use, and management in the basin. Under Article II of the compact, all projects affecting the water resources of the Delaware Basin must be planned in consultation with the DRBC. The DRBC is required by the Compact of 1961 to develop and adopt a comprehensive plan for the water resources of the basin, and this comprehensive plan differs from the usual master plan in that it serves not only as a guide for development of the natural resources, but also as a management and regulatory mechanism (U.S. Department of Commerce 1980a).

ROLES FOR THE DRBA IN PLANNING AND DEVELOPMENT

Federal and state financial cutbacks, state and county administrative reorganizations, and limited financial resources in both New Jersey and Delaware all are substantially changing the ability of existing agencies to plan and develop the Delaware Estuary region. Above all there is a lack of any formal bistate planning and development agency. A good example of bistate friction is the Salem County situation. In most of Salem County, the Delaware -New Jersey boundary is the mean low water line on the eastern New Jersey shore of the Delaware River. Both New Jersey and Delaware coastal management agencies had met and discussed this issue, concluding that any project extending beyond the mean low water line must obtain both a subaqueous permit from Delaware's DNREC and a coastal zone permit from New Jersey's DEP. Delaware's Coastal Management Program, specifically the Coastal Zone Act (which Salem County is subject to) proscribes multi-user ports. Salem County has little industrial land available in the coastal zone, but it plans to develop it, including the construction of a multi-user port. Potential conflicts exist in this situation and Salem County officials have appealed to the National Oceanic and Atmospheric Administration's Office of Coastal Zone Management, calling for a bistate coordination of permit processes (C. Warren, personal communication).

The DRBA could greatly assist in the resolution of such problems as the Salem port permitting. The DRBA is the only bistate authority in the region and should be involved in reconciling jurisdictional conflicts of this type. Not only has the DRBA established itself as an agency with information for a broad environmental overview through its support of the Delaware Estuary Project, but it also has a potential mandate for a regional overview in development.

On 6 August 1962 the United States Congress approved the agreement of New Jersey and Delaware for the creation of "...The Delaware River and Bay Authority for the development [author's underscoring] of the area in both states bordering the said Delaware River and Bay [U.S. Congress, 1962]." The objectives were the planning and construction of crossings of the estuary with the potential for developing and managing transportation and terminal facilities and such other responsibilities as the two state legislatures might entrust to the DRBA. Moreover, all municipalities, political subdivisions, and every agency, department, or public body of each state were authorized to cooperate with, aid, and assist the work of the DRBA.

The importance of the river crossings to the economy and welfare of the two states, the need to consider population shifts and regional development priorities, and the impact of the operations of all ports and terminals in the area served by the DRBA, all validate the need for a bistate planning and development agency. No such agency presently exists south of the Delaware Memorial Bridge. The DRBA is the proper agency to become that bistate planning and development agency. Only the DRBA can bring together in one forum the fragmented and often incoherent plans of agencies or the local, county, and state levels in both Delaware and New Jersey for analysis and recommended actions.

Several examples of such regional activities exist. Because of its mandate to plan, develop, and promote commerce within its jurisdiction, the Port Authority of New York and New Jersey works closely with the Division of Coastal Resources (in the NJDEP) in the planning and development of large waterfront areas. Such activities led both the New York and New Jersey legislatures in 1978 to empower the Port Authority to develop an industrial park program for revitalization of the inner cities of the Port District and development of manufacturing sites. Although the Port Authority's program will entail an investment of over $1 billion in both public and private funds over the next decade, the Port Authority plans to invest $400 million on a self-supporting basis (U.S. Department of Commerce 1979). In early March 1983, the Department of Commerce's International Trade Administration ruled that state port authorities, as well as other local government bodies and new companies without previous business experience, may be certified as export trading companies. To stimulate more exports in its region, the Port Authority of New York-New Jersey took the initiative and applied for and received an export trading company certificate.

There are several other examples of regional planning agencies throughout the United States. The San Francisco Bay Conservation and Development Commission, first formed in 1965 and then instituted in 1969, has had substantial success in resolving conflicting environmental and regulatory issues, such as shoreline protection, water pollution, wetlands filling, and restricted beach access (Scott 1975). It conducts scientific-management studies; it plans for regional seaports, special areas (ecologically sensitive areas), energy facilities siting; and it issues permits for all projects involving filling, dredging, or shoreline alteration (San Francisco Bay Conservation and Development Commission 1978).

Concerns over the aesthetic value of Lake Tahoe and potential environmental deterioration from accelerating development along its banks spawned a series of studies out of which emerged the need for a regional planning agency of that bistate body of water. An interstate compact between California and Nevada instituted the Lake Tahoe Regional Planning Agency to prepare plans for and to issue regulations on all land use development in the Lake Tahoe Basin (Bosselman and Callies 1971).

The undertaking of such activities by the DRBA, however, would require additional studies and, if necessary, legislation. The Delaware Bay and Estuary as discussed in this report is a multiple-use resource which is shared by the states of New Jersey and Delaware. Research has shown that Delaware Bay is a unique estuary which should be conserved for future generations and one that can accommodate special kinds of marine-related development. There are inherent characteristics of the estuary that should be promoted. These include its role as a nursery ground for fish and shellfish, its attraction as a recreational resource, and its strategic location and geography for existing ports and developing ports.

Use of the Delaware Estuary must also be balanced, especially in situations where short-run gains could result in the forfeiture of long-run economic benefits. This is a concern of paramount importance given the fact that there is presently no comprehensive plan for the estuary that articulates specific development and conservation goals for the resource.

There is a tendency for planning agencies to begin work without long-term goals and financial support for continuing efforts. There is often a sheer lack of knowledge of the activities of other planning agencies, let alone technical and legal information about the requirements for development. Additionally, there is too often no liaison between planning and development agencies in the private and the public sectors that must eventually participate in development plans, not only as entrepreneurs but also as people whose domestic lives and livelihoods are affected by such development. The recommendation for the DRBA to assume the role of bistate planning and development for the Delaware Estuary is made with the suggestion that the DRBA methodically work into this role by starting with coordination functions. At a future date, after recognition of its coordination role, the DRBA would probably be in a position to fulfill a more formal planning and development role.

The role of coordinator is often thankless. Yet without a coordinator in regional planning and development the most earnest planning efforts wind up as unread documents that are never implemented for lack of unity, for lack of perseverance, and for lack of money. The DRBA could supply that need for initiative, for coordination, and for continuity that is so essential for the sound development of the region that it serves.

Chapter 16

ENVIRONMENTAL PROTECTION: INSTITUTIONS AND REGULATORY PROGRAMS

A.W. Wypyszinski

INTRODUCTION

In order to narrow the range of issues related to environmental protection in the Delaware Estuary, those federal, state, and local institutions will be described, as well as the regulatory programs, likely to be encountered by a developer or developers seeking permits and/or other authorization for projects in the lower Delaware Estuary.

This approach is based on an assumption that the Delaware River and Bay Authority (DRBA) has or could have a lead role in planning or development in the region. This was discussed in Chapter 15. The DRBA's financing and development experience could be put to good use by state agencies and by private investors; the environmental permitting process could be coordinated to benefit taxpayers and private investors; a comprehensive planning effort for selected areas could be directed by the DRBA; and, combining the scientific, management, and planning expertise available to the DRBA could result in a public/private forum for environmental dispute resolution or mediation. In any case, the present role of the DRBA as an environmental regulator is extremely limited by terms of the compact. On the other hand, environmental regulation as it affects economic development and activity in the region is of obvious interest and appropriate future roles would depend on concurrent legislation of the two states.

PROBLEMS

Government in the DRBA region is becoming more and more complex as the demand for coastal and marine resources continues to increase. As growth and change occur, the dimensions of jurisdictional zones also change, with a corresponding strain on intergovernmental relations (Marr 1979). Problems involving environmental regulation most often are related to the fact that federal, state, and local regulatory agencies administer a fragmented and overlapping system of licenses, permits, and direction of uses of air, water, and land resources. For development purposes, this system results in the expenditure of significant amounts of time, money, and energy, often in a duplication of efforts, to satisfy the regulatory requirements of the various agencies. Decisions, whether administrative or judicial, if not based on an adequate data base, are per se unsatisfactory.

Some form of state and local participation in program planning and implementation is assumed under terms of the Clean Air Act, the Federal Water Pollution Control Act (FWPCA), the Resource Conservation and Recovery Act (RCRA), the Flood Disaster Protection Act, and the Coastal Zone Management Act (CZMA), among others. Environmental management programs are nonetheless difficult to develop and implement since each of the programs above is implicitly or explicitly based on an assumption that state and local governments are not performing adequately with respect to environmental management concerns.

Fragmented jurisdictions, even if overlapping, remain essentially limited. There is no agency or unit of government in the bistate region with the mission or authority to prepare a comprehensive land, air, and water use policy developed from a perspective of examining and treating the Delaware Estuary as a system.

The time and cost of litigation or potential litigation often acts as a constraint on development, whether or not a plan is environmentally sound. By developing the "best available" information pertaining to the Delaware Estuary region and a comprehensive policy related to exploitation and protection of environmental resources, the DRBA could provide an alternative dispute resolution mechanism.

Most projects in the lower Delaware Estuary require a number of permits from a number of agencies at each level of government. The two key federal permits, Section 10 of the Rivers and Harbors Act and Section 404 of the FWPCA, have been consolidated and are administered by the U.S. Army Corps of Engineers (USACE). Issuance of these permits is contingent on state certification that federal approval is consistent with state coastal zone management programs (by terms of the CZMA and Section 401 of the FWPCA). Each state also administers separate environmental permitting programs. The most widely employed form of land-use control is zoning which is normally administered at local or county level. Finally, federal environmental agencies are given the opportunity to evaluate and comment on applications for USACE permits. Realistically, a developer most often must comply with conditions imposed by these agencies as a prerequisite to approval of an application.

FEDERAL PROGRAMS AND AGENCIES

Involvement of federal agencies in the Delaware Estuary area extends from the coastal rim to the high seas. Historic federal interests include national defense, international relations, maritime commerce, and more recently, environmental protection. Management agencies include those responsible for fisheries, maritime commerce, maintenance of navigation, management of navigation, management of federal properties, and the operation of national recreational sites. The Departments of Defense, Commerce, and Interior carry out management responsibilities for land and water resources of the Delaware Estuary. Although federal legislation provides the states with the rights to income from mineral production, the right to engage in fisheries regulation, and the right to regulate environmental quality in the territorial sea, the federal government maintains a distinct presence in this area as well.

U.S. Army Corps of Engineers

Primary functions of the USACE in the Delaware Estuary region include: (1) improvement and maintenance of harbors and navigation channels; (2) beach erosion control; and (3) issuance (or non-issuance) of dredging, filling, and construction permits in navigable waters.

Since 1824, responsibility for construction and maintenance of waterways-related public works has been the traditional role of the USACE, which remains the primary federal agency in this role. The USACE authority was expanded by the Rivers and Harbors Act of 1899 to include control over private construction and other activities affecting or potentially affecting the navigable waters of the nation. During the history of the Rivers and Harbors Act and with the permitting authority given to the Corps by Section 10 of that act, the only criterion used to evaluate a Section 10 permit application was the potential effect of a project on navigation. With the advent of the environmental movement in the U.S. during the late 1960s and early 1970s, USACE authority was further extended when dredge spoil and other forms of discharges into navigable waters were determined to require USACE Section 10 permits.

The environmental regulatory responsibilities of the USACE were also enhanced with passage of the Federal Water Pollution Control Act of 1972 (now the Clean Water Act of 1977). Regulation of dredge and fill operations in the waters of the U.S. is controlled by the FWPCA Section 404 permit process. A 404 permit is evaluated by the USACE according to guidelines prepared by the U.S. Environmental Protection Agency (EPA), which has veto power over USACE decisions to issue permits for dredge and fill activities.

Projects are no longer evaluated solely on navigational criteria. The USACE permit decision is basically an evaluation of whether the benefits of a project outweigh the costs. Economics, aesthetics, environmental concerns, historic values, water supply, fish and wildlife values, flood-damage prevention, land-use classifications, and water-quality criteria are employed in cost-benefit analyses. Permit applications are also evaluated according to: (1) the public and/or private need for the proposed project; (2) the desirability and availability of alternative locations; (3) the extent of long-term benefits and costs; and (4) the effects of cumulative impacts (33 C.F.R - 209.120).

Special review policies have been adopted by the USACE for projects proposed to be located in wetland environments (defined as land and water areas subject to regular inundation by tidal, riverine, or lacustrine flowage). The unnecessary alteration or destruction is discouraged of wetlands which are: (1) important habitat for aquatic and land species; (2) important sanctuaries, refuges, or sites for study; (3) significant for protecting other areas from wave action, erosion, or storm damage; or (4) prime natural recharge areas (33 C.F.R. - 209.120).

A number of other federal agencies are given the opportunity to review, evaluate, and comment on applications for USACE permits. Comments from appropriate state and local agencies are also solicited. As a matter of policy, the USACE does not issue a permit when another federal, state, or local agency required by law to authorize a proposal has not done so or refuses to do so. Considerable weight is given to comments received from state, regional, or local agencies even when official approval is not required by law (33 C.F.R. - 209.120). The roles of the EPA, the U.S. Fish and Wildlife Service, and the National Marine Fisheries Service are of particular importance in the USACE permit review process, and will be discussed below.

In addition to the regulatory permit programs administered under the Rivers and Harbors Act of 1899 and the Clean Water Act of 1977, the USACE, in the Delaware Estuary as well as other navigable waters, is engaged in a Civil Works Program.

The USACE directs individual public works projects authorized by Congress for purposes such as flood control, navigation, shore protection, enhancement of fish and wildlife resources, water storage for irrigation, and water quality control (USACE 1981).

U.S. Environmental Protection Agency

Among the most important provisions of federal legislation are the requirements that all federal agencies give full consideration to environmental effects in planning and carrying out their programs. More specifically, the National Environmental Policy Act (NEPA) requires all federal agencies to conform to strict procedural requirements when making decisions significantly affecting the quality of the environment. The Act declares it to be the continuing policy of the federal government"... to use all practicable means and measures... to create and maintain conditions under which man and nature can exist in harmony, and fulfill the social, economic and other requirements of present and future generations of Americans."

An environmental impact statement must be prepared for every federal action that might significantly affect the quality of the human environment. The statement is required to address any adverse environmental impacts that cannot be avoided should the proposal be implemented, the alternatives to the proposed action, the relationship between local short-term benefits and the enhancement of long-term productivity, and any irreversible and irretrievable commitment of resources involved in the proposed action. Environmental impact statements must be circulated to other federal agencies, to state and local governments, and to the public. Federal agencies (such as the USACE) that perform services or build and finance facilities are most directly affected by the provisions of NEPA.

A second important feature of the NEPA was the creation of the EPA. The EPA prepares guidelines for the USACE Article 404 permit application review. It has primary federal responsibility for regulation of water pollution; establishes criteria and administers an enforcement program to protect against pollution of interstate and navigable waters from municipal and industrial discharges and from ships in the territorial sea and in the contiguous zone, and issues permits for dumping sewage sludge, industrial wastes, and dredge spoils outside of the territorial sea. EPA is also responsible for formulation of regulations pertinent to drilling platforms on the outer continental shelf.

National Marine Fisheries Service

While the primary responsibility of the National Marine Fisheries Service (NMFS) is the regulation and licensing of foreign fishing in the fishery conservation zone and the development of fisheries information and fisheries management programs, NMFS also plays a role in the environmental regulation and permitting process by reviewing applications for permits to assess the potential impact on (marine) fisheries.

Fish and Wildlife Service

Protection of fish and wildlife resources on coastal wetlands, reduction of habitat damage, and improvement of coastal zone fish and wildlife resources are the primary responsibilities of the Fish and Wildlife Service (FWS), which is also responsible for assessing the effects of proposed development projects on fish and wildlife and conservation of estuarine environments.

U.S. Coast Guard

The U.S. Coast Guard (USCG) acts in concert with NMFS in enforcement of compliance by foreign fishermen with agreements to protect fish stocks. The USCG is also responsible for installation of aids to navigation, licensing of commercial and recreational boats, and review of outer continental shelf platform siting and personnel and equipment safety. The USCG has limited regulatory authority over the oil lightering activity in the lower estuary (see Chapter 19) through their oil spill monitoring responsibilities.

Other

The federal presence extends to virtually every area and activity in the region. Other permit-granting agencies in the region include the Federal Energy Administration (permits for offshore drilling); the Occupational Health and Safety Administration (working conditions on platforms); Bureau of Land Management; the Public Health Service; the Interstate Commerce Commission (regulation of oil transmission); and the Federal Power Commission (natural gas transmission in pipelines).

STATE PROGRAMS AND AGENCIES

Coastal zone management refers to the comprehensive management of many uses and resources within a defined region or zone. Coastal zone management typically is concerned with managing conflicts among many users and determining the most appropriate use of coastal resources (Hershman and Feldman 1979). Questions of beach access, shore erosion and protection, wetlands protection, and protection of water quality can broadly be defined as coastal management problems, but the fundamental purpose of a Coastal Zone Management Program (CZMP) is to strike a balance between environmental values and economic development demands (Wypyszinski 1981b).

With passage of the Coastal Zone Management Act (CZMA) of 1972, Congress declared the following to be national policy: (1) to preserve, develop, and where possible, to restore or enhance, the resources of the nation's coastal zone for this and succeeding generations; and (2) to encourage and assist the states to exercise effectively their responsibilities in the coastal zone through the development and implementation of management programs to achieve wise use of the land and water resources of the coastal zone.

Both Delaware and New Jersey have developed approved CZMPs designed according to federal guidelines and evaluated and monitored by the National Oceanic and Atmospheric Administration (NOAA) Office of Coastal Zone Management (OCZM). There are four key attributes to the federal program which are noteworthy: (1) The CZMA authorized a federally supported grant assistance program for comprehensive planning and management. (2) The focus of the CZMA is on state government, providing impetus and assistance to state action in partnership with local governments. (3) The CZMA attempts to balance ecological and economic needs, giving full consideration to ecological, cultural, historic, and aesthetic values as well as to needs for economic development. (4) Explicit provision is made for intergovernmental coordination and cooperation (Johnson and Goldsmith 1977).

It was recognized by Congress that local and even state governments could not focus on a large enough area and that the federal government did not have the resources to focus on a small enough area (Wypyszinski 1981a). Section 302 (h) of CZMA declares that "(t)he key to more effective protection and use of the land and water resources of the coastal zone is to encourage the states to exercise their full authority over the lands and waters in the coastal zone by assisting the states, in cooperation with federal and local governments <u>and other vitally affected interests</u> [author's emphasis], in developing land and water use programs for the coastal zone, including unified policies, criteria, standards, methods, and processes for dealing with land and water use decisions of more than local significance."

NEW JERSEY COASTAL ZONE MANAGEMENT PROGRAM

Designed in two portions, the final New Jersey Coastal Management Program and Final Environmental Impact Statement (EIS) was approved by the U.S. OCZM in September of 1980.

Substantive regulatory provisions of the CZMP "network" include three pieces of legislation: the Waterfront Development Act, the Wetlands Act, and the Coastal Area Facility Review Act (CAFRA). To make the plan functional, to increase the predictability of coastal decision-making as well as to limit administrative discretion, policies have been adopted by the Department of Environment Resources Bureau of Coastal Planning and Development as administrative rules.

A three-step process has evolved: location, use, and resource policies are employed separately in making final decisions. Specific policies in each of the three steps may be applicable depending on the proposed use, project design, location, and surrounding region. The CZMP states that "these policies represent the consideration of various conflicting, competing, and contradictory local, state, and national interests in diverse coastal resources and in diverse uses of coastal locations." Boiled down to essentials the statement means that while the Department of Environmental Protection (DEP) will consider different points of view, it has assumed the delegated responsibility of deciding what will happen to the New Jersey coast. The three coastal permit programs were authorized by the previously mentioned Waterfront Development Act, Wetlands Act, and CAFRA (Goldshore 1979).

A waterfront development permit allows DEP to regulate the construction or alteration of a dock, wharf, pier, or similar development on or adjacent to navigable waterways or streams. The waterfront regulated includes both the tidal waterway and the land adjacent to it inland between 100 and 500 feet. Persons applying to the DEP Division of Coastal Resources for a permit must first hold a valid tidelands grant, lease, or license for the tide-flow portion of a site. In addition to the activities listed above any construction, reconstruction, structure, or land or extension of land requires a waterfront development permit.

Wetland permits are required for any coastal wetlands which are those subject to tidal action along specified water bodies (including Delaware Estuary). Regulated coastal wetlands are those designated as such on maps promulgated by the DEP and filed following notice to affected property owners and a public hearing. By 1972 this process was essentially complete. Also administered by the DEP Division of Coastal Resources, the wetlands permit allows the state to regulate virtually all types of development and any form of disturbance on mapped coastal wetlands, except for mosquito control and some forms of agricultural activity.

Approval of location, design, and construction of major facilities in an area which includes coastal waters, barrier beach islands, all of the state's coastal resort areas, and portions of the Pinelands, is evidenced by issuance of a CAFRA permit. The types of facilities which require CAFRA permits include: (1) marine terminals, cargo handling and storage facilities; (2) food and food by-products, paper and agrichemical production; (3) electric power generation, including oil, gas, coal-fired or nuclear; (4) public facilities, including housing developments of 25 or more dwelling units (a major loophole), roads and airports, parking facilities of 300 spaces or more, wastewater treatment systems and components, and sanitary landfills; and (5) mineral products, chemical and metallurgical processes.

The area of jurisdiction of CAFRA, the Wetlands Permit, and the Waterfront Development Permit (in essence the New Jersey coastal zone), encompasses 17% of New Jersey's land mass, about 1,792 miles of tidal coastline. An application for a CAFRA permit requires submission of an EIS, and a public hearing and evaluation of the EIS by other DEP division and state agencies before a decision is made on the application. There are a number of related programs in NJCZMP.

The DEP Division of Water Resources is responsible for water quality planning and maintenance, water supply, and flood plain management. The division has the authority to regulate the building or alteration of structures within stream areas and to regulate development and land use in designated floodways under the Flood Hazard Areas Control Act (NJSA 58:16A-50 et seq.). In addition, this division has authority over canals, dams, drainage basins, flood control, flood plains, landfills, potable water reservoirs, septic tanks, sewerage systems, shellfish harvest areas, soil conservation, stream encroachment, and water supplies. It is responsible for supervising the development of the State Water Supply Master Plan. It is the designated water-quality planning agency under Section 208 of the Federal Clean Water Act. In addition, it has authority under provisions of the New Jersey Water Pollution Control Act (NJSA 58:10A-1) to administer NPDES permits (EPA delegated this responsibility to DEP in April of 1982). Standards set by the Division of Water Resources under the Clean Water Act are incorporated into the CZMP.

The DEP Division of Environmental Quality supervises air quality planning and monitoring and is the agency designated to administer the Federal Clean Air Act in New Jersey. It is also responsible for the state's radiation, noise, pesticide control, and solid waste management programs.

The Division of Parks and Forestry is responsible for operating, maintaining, and acquiring historic sites and state parks. The division reviews CAFRA permit applications and coordinates park and recreation policies with the Division of Coastal Resources.

The Green Acres Administration develops a comprehensive recreation plan and works with the Division of Parks and Forests and the Division of Fish, Game and Wildlife to identify and rank possible sites to be purchased with Green Acre funds. Major policies include emphasizing open space in urban areas, developing recreation facilities, increasing public access to recreation resources through mass transit, and developing barrier free recreation facilities.

The New Jersey Department of Energy has broad planning authority over energy-related matters, including the regulation and planning of energy facilities. The department participates in energy-facility siting decision-making, and is the lead agency for the Coastal Energy Impact Program (CEIP), established to provide federal financial assistance to coastal states to respond to the growth and impacts of new energy exploration and development. The department is also responsible for planning and development of the State Energy Master Plan (formally adopted in October 1978) which deals with production, consumption, distribution, and conservation of energy.

The Board of Public Utilities has broad regulatory authority over public utilities, including the power to supersede local zoning decisions.

DELAWARE COASTAL ZONE MANAGEMENT PROGRAM

The State of Delaware has made the decision to preserve the environmental integrity of its coastal region and to devote this area primarily to recreation and tourism. Since June 1971, the State of Delaware has taken significant regulatory steps in coastal land use management through passage of three laws, "networked" into the federally approved CZMP. Formerly developed and administered by the Environmental Policy Section of the Delaware State Office of Management, Budget and Planning (OMBP), and now by the Department of Natural Resources and Environmental Control (DNREC), the CZMP provides for regulation of an area which extends from the limits of the territorial sea inland across beach areas and wetlands to a statutorily defined line, generally the first state highway more or less parallel to the coast. The statutory scheme thus provides for industrial regulation in the coastal zone, beach preservation and wetlands preservation (Pedrick 1976).

The Coastal Zone Act (7 Del. Code Ann., Section 7001 et seq.) was passed to prohibit the construction of new heavy industry and offshore bulk-transfer facilities in the coastal zone. The act has been surrounded with controversy since its passage. It defines prohibited heavy industries and types of expansion or extension projects of pre-existing industrial facilities which require permits. Industrial development not classed as heavy industry also requires a coastal zone permit.

Applications must contain: (1) evidence of approval by the appropriate county or municipal authorities; (2) detailed description of the proposed construction and operation of the project; and (3) an EIS that evaluates the "effect of the proposed land use on the immediate and surrounding environment and natural resources such as water quality, fisheries, wildlife, and aesthetics of the region." Permit decisions are based on: (1) environmental impact (comments are solicited from interested offices in DNREC); (2) economic effect, including the effect on jobs; (3) aesthetic effect; (4) supporting facilities required; (5) effect on neighboring land uses; and (6) effect on local comprehensive plans.

A Coastal Zone Industrial Control Board is empowered to hear appeals from adverse decisions of the OMBD. Either the OMBD or "any aggrieved person" may appeal an adverse Industrial Control Board decision to the Superior Court, which has exclusive original jurisdiction over violations.

The Beach Preservation Act (7 Del. Code Ann., Section 6801 et seq.) was passed to empower the state to prevent damaging alteration to the protective primary dune line. The object of the act as stated is to "enhance, preserve, and protect the public and private beaches of the State of Delaware, to prevent beach erosion and to make certain acts destructive of beaches punishable as crimes..." The beach thus protected extends from mean low water inland for 1000 feet or to a currently established improved roadway, whichever is closer. Since private property ownership in Delaware extends to mean low water in tidal areas, the act limits uses of private property as well as public property.

Any project making a "substantial change in the existing charcteristics of any beach" requires a permit from the DNREC Division of Soil and Water Conservation. Adverse decisions may be appealed to the secretary of DNREC, and then to the Superior Court. Original jurisdiction to hear cases involving alleged violations of the act is in the Justice Court.

The Delaware Coastal Wetlands Act (7 Del. Code Ann., Section 6601 et seq.) gives the state complete control of land use within the coastal salt marsh. The object of the act is "to preserve and protect the productive public and private wetlands and to prevent their despoliation and destruction...." All dredging, draining, filling, dumping, bulkheading, and construction activities, including the expansion of a pre-existing use on regulated wetlands, with specified exceptions, requires a permit issued by the DNREC. An application must have prior approval of county and municipal zoning authorities before it will be reviewed by the DNREC. Permit decisions are based on essentially the same criteria as coastal zone permit decisions. A Wetlands Appeals Board may affirm or reverse a decision of the Secretary of the DNREC. A board action (or failure to act within 90 days) may be appealed to the Superior Court, which also has jurisdiction over offenses.

All submerged lands covered by the territorial sea or inland waters and all lands covered by tidal and navigable waters belong to the state, pursuant to the Public Trust doctrine. Uses of such land by private parties or by another state agency requires a permit, lease, or grant issued by the DNREC, which requires that projects have a minimum detrimental effect on water quality, navigation, fish and wildlife, and public and riparian rights. Subaqueous projects requiring approval include, among other projects, any dredging or filling, including filling of lands adjacent to public subaqueous lands, any excavation planned to connect with public subaqueous land, and the erection of any structure.

Administration of the National Pollution Discharge Elimination System (NPDES) program has been delegated by the EPA to the DNREC. Discharges of pollutants from any point source are regulated through this permit system.

THE DELAWARE RIVER BASIN COMMISSION

The Delaware River Basin Commission (DRBC) is a joint agency of New York, Pennsylvania, New Jersey, and Delaware. The Delaware River Basin Compact mandates that "the commission shall develop and adopt and may from time to time review and revise a comprehensive plan for the immediate and long-range development and use of the water resources of the basin." Subsequent to a U.S. Supreme Court decree that (regional chief executives) "enter into serious good faith discussions to establish the arrangements, procedures, and criteria for management of the water [author's emphasis] of the Delaware River consistent with the terms of the Compact," on 23 February 1983 the Governors of New York, Pennsylvania, New Jersey, and Delaware, as well as the mayor of New York City, announced an agreement for management of water resources in the Delaware River Basin. Accordingly, the DRBC was presented with a set of recommendations designed to apportion available water during shortages, assure that stream flow levels repel ocean water salt during droughts, protect fisheries and recreational uses, institute mandatory conservation measures, and support development of water supply storage at four existing reservoir projects (DRBC 1982).

In addition, the DRBC has for two decades established water quality standards and, based on models of the assimilative capacity of the Delaware River, allocated wastewater load levels to the states. Major industrial and other projects with potential adverse effects on water quality are subject to the DRBC review. Project approval is generally withheld pending approval of state permit applications, and the DRBC comments are also solicited as part of both state and federal permitting processes.

LOCAL PROGRAMS AND AGENCIES

Land-use planning traditionally has been a responsibility of local government. Most state governments have delegated land use and management authority to local governments, although the trend, particularly with growth of the environmental movement, has been to reassert state authority over land management and use policy. Zoning remains the most common form of control.

Coastal states with CZMPs have continued this trend by developing more or less comprehensive policies directed at coastal land use (and resource use in general). A good deal of contention has resulted from the debate over whether primary land-use planning responsibility should lie with state or with local authorities (Hildreth and Johnson 1980).

Zoning in New Jersey remains primarily a local (township) responsibility, although, obviously, obtaining local building permits does not insure that coastal zone permits will be approved. The Department of Community Affairs Division of State and Regional Planning has prepared a Development Guide Plan. The Development Guide divides the entire state, including the coastal zone into growth areas and limited growth areas (see Chapter 15). While local decisions need not necessarily conform to the state plan, state contributions to the cost of infrastructure (sewers, roads, etc.) are determined according to Development Guide priorities. The lack of state-wide land-use controls in New Jersey is mitigated somewhat by the coastal zone management plan, which through its permitting procedures established goals, priorities, and conforming uses according to environment criteria.

Another factor limiting local and municipal discretion in land-use decision-making in New Jersey was created by the passage of the Pinelands Protection Act of 1979, which created a state planning area which includes almost a million acres in southern New Jersey, including coastal areas in Cape May and Cumberland counties which are within the DRBA region. A Comprehensive Management Plan for the Pinelands was adopted on 21 November 1980, which requires all counties and municipalities within the management area to revise master plans and zoning ordinances to conform to the plan. The management plan also establishes sixteen management programs which govern protection of air and water quality, vegetation, wetlands, wildlife, scenic and cultural resources, agriculture and other environmental characteristics (Pinelands Commission 1981).

The Coastal Zone Management Plan in Delaware was designated in part to be the state land use plan with authority to supersede any local planning responsibilities. Regulations have yet to be developed to implement this facet of the Delaware CZMP.

ROLES FOR THE DRBA IN ENVIRONMENTAL PROTECTION

Large areas of the DRBA region consist of beach and dune formations, wetlands, and other sensitive ecosystems. Prospective developers of virtually any project to be located in the region must contend with a veritable maze of regulatory requirements designed to protect the environment by establishing a balance between development needs and environmental needs.

It is extremely difficult to establish an accurate account of the federal presence in the DRBA region, particularly since the environmental movement in recent years has changed the nature and complexity of federal involvement. Federal authority to manage coastal resources is derived from specific powers enumerated in the U.S. Constitution, principally the commerce power. Expansive judicial interpretation of the commerce power allows the federal government to regulate navigational improvements, beach erosion control programs, dredging, filling and construction in navigable waters, water pollution, and wetlands uses, among other things. The USACE is the principal actor in the federal regulatory regime in the coastal area, although the U.S. Fish and Wildlife Service, the NMFS, and the EPA also play major roles in environmental regulation and protection. It is important to note that presently only the Coast Guard has regulatory authority over oil lightering activities and would be the only federal regulator of proposed coal transfer activities (see Chapter 19).

Both Delaware and New Jersey have designed coastal zone management programs which have been approved by the OCZM in the U.S. Department of Commerce. While approval of the individual programs was contingent on their meeting several criteria established by the OCZM, the states were allowed to develop their own programs and policies to meet those criteria. For this reason the focus and approach of the two CZMPs differ slightly. For example, the Delaware Coastal Zone act has as an objective the prohibition of new heavy industry in the coastal region and the severe restriction of expansion of existing heavy industry. The New Jersey CAFRA does not contain an outright prohibition, but requires a detailed, careful examination of all issues involved in siting of major facilities in the coastal zone. Neither state exerts any authority over cargo transfer (oil, coal) within the estuary itself.

Comprehensive planning for the coastal zone, as well as implementation of the CZMPs is the responsibility of the Office of Coastal Planning and Development of the DEP in New Jersey and the Environmental Policy Section of the OMBD in Delaware. In addition, a number of narrower, mission-oriented programs are administered by other agencies in both states.

Local units of government are also involved to a degree in the development, management, and regulation of the DRBA region. Local construction and building permits are required for projects located in the coastal zone (as elsewhere). Furthermore, evidence of local authority approval of a project is required prior to issuance of a coastal zone permit in Delaware; the opportunity for local authorities to comment on permit applications is provided for in the New Jersey permitting process.

There are two principal regional agencies involved in the management and regulation of resources in the Delaware Estuary. The DRBC is primarily concerned with the preservation and enhancement of water quality, development of water supply storage, conservation measures, and assuring stream flow levels. The primary focus of the DRBC is management of the water. The states of New York, Pennsylvania, New Jersey, and Delaware are represented on the DRBC.

The DRBA is at present the only Delaware-New Jersey institution with legally defined responsibilities directed at the region below the Delaware Memorial Bridge as a management unit. The DRBA has been charged by terms of the compact with planning, financing, development, construction, purchase, lease, maintenance, improvement, and operation of crossings and of transportation or terminal facilities in the region. The compact further provides for an expanded role and the performance of additional appropriate functions.

Three recommendations are made on potential roles for the DRBA.

(1) The DRBA should serve in an advisory and guidance capacity on water management, coastal zone management, regulatory compliance, and other matters involved in use of the environment. It is a role that is an obvious outgrowth of the DRBA as the major supporter of the Delaware Estuary Project.

Development and refinement of water and coastal zone management policies in the DRBA region are primarily the responsibility of state agencies both in Delaware and in New Jersey. Periodic review and reevaluation of existing policies occur as circumstances dictate and as new information becomes available. As the repository of "best available" information (both scientific and management) for the Delaware Estuary, the DRBA could play a role in identifying inconsistencies in the two programs, in identifying development and environmental protection needs peculiar to the area, in participating in public hearings, and in commenting on proposed revision of existing CZM policies and development of new policies.

The sheer weight of regulatory and permitting requirements at federal, state, and local levels of government acts as a disincentive to development, particularly small- and medium-size projects (Wypyszinski 1983). Constraints affect private developers as well as public agencies. Not only industrial and commercial development is affected, but also development of recreational areas, marinas, small-boat launching sites, and other less environmentally disruptive activities. The DRBA, again as the repository of extensive planning and development expertise, as well as best available scientific information, could give guidance to those developing projects that require regulatory and permitting information. This would be part of a broader regional planning and development function.

Joint public/private ventures have achieved a measure of success in various locations in the U.S. The redevelopment of the Boston and Baltimore waterfront areas was directed by joint public/private or quasi-public institutions. The Port Authority of New York-New Jersey has assumed a multi-use development role pursuant to joint legislative authorization. The DRBA could examine and evaluate the structure of individual institutions as they emerge in the estuarine region and the potential applicability of individual projects to development in the region. This role is a part of larger role of a planning and development agency as suggested in Chapter 15.

(2) Although some form of environmental mediation is probably needed, this role would appear to fall outside the present mandate and even beyond other functions originally considered for the DRBA (DRBA 1975). However, through inclusion of this subject in this report, the DRBA can advocate sound environmental mediation to resolve environmental conflicts.

A major constraint of the environmental permitting process is the time and cost of dispute resolution, and particularly of litigation (Busterud 1980). Normally, dispute or conflict resolution requires first the exhaustion of administrative remedies (federal, state, or local), then, the initiation of the litigation process. While administrative decision-making is governed by time limits set by legislation, judicial decision-making is not so constrained. Initial hearings in some cases occur literally years after a case is filed, with additional years required to pursue a final decision through the appellate courts. Very often, neither lawyers nor judges are sufficiently trained or prepared to properly evaluate scientific and technical data necessary for the proper analysis of disputes in the area of environmental regulation.

A number of alternative dispute resolution mechanisms have emerged in recent years in response to backlogged court dockets and other limitations of the judicial system. These mechanisms do not replace the court system as the final authority in conflict resolution, but are designed to allow negotiation or mediation prior to actual litigation (Cormick 1976). The most common form of this type of intervention is labor-dispute mediation; another common form is family-dispute mediation.

There has been increased interest in recent years in the subject of environmental mediation as an alternative form of environmental conflict resolution (Cormick 1980). A critical element is the establishment of credibility in the mediation structure. As a bistate institution, with a distinct role separate from the federal, state, and local regulatory agencies, and once again as the repository of best available scientific information, the DRBA should advocate environmental mediation based on sound information.

(3) The DRBA should seek a permitting role for cargo transfer in the lower estuary. Oil lightering presently takes place with no regional or state regulations and only limited federal control by the U.S. Coast Guard. Oil lightering has successfully been self-regulating (see Chapter 19). However with the potential of extensive coal transfer and the declaration by the Coast Guard that, even uncontrolled, this transfer activity poses no environmental threat (Silberman 1983), it may be appropriate for some regional agency to have an overview of this operation. In order for coal transfer to not pose an environmental threat, some rules are necessary as opposed to uncontrolled transfer operations. It had been previously suggested that the DRBA have a regulatory role in oil transfer (Delaware Bay Oil Transport Committee 1973a) and this idea should now be considered again. Actual regulatory activity should probably be left to the states of Delaware and New Jersey. However, in a permitting role, the DRBA, with an environmental and economic overview could

give guidance and set rules. This role would clearly require concurrent legislation from the States of Delaware and New Jersey. There are precedents for regional agencies serving in both planning and permitting roles as was noted for the San Francisco Bay Conservation and Development Commission and the Lake Tahoe Regional Planning Agency (see Chapter 15).

Chapter 17

THE MANAGEMENT OF FISHERIES

A.T. Manus, S.L. Scotto

INTRODUCTION

Discussions of natural resource harvesting from the ocean and adjacent waters usually are separated into non-living and living resources. In the Delaware Estuary, there are two small successful industries extracting magnesium from the water near the mouth of the estuary. Other than these, essentially all other natural resource harvesting deals with living resources and can be considered in the category of fisheries.

In recent years there has been an increasing recognition of the importance of fisheries resources and the need to manage the species indigenous to the mid-Atlantic region. While regional fishery management councils under the Fishery Conservation and Management Act of 1976 have made headway within waters from 3 to 200 miles from shore, fish stocks within each state's internal waters and three-mile boundary are managed by the respective states. This is a particularly acute problem within the Delaware Estuary because the current situation is clouded with respect to bistate fisheries management within the bay itself.

In determining a potential role for the Delaware River and Bay Authority (DRBA) involvement in fisheries, two specific areas of concern, fisheries management and fisheries development, are discussed. For the purposes of this chapter, fisheries management is defined as acquiring an understanding of all aspects of fish populations (i.e., growth and reproduction, feeding habits, migration, predator-prey interactions, and fishing pressure) that lead to the enactment of regulations to manage fishing. Fisheries development refers to providing opportunities, support facilities, and/or coordination that encourage growth in either recreational or commercial fisheries. The distinction between these two terms is important to understand in determining what role, if any, the DRBA has with respect to the fisheries resources of Delaware Bay.

This chapter is organized with discussions first of commercial fisheries in the two states, followed by recreational fisheries, legislative and regulatory regimes, and finally, potential roles for the DRBA.

NEW JERSEY COMMERCIAL FISHERIES

Port Norris-Bivalve

Port Norris-Bivalve is Cumberland County's major port and the seat of the shellfish industry. Maximum employment is 500 to 750 people, including 200 to 250 oystermen; 60 gillnetters, crabbers, and eelers; a minimum of 10 dock workers; and 250 wholesalers, processors, and administrators (Table 17-1).

These are inshore bay fisheries, completely dependent upon the Delaware Bay and its tributaries. Oysters and blue crabs account for 90% of the annual landings. In 1979, of the 2.5 million pounds of all species landed in Cumberland County, 1.7 million pounds were oyster meat and almost 0.5 million pounds were blue crabs. Other species harvested include weakfish, menhaden, striped bass, shad, carp, eel, bluefish, white perch, catfish, croaker, spot, terrapin, and snapping turtle, with a dockside value of approximately $50,000 annually.

Table 17-1. Fishermen and boats in the New Jersey commercial fisheries. Data from Caruso (1982).

Fishery	Fishermen	Boats
Cape May Harbor		
Clam	128	32
Scallop	135	9
Trawl	137	26
Lobster	18	6
Gill net	4	2
Eel	8	8
Blue crab	6	3
Port Norris-Bivalve		
Oyster	240	60
Gill net	40	20
Crab	10	10
Total for the Delaware Bay	726	176

There are 53 fishermen in Port Norris-Bivalve licensed to operate oyster dredge boats. However, because individuals may own more than one boat under each license, the actual number of working boats may be closer to 60. In 1979, the wholesale processed value of oysters to Port Norris-Bivalve was $7 million.

This port has processing facilities for oyster shucking and packing, and clam shucking and processing. The markets available to this port include major East Coast cities and Canada, in addition to the foreign markets of West Germany, Austria, Switzerland, Belgium, France, and the Netherlands. The replacement value of the oyster industry is approximately $19.4 million, with boats and equipment worth $11 million and docks and processing equipment worth $8.4 million. Annual wages to Port Norris-Bivalve fishermen total more than $3.1 million.

This port has still not recovered from the effects of MSX disease (see Chapter 13) on the oyster industry. Docks today remain abandoned and in disrepair. Another problem is competition for leased oyster-rearing bottom.

The heavy use of Delaware Estuary water by upstream municipalities could also have an effect on the oyster industry by causing the landward migration of the salt line (see Chapter 2), causing an increase in salinity and an increase in MSX disease and predation by oyster drills (Caruso 1982).

Cape May-Wildwood Port

Cape May-Wildwood is New Jersey's largest commercial fishing port. It has 12 major docks that handle 50 to 150 fishing vessels and two processing plants. More than 800 people are employed as fishermen, onshore workers, processors, and wholesalers during periods of peak activity. Table 17-1 shows numbers of fishermen and boats per fishery.

The major fish species landed at Cape May-Wildwood include weakfish, summer flounder, blackback flounder, Atlantic mackerel, croaker, scup, sea bass, bluefin tuna, whiting, surf clam, ocean quahog, and sea scallop (see Chapter 12). The Delaware Bay fisheries include gillnetting, eel fishing, and crabbing. Due to the long distance from Cape May Harbor to Delaware Bay via the Cape May Canal, very few baymen dock their boats in the harbor. Instead, most dock their vessels at marinas or private residences along Cape May's bayshore.

Cape May-Wildwood has processing facilities and access to many state and East Coast markets, in addition to the foreign markets of Japan and France. The replacement value to Cape May-Wildwood's commercial fisheries is estimated to be in excess of $65 million, which includes land, docks, equipment, processing facilities, boats, and fishing gear.

Many fishermen at this port consider intervention by state and federal management agencies unnecessary and intrusive. They maintain that the fishing industry is self-regulating, in that fishermen will no longer pursue a species that has declined to the point of being unprofitable. Entrance into crowded fisheries is limited by access to commercial docks and markets and by the high cost of boats (Caruso 1982).

DELAWARE COMMERCIAL FISHERIES

In 1982, the Delaware Division of Fish and Wildlife surveyed the commercial finfisheries in the state. Included in this effort was a documentation of total catch in weight, total effort, and a determination of the magnitude and importance of commercial finfisheries in Delaware. During the study period from 1 January to 31 December 1982, 45 commercial gillnet crews were identified in Delaware (Seagraves and Rockland 1983b).

Tables 17-2 and 17-3 reveal by species the respective primary economic impact and analysis of the activity in the State of Delaware. According to Seagraves and Rockland (1983b), "When the primary effects from [Table 17-2] are multiplied by the relevant multipliers from the input-output model, a total output of $2,172,511 is estimated for trout. This amount involved 87.79 jobs which resulted in $846,871 in wages. Value added resulting from the sale of trout in 1982 was $1,303,481" (Table 17-3). This type of analysis was conducted for the other species indicated. As an industry, gillnetting produced $3.3 million in economic activity in 1982 (Seagraves and Rockland 1983b).

NEW JERSEY RECREATIONAL FISHERIES

A survey of New Jersey's recreational fisheries industry was conducted in 1980-81 by New Jersey's Fish, Game and Wildlife Division of the Department of Environmental Protection. Its survey of the spring fishery in Delaware Bay for the months of April and May showed that the average expenditures for a fishing day per participant totaled $44.33. Total participation in the two-month spring fishery generated approximately $4.9 million in angler expenditures in the State of New Jersey (Figley and McClain 1981).

In 1980, the Division of Fish, Game and Wildlife conducted a survey of recreational shellfishermen. For the entire state, 28,000 of the 30,420 licensed shellfishermen harvested shellfish for recreation. An additional 1,200 shellfished primarily for sport, but sold some of their catch. A total

Table 17-2. Primary economic impact of gillnetting in the Delaware Estuary on the State of Delaware, 1982. Data from Seagraves and Rockland (1983b).

Species	Fishermen	Wholesaler	Retailer	Restaurant	Total
Trout	$657,737	$230,335	$237,642	$335,894	$1,461,607
Bluefish	105,444	89,715	29,490	77,242	301,891
Shad	133,468	67,937	13,601	15,957	230,963
Perch	35,086	11,916	55,288	-0-	102,290
Menhaden	4,370	11,660	-0-	-0-	16,030
Striped bass	28,373	5,140	-0-	-0-	33,513
Flounder	6,000	1,350	8,646	-0-	15,996
Other	8,405	5,310	16,136	-0-	29,851
Total	$978,883	$423,363	$360,803	$429,093	$2,192,141

Table 17-3. Economic impact analysis of commercial gillnet activity in Delaware during 1982. Data from Seagraves and Rockland (1983b). Wages and Value Added are components of total economic impact.

Species	Jobs	Total Economic Impact	Wages	Value Added
Weakfish	87.79	$2,172,511	$ 846,871	$1,303,481
Bluefish	19.34	451,241	178,117	266,464
American shad	10.65	337,614	128,994	207,785
White perch	6.80	158,250	73,278	103,646
Atlantic menhaden	0.93	25,721	10,821	15,861
Striped bass	0.98	46,248	16,037	28,878
Summer flounder	1.04	24,546	11,284	16,094
Other species	2.03	46,899	22,011	30,654
Total	129.61	$3,263,030	$1,287,413	$1,972,863

of 270,000 man-days of effort was recorded with 90,000 commercial and 180,000 recreational man-days. Of this total, less than 65 man-days of effort were expended by recreational shellfishermen in Delaware Bay (Figley and McCloy 1981).

DELAWARE RECREATIONAL FISHERIES

Within Delaware Bay, there are several points available to recreational fishermen. Charter and head boats can be secured from Delaware City, Mispillion Inlet, Bowers Beach, and Lewes. Public access to the bay can be obtained at Augustine Beach, Woodland Beach, Port Mahon, St. Jones River, Bowers Beach, Cedar Creek (Mispillion River), and Lewes.

In 1982, the Division of Fish and Wildlife undertook a study to survey the sportfishery of Delaware Bay. This study was conducted in an effort to update estimates of total participation and catch by marine recreational anglers (Seagraves and Rockland 1983a). In addition, expenditure data were collected and an estimate made of the gross economic impact of recreational fishing on the economy of the state.

Aerial counts and on-site canvassing were conducted to determine the total number of participants. Summary data revealed that 514,802 man-days of marine recreational fishing occurred in Delaware waters during the study period of 15 April to 30 October 1982. Of these days, 261,492 were from private boats (178,311 from shore, 31,901 from charter boats) and 43,908 from head boats (Seagraves and Rockland 1983a).

An analysis of the catch data reveals that from the projected 756,053 fish landed, 87.5% of the total was dominated by four species. The most frequently landed fish were summer flounder (327,649), followed by bluefish (166,594), weakfish (114,178), and shark (53,983) (Seagraves and Rockland 1983a).

This study also included an angler expenditure analysis derived from 2,034 interviews. The findings documented an expenditure of approximately $8.9 million that was related to sport fishing during 1982. Using an economic input-output model, the economic impact of these expenditures was calculated to be $12.9 million (Table 17-4). This includes charter boats, head boats, private boats, and shore impacts.

LEGISLATIVE AND REGULATORY REGIMES

The management of finfish and shellfish resources in the Delaware Estuary falls under the purview of several state and federal agencies. In addition to these management programs, there exist several grant-in-aid programs that pertain to the planning and promotion of specific fisheries activities. A description of the management programs are briefly highlighted in this section.

The Fishery Conservation and Management Act of 1976

The Fishery Conservation and Management Act.(FCMA) of 1976 established for the first time a comprehensive system for managing fisheries in a conservation zone that extends seaward from 3 to 200 miles, an area of over two million nautical square miles. U.S. fishermen, both commercial and recreational, have first claim to resources in this area, the fishery conservation zone. Surpluses are allocated to foreign nations that comply with the provisions of the FCMA.

The FCMA requires individual states to participate in regional management councils that govern and manage the fisheries by creating plans for each species in a given region. Based on the best available scientific data, these plans set quotas on foreign and domestic fishing. Each plan must conform to national standards and take into consideration social, economic, and biological factors associated with the fishery. Each plan must also be approved by the

Table 17-4. Total estimated economic impact on the State of Delaware resulting from expenditures related to sportfishing in Delaware marine waters during 1982. Data from Rockland (1983).

Mode	Jobs	Wages	Value Added	Total Impact
Charter boat	94.05	$ 674,948	$1,043,017	$ 1,785,966
Head boat	81.94	605,442	1,006,291	1,739,354
Shore	108.96	838,917	1,715,010	3,260,400
Private boat	154,01	1,441,765	3,185,134	6,107,191
Total	438.96	$3,561,072	$6,949,452	$12,892,911

U.S. Secretary of Commerce. The basic goal of the FCMA is the allocation of the common property, renewable resource among conflicting resource users, while planning for the future of the resource.

The National Marine Fisheries Service

The National Marine Fisheries Service (NMFS) is an agency of the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce. The mission of the NMFS is to protect fishery resources and encourage their optimum utilization. Because the NMFS is involved with the wise use and conservation of marine fisheries resources, it works with other federal and state agencies, academic institutions, commercial and recreational industries, and the general public.

The NMFS Federal Aid Branch, through the Grant-in-Aid Program, helps finance many state fisheries research and development projects. The Grant-in-Aid Program is authorized by the Commercial Fisheries Research and Development Act of 1964 and the Anadromous Fish Act of 1965.

Regional Fishery Management Councils

The eight regional fishery management councils were created under Title III of the FCMA of 1976. The Mid-Atlantic Fishery Management Council prepares, monitors, and revises all fishery management plans for the fishery resources in the Atlantic Ocean (except for highly migratory species) seaward of the states of New Jersey, New York, Delaware, Pennsylvania, Maryland, and Virginia, provided that the states, the fishing industry, consumers, environmental organizations, and other parties interested in the establishment and administration of such plans do participate. These plans must take into account the social and economic needs of the states using the best available biological information about the fish stocks.

Office of Coastal Zone Management

The Coastal Zone Management Act of 1972, PL 92-583 as amended, authorized the use of federal resources to assist states in the development and administration of comprehensive management programs for their coastal areas (see Chapter 15). The Office of Coastal Zone Management (OCZM) in NOAA has regional managers who handle inquiries regarding the status of coastal zone management in their respective regions. It awards three types of grants: planning grants, implementation grants, and estuarine sanctuary grants. Both Delaware and New Jersey have approved coastal management programs (see Chapter 16). The OCZM can assist state fisheries agencies by conducting studies on available facilities, providing technical assistance, financial incentives, and capital investment needed to encourage harvesting, processing, and marketing of fisheries products. In addition, the OCZM can influence the public and private sectors to provide these expressed needs. The OCZM administers the Coastal Fisheries Assistance Program.

The Atlantic States Marine Fisheries Commission

The Atlantic States Marine Fisheries Commission, established in 1950, is composed of representatives from the coastal states from Maine to Florida. The agreement states that "the purpose of this compact is to promote the better utilization of the fisheries-marine, shell, and anadromous - of the Atlantic seaboard, by the development of a joint program for the promotion and protection of such fisheries, and by the prevention of the physical waste of the fisheries from any cause" (Montgomery 1977). The commission recommends necessary administrative action and legislation to the governors and legislatures of the states, assisted by NMFS.

Amendment One of the compact made provisions for any two or more states to set up joint regulations for the management of common fishery resources. Amendment One, however, has not been ratified by New York and Delaware.

Bistate Management - The 1905 Compact

Historically, the management of Delaware Estuary fishery resources has been influenced by the separate regulatory authorities of New Jersey and Delaware. Early efforts to develop a coordinated management strategy via the 1905 Bistate Management Compact have been cosmetic and ineffectual. Recently both states have recognized that existing fishery laws need revision.

Throughout the 20th century, the states of Delaware and New Jersey have had disputes over fishery rights. In 1878, the State of New Jersey filed an injunction against the State of Delaware to prevent Delaware from enforcing its fishing laws that restricted New Jersey residents from fishing in Delaware's portion of the Delaware Estuary. In order to resolve this conflict, the legislatures of each state agreed to appoint three commissioners from each state to a bistate commission to establish a compact that would detail compatible fishing laws for both states in the Delaware Estuary. In 1905, a compact was ratified by each state and the U.S. Congress. This compact stipulated that each state's fisheries laws be consonant with the laws of the other state. In 1923, the compact commissioners again met to revise the laws regulating the catching and taking of fish in the Delaware River and Bay. By 14 March 1923, the General Assembly of Delaware adopted new laws with the recommended revisions, but stipulated that the new law would not become effective until a similar law was enacted by the state of New Jersey. New Jersey did not enact similar legislation, due in part to a boundary dispute that existed between the states which restricted New Jersey fishermen from fishing in the Delaware Bay.

In order to resolve the boundary-line dispute, the two states went before the U.S. Supreme Court. In 1934 an opinion was rendered that settled the dispute. Despite the resolution of this conflict, no compatible legislation that ensured reciprocal fishing privileges was drafted by either state. Consequently, the laws regulating fishing in the Delaware portion of the Delaware Estuary are for the most part the same as those adopted by the Delaware General Assembly in 1905 and in the subsequent Delaware Code revisions of 1915, 1935, 1953, and 1974. In 1979, New Jersey adopted comprehensive legislation for reasonable management and development of New Jersey's fishery resources.

New Jersey Fisheries Laws

In September of 1977, Governor Brendan Byrne created a Marine Fisheries Advisory Committee that reviewed the status of commercial fishing in New Jersey. The committee found the following with respect to marine finfisheries: (1) The small size of a processed finfish industry in the state is attributed to the absence of both adequate facilities and state-sponsored market research. (2) The state organizational structure concerned with marine resources is underfunded. (3) The opportunity for expansion of the industry presented by the 200-mile limit (fishery management and conservation zone) will be lost if the state does not become involved in a fisheries development program (Byrne 1979). As a consequence of these findings an act was passed to address these issues. The act is titled the Marine Fisheries Management and Commercial Fisheries Act (Senate Bill 1399, 1979).

The policies and objectives of the Marine Fisheries Management and Commercial Fisheries Act are: (1) conservation of fisheries resources and their habitat; (2) maintenance and enhancement of both recreational and commercial fisheries; (3) development of an active and modern commercial fisheries fleet; (4) encouragement of citizen participation in decisions concerning the distribution and allocation of fisheries resources; and (5) creation of conservation and management measures involving a reciprocal and cooperative relationship with other states and with the federal government.

The comprehensive management framework created by the law provides for shared responsibilities among the Commissioner of the Department of Environmental Protection (DEP); the Marine Fisheries Council (MFC); the Division of Fish, Game and Wildlife; and to a lesser extent, all other state agencies which affect fisheries resources. The MFC is mandated by law to hold periodic public hearings on current issues affecting the operation of the marine fisheries program and to recommend the convening of species-related citizens panels where appropriate. The Commissioner of the DEP has also been given the duty of establishing programs for public education concerning the conservation, utilization, development, and enhancement of fisheries resources.

The responsibility for the regulation of finfish involves effective regulatory control over the harvesting and selling of marine fishery resources, accomplished through the licensing of any person engaged in the commercial buying, packing, storing, wholesaling, marketing, or processing of any fisheries resources in the state. Accurate records must be kept and are subject to inspection by the Division of Fish, Game and Wildlife of the DEP. Licenses for fyke nets, seines, gillnets, pound nets, and trawls are issued by the Division through its offices in Trenton or the Bivalve Shellfish Office.

For shellfish, all persons must be licensed for the harvesting of clams, oysters, and scallops in the State of New Jersey. The Bureau of Shellfisheries of the Division of Fish, Game and Wildlife is responsible for the management and regulation of shellfish. Gear restrictions and license fee schedules are used to regulate the fishery. The Bureau of Shellfish Control of the Division of Water Resources is responsible for classifying waters open to the harvesting of shellfish (NJDEP 1982).

Delaware's Fisheries Laws

According to the Director of the Delaware Division of Fish and Wildlife "the laws governing fishing in Delaware Bay are complicated and often confusing even to professional staff members of the Division" (Lesser 1981). These laws were briefly discussed above in reference to the 1905 compact.

In 1977, Delaware's Division of Fish and Wildlife considered revising and updating the fishery laws of the state. To do so, the Division requested the State Attorney General to issue an opinion on the question "Does the Delaware-New Jersey Compact of 1905 require that Delaware's fisheries management laws and regulations for the Delaware River and Bay be uniform with those in New Jersey?" (Lesser 1981). The opinion was negative.

Thus, Delaware is free to enact fishery laws and regulations that may be different than those of New Jersey. The Division of Fish and Wildlife has been reviewing Delaware's finfishery laws and has found that changes in the intent of the laws have occurred throughout the revision of the Delaware Code. For example, Section 2509 of the 1905 Delaware Code was entitled "Anchored nets across or before mouths of streams prohibited." In 1933, Section 1509 was changed to Section 2997. Keeping the same title, the section underwent some important changes in intent. Then in 1953, Section 2997 became Section 910 and the title was changed to read "Anchored or Staked Net Regulations, Violations, and Penalty." This new section omitted reference to" mouths of streams" which was the originally intended prohibition. When the 1974 revisions in the Delaware Code were made, the code contained the language that implied that anchored or stake nets are illegal in any of the waters in Delaware River and Bay other than where oyster stakes are used (Lesser 1981).

The implications of this modification have little to do with the original intent of the law; that is, to protect fish when they migrate in and out of the streams that enter the Delaware Bay by prohibiting any fastened net in areas that would interfere with this migration.

Another example of a change that took place in the revision of the Delaware Code can be seen in the law affecting sea trout (weakfish). The law today for netting weakfish had its origin in the 1905 Code, Section 2508, and now appears as Section 936 in the 1974 Delaware Code. Originally, the law stated that it was illegal to take weakfish with a net of any character having meshes of less than 2-1/2 inches stretched measure and it was illegal to take weakfish with a net between noon on Saturday and midnight Sunday. Today, this amended section reads "no person shall catch and take...from the water of the Delaware River or Bay any trout or weakfish with a net of any character excepting with a shore or hauling seine the meshes of which shall be no less that 2 inches stretched measure, or with a drifting gillnet the meshes of which shall be no less that 2-3/4 inches" (7 Delaware Code 936). Hence, the use of anchored or staked gillnets that are the predominant gear used by commercial fishermen in the capture of weakfish is not supported by law.

There are additional areas of the Delaware Code pertaining to fisheries that are outdated or unworkable. The Director of Fisheries recently stated that "fishing laws are so out of tune with today's fisheries that public interpretation of the laws is difficult at best" (Lesser 1981).

The taking of shellfish is regulated under authority provided in Chapters 19, 21, 23, and 25 of the Delaware Code. The Division of Fish and Wildlife Shellfisheries Section is responsible for the licensing of commercially caught crabs, clams, oysters, and lobsters. The Division of Public Health is responsible for classifying state waters suitable for the harvesting of shellfish.

The General Assembly of the state has authority for revising existing finfish regulations through legislative rather than regulatory reform. As such, it requires legislative initiative to enact changes in the existing finfish laws that specify seasonal closures, gear restrictions, and catch limitations. The Division of Fish and Wildlife Finfisheries Section is responsible for insuring the health of fish stocks in Delaware.

Currently the state of Delaware is involved with revising its finfisheries regulations. Senate Bill 107 before the 132nd General Assembly has been introduced with the expressed purpose of effectuating a policy toward the management and conservation of coastal finfishery resources. This bill, if passed, would replace the existing statutes relating to finfishing in Delaware.

ROLES FOR THE DRBA IN FISHERIES

Presently, there is no clear direct role for the DRBA in fisheries in the Delaware Estuary through performance of either their specified or latent functions. However, some of the roles detailed in other chapters of this report have direct bearing on fisheries. So, in both management and development of fisheries, activities of the DRBA should have indirect impacts, but no direct roles are suggested.

The potential role of the DRBA with respect to regulation of the Delaware Estuary fisheries is non-existent. From the previous discussion, it is evident that such a role has been pre-empted because regulatory authority is vested and shared with existing federal, state, and regional bodies. However, part of fisheries management involves acquiring an understanding of all aspects of fish populations leading to enactment of regulations. Here the DRBA has already established itself through its support of the Delaware Estuary Project. Where there are potential conflicts between regulations of the states of Delaware and New Jersey and between commercial and sport fisherman, the DRBA as a disinterested regional party can provide an overview and perspective representing the entire estuary rather than just that of one state or one fishing constituency. The influence of the DRBA can be expressed through avenues such as this report and the DRBA can be called on for advice as a bistate planning and development agency.

Two central themes that run through the discussion of the fisheries resources of the estuary are the need to understand the decline of certain stocks over time (also see Chapters 12 and 13) and how to allocate catch among existing stocks by various groups, notably commercial and recreational fishermen. From a fisheries development standpoint, there is also an indirect role for the DRBA. Such a role would be concerned with recreational access to and enhancement of the fisheries resources and development of growth opportunities for the commercial industry of the estuary. Building on its expertise with capital construction projects and as a repository of environmental information, the DRBA could contribute indirectly in several ways to fisheries development in the bay.

Development of Onshore Facilities for the Fishing Industry

With the passage and implementation of the federal legislation establishing the 200-mile limit, U.S. landings have increased. The commercial fisheries of the mid-Atlantic region have experienced encouraging growth in the past few years. The abundance of traditional species (menhaden, fluke, bluefish, and sea trout) are up, and there has been a rapid development of the surf clam industry. In addition to these species, interest has increased in harvesting and processing underutilized species indigenous to the region. The underutilized species receiving most of the attention include squid, whiting, and dogfish.

Currently, there is no comprehensive plan for onshore facility development for the fishing industry in the Delaware Estuary. Most facilities that exist were developed as a result of private capital investment or a conglomeration of piecemeal federal support programs. Consequently, the onshore facilities that do exist reflect only local needs. This situation can lead to a duplication of efforts and the possible over-building of facilities in the region. The U.S. Department of Commerce (1978) recognized this dilemma and made several recommendations to alleviate this situation. In the section on Marine Fisheries—Economic Development (III-26), it noted "Given the independent nature of persons in the fishing industry and the potentially confusing array of federal assistance programs, there are suggestions that assistance needs to be better focused and easier to obtain if the programs are to achieve the objective of a stronger domestic fishing industry."

The DRBA's expertise with capital construction projects and knowledge of the Delaware Estuary and mid-Atlantic region places it in an ideal position from which to assess the economic feasibility of developing new onshore facilities for the fishing industry or expanding existing sites. In its role as a bistate planning and development agency, the DRBA could serve as the coordinating entity along with the other agencies to examine the seafood industry's resource base, industry attitudes, site locations, and physical specifications for facilities.

Artificial Reefs and Fishing Piers

The rationale behind the establishment of artificial reefs is to establish cover and create habitat for fish. According to Ditton and Graefe (1978), offshore artificial reef construction began in earnest in 1935 with the sinking of four vessels and tons of other material off Cape May, New Jersey. At present, there is considerable interest in artificial reefs throughout the United States. There are several ongoing deployment and monitoring programs, notably in the states of Alabama, Florida, and Texas. Beyond just supplying cover and creating new habitat for fish, several states have embarked upon the development of artificial reefs to protect and enhance saltwater fish habitats.

Fishing piers can be viewed as structures that provide direct access for anglers to the waters of the Delaware Estuary. A recent report on urban fishing piers (Leedy et al. 1981) makes the point that "urban developers are beginning to realize that fish and wildlife are integral parts of the environment and that the healthy environment can contribute to social, economic, and aesthetic improvement." One of the ways in which this goal can become operational for the public is the development of urban fishing programs. A key component of any such program for the Delaware Estuary might be the establishment, design, construction, and operation of fishing piers. In a recent report it was noted that "the development of a comprehensive fishing pier management strategy, encompassing such divergent concerns as structural designs, anglers' desires, and fishery harvest rates is a relatively new concept in fisheries management" (Buckley and Walton 1981).

The DRBA as a bistate planning and development agency could provide important environmental and capital construction background for artificial reefs and fishing piers and thus be an advocate of this type of development.

Coordination of Aquaculture Planning

Aquaculture is defined as the culture of plants or animals in an aquatic medium. In Delaware Bay, aquaculture is a fairly new (with the exception of extensive culture of oyster grounds) and evolving industry that must compete for coastal locations along with other more traditional coastal industries.

Aquaculture operations evolving in the bay are primarily restricted to research and development efforts. These operations are through Rutgers University at Bivalve, New Jersey, and the University of Delaware at Lewes, Delaware. The commercialization of aquaculture in bay waters is constrained by a number of factors, including economic feasibility, competition for physically suitable sites, and a great deal of regulatory uncertainty.

There has been little in the way of new development for aquaculture in Delaware Bay since the issuance of the URS/AD Little report (URS 1980). The most significant developments have been the further examination of institutional impediments facing the industry. A recent study (Wypyszinski 1983) outlines the legal constraints on aquaculture that any emerging commercial operations might encounter. This issue coupled with several other issues, such as the scaling of the laboratory techniques and availability of venture capital, are unlikely to be resolved in the near future.

The DRBA role with respect to aquaculture development in the Delaware Estuary is limited in light of the previous issues mentioned. However, the DRBA might serve as the catalyst and convening agency in promoting the development of an aquaculture plan for the Delaware Estuary. Such an effort would bring together the respective responsible agencies of Delaware and New Jersey to examine, coordinate, and determine the most realistic development opportunities for aquaculture in the Delaware Estuary.

Chapter 18

PORTS AND TERMINALS IN THE UPPER DELAWARE ESTUARY

G.J. Mangone

INTRODUCTION

The Delaware Estuary, as the corridor to the Trenton-Philadelphia-Camden-Wilmington expanded urban region and as a route to the Port of Baltimore (through the Chesapeake and Delaware Canal), is one of the largest ports in the United States. Ships pass through the lower estuary to upstream ports; but additionally, considerable cargo transfer takes place in the lower estuary through oil lightering. Coal transfer activities are also being planned for the lower estuary. The issue of lower estuary transfers is mentioned in Chapters 16 and 19.

Maritime traffic in the Delaware Estuary has declined in recent years and may continue to do so in the future. There is legitimate concern for the future of this transportation corridor if careful planning and development are not instituted.

The Delaware River and Bay Authority (DRBA) at present has involvement only in crossings of the lower Delaware Estuary. A recent study showed no needs for additional crossing facilities in the decade of the 1980s but did indicate that the DRBA might become involved in other activities (URS 1980).

THE PRESENT STATE OF TRANSPORTATION IN THE DELAWARE ESTUARY

Decline of Maritime Traffic in the Delaware Estuary

Oceanborne general cargo imports and exports at U.S. ports decreased 7.8 percent in 1982; U.S. exports in 1981 dropped from 54.6 million tons in 1981 to 49.8 in 1982 (an 8.7 percent decrease), while U.S. imports decreased from 57.4 million tons in 1981 to 53.4 in 1982 (a 7 percent decrease) (Armbruster 1983). There was a 7.2 percent decline in U.S. import and exports at North Atlantic harbors, from Portland, Maine, to Norfolk, Virginia. U.S. exports from North Atlantic ports declined from 8.3 million tons in 1981 to 7.1 million tons in 1982 (a 14.7 percent decline), while U.S. imports into North Atlantic ports decreased from 15.4 million tons in 1981 to 14.9 million tons in 1982 (a 3.1 percent decline) (Armbruster 1983). Total imports and exports at North Atlantic ports were just short of 22 million tons, compared with 23.7 million tons in 1981 (Armbruster 1983).

These figures are largely attributable to the world-wide economic recession and by 1983 there were hopes that maritime commerce would revive vigorously. But there are structural problems inherent in the changes of technology, geographical location, rising labor costs, and management capacities that affect the competition for trade among the ports of the world.

The mid-Atlantic region and the Delaware Valley in particular were also affected by the decline in maritime commerce. There has been a total drop in imports and exports of about 11.8 percent at Baltimore, 10.8 percent at Norfolk, and 10.5 percent at Philadelphia (Armbruster 1983). In recent years, moreover, Delaware Estuary ports have been losing cargo to southern ports from Virginia to Florida due to longer inshore steaming time, higher fuel costs, and higher labor costs. More significantly a large percentage of cargo originating in Delaware and New Jersey does not pass through Delaware ports at all. The port of New York exports about 34 percent of cargo originating in Delaware. The ports of Baltimore and Hampton Road take another 25 percent of this maritime commerce (Booz/Allen Hamilton 1982). The port of New York exports about 78 percent of cargo originating in New Jersey, and only 11 percent of New Jersey's cargo is exported through Delaware Estuary ports (Hamilton et al. 1982).

Increasing Costs of Upriver Traffic

Waterborne commercial activity is vital to the economy of the Delaware Valley, possibly accounting for as many as 34,000 jobs directly and 90,000 jobs indirectly, with annual incomes in excess of $1 billion and tax revenues upwards of $50 million (Booz/Allen and Hamilton 1982). The ports of the Delaware Estuary still account for more tonnage than any other single port in the United States, excluding the Port of New York and New Jersey. The situation for the future is far from bleak, depending upon responsiveness to emergent commercial needs and thoughtful management.

There are some significant trends that will prove a challenge to planning and implementation of a rational system for the prosperous operation of the ports on the Delaware Estuary. The fact that the Philadelphia/Camden and Wilmington ports lie 85 and 60 nautical miles, respectively, upriver from the mouth of the estuary and that each requires constant dredging which is costly to accommodate vessels of a 35-to-40-feet draft cannot be ignored. The movement of the federal government to impose a user-fee system for dredging river channels, if not apportioned among all ports of the United States, would effectively destroy the competitive pricing of the existing Delaware Estuary ports. Moreover, the inability of the ports to accommodate deep-draft vessels limits their market and requires lightering for oil transport that adds burdensome costs for time and labor.

A second fact, and perhaps more important, has been the lack of rationalization of terminal facilities in view of the specialized needs of waterborne commerce and the severe competition among ports for identical cargoes. The break bulk-dry bulk terminals in the Delaware Estuary have been operating at about 44 percent capacity (Booz/Allen and Hamilton 1982). With the great rush to capture the container market that revolutionized marine transportation after 1956, facilities were expanded beyond the capacity of traffic both in the Delaware Estuary and elsewhere. With an economic recession, the situation for container ports worsened, and lately the container facilities of the Delaware Estuary ports combined have been operating at about 21 percent capacity (Booz/Allen and Hamilton 1982).

Diverse Jurisdictions Over Ports and Terminals

Projections of a modest growth of waterborne foreign commerce for the Delaware Estuary ports seem reasonable, but there will likely be a demand for terminal facilities that are specialized for the products (container, temperature-controlled, bulk, etc.), that will ensure a rapid interface with shore distribution modalities, and that will be competitive in cost (labor, docking fees, storage, etc.). For the Delaware Estuary ports this will require long-range planning and management to maximize the opportunities for maritime commerce in a number of ports under diverse jurisdictions.

Perhaps the gravest challenge to the viability of the Delaware Estuary waterborne commerce is the diversity of jurisdictions over ports and terminals that line the shores of three states served by a single river system. As will be shown in detail, there is no overarching authority for planning and development of these ports and terminals that must share essentially the same channel, the same markets, and the same limitations of geography, and more or less the same labor costs. There should be varieties in the services rendered to optimize the facilities of individual ports in the Delaware Estuary. But with no forum for planning, no agreement upon priorities, and no ability to bring changes about through either legal constraints or financial inducements, it will be difficult to meet the challenges of marine transportation in the future and ensure prosperity for any of the ports in the region.

Delaware involvement in marine transportation. The Coastal Zone Act (CZA) of Delaware proscribes heavy industries in the coastal strip of the state and forbids bulk product transfer facilities as well as multi-user port facilities (see Chapter 16). Because development had long been concentrated in

Wilmington, and the Port of Wilmington antedated the act, that port was exempted from the act. The CZA also prohibits offshore bulk product transfer facilities, but it allows piers or docking facilities solely for a single industrial user or manufacturer. Marina construction for use by pleasure craft is outside the regulation of the CZA, and the State Planner has ruled that such a marina would be of commercial nature rather than industrial or manufacturing and would not involve offshore bulk transfer or cargoes (U.S. Department of Commerce 1979b).

Over a period of seven years the Delaware Attorney General has held that any port or dock facility, whether an artificial island or attached to shore by any means for the transfer of bulk quantities of any substance from a vessel to an onshore facility or vice versa comes under CZA (U.S. Department of Commerce 1979). Although Delaware does not have a port planning process, it would take a dim view of any new or expanded ports that would involve continual dredging and spoil disposal unless it could be clearly established that such facilities could be developed in an environmentally sound way and without imposing continuing maintenance costs upon the public.

The state has conducted studies of the economic development potential for the landings or the historical ports on the St. Jones, Murderkill, Mispillion, and Broadkill rivers, but no state agency is planning port development and the state itself does not operate a port.

New Jersey involvement in marine transportation. Under the New Jersey Coastal Management Program, port-related development and marine commerce are encouraged, but new port use outside existing ports is acceptable only when there is a clear demonstration of need and where suitable land or water areas are not available within or adjacent to an existing port. Moreover, new or expanded ports must be compatible with surrounding land uses (see Chapter 16). They must provide open space and physical access to the waterfront so long as such access does not interfere with port operations or endanger public safety. New and expanded ports cannot interfere with any parks or recreational areas or wildlife refuges.

New, expanded, or redeveloped port facilities must have direct access to navigable channels with sufficient depth so that there will be minimal dredge and fill activities for the vessels anticipated at such ports, and there must be adequate access to road and railroad facilities with land that can safely support the necessary structures for port operations.

A limited amount of port-related activity is permissible in the coastal zone in support of such water-dependent activities as commercial fishing or oil spill containment. Moreover, new or expanded marinas for recreational boating are acceptable so long as there is a demonstrated need for such marinas. They must provide a mix of dry-storage areas with public launching facilities as well as adequate pump-out stations for wastewater disposal from boats in a manner consistent with state and federal regulations. New marinas for oar and sail boating are particularly encouraged, and existing marinas may be expanded by limiting non-water-dependent land uses that would preclude support facilities for boating.

EXISTING MANAGEMENT STRUCTURES

Delaware River Port Authority

The Delaware River Port Authority (DRPA) was created by an interstate compact between New Jersey and Pennsylvania to construct and operate mass transit connections between the two states, to operate port facilities, and to study and to promote the use of all Delaware River ports in two counties of Pennsylvania and seven counties in southern New Jersey. For the three counties of Cumberland, Salem, and Cape May in New Jersey there is clearly an overlap of potential responsibilities between the DRPA and the Delaware River and Bay Authority.

Despite its broad mandate to operate port facilities, the DRPA neither owns nor operates any port on the Delaware River. It does operate four bridges spanning the Delaware River connecting southeast Pennsylvania with southern New Jersey, and through a subsidiary (PATCO) operates the Lindenwold High Speed (rail) Line linking South Jersey and Central Philadelphia.

The importance of the bridge crossing can be seen by the number of vehicles making the trip between the two states: 17.6 million in 1980 and 18.3 million in 1981 accounting for almost $16 million in total toll revenues. In recent years the DRPA has moved more aggressively to study and promote the use of the Delaware River ports within its mandate through its World Trade Division, but such activities apply largely to Philadelphia/Camden and cannot take into account either the Port of Wilmington or the rationalization of cargo for ports of the entire Delaware Estuary, including a new deepwater terminal.

The DRPA has had under examination proposals for a high-speed rail line from Philadelphia to Atlantic City that might obtain federal financing. With its attention focused on the bridge crossings, rail transit, and an increase of Philadelphia/Camden maritime trade, the DRPA has not indicated any interest in owning or operating a port in the future. Nevertheless, it maintains a continuing interest in the success of the ports of the Delaware River and their impact on the economy of both New Jersey and Pennsylvania.

Philadelphia Port Corporation

The Philadelphia Port Corporation (PPC) administers the terminals within the city and county of Philadelphia that are owned by the city. It has responsibilities for the planning, construction, extension, and improvement of the waterfront facilities, originally the mandate of the DRPA; and at some future time, with the consent of the City Council, the Mayor, and the Chamber of Commerce of Philadelphia as well as the Governor of Pennsylvania, the functions of the PPC could be transferred to the DRPA.

Although a private corporation, the PPC has a board of directors drawn from the city and state government, the Chamber of Commerce, the general public, and the DRPA. Moreover, subsidies from the operation of the PPC have been paid by both the City of Philadelphia and State of Pennsylvania.

In addition to administering the port facilities through leases to private terminal operators and administering other contacts to use abandoned piers for warehousing or refurbishing the waterfront with a maritime museum, historic vessels, and other public amenities, the PPC has sought to promote the port for foreign trade, a task also undertaken by the World Trade Division of the DRPA.

The jurisdiction of the PPC is limited. It is necessarily competitive and not concerned with rationalization of the waterborne commerce on the Delaware River, for unlike the DRPA it is fundamentally a Philadelphia and Pennsylvania organization although its fortunes to some extent are dependent upon the planning and development of the entire Delaware Estuary port system.

South Jersey Port Corporation

The major marine terminals in Camden are either owned and operated or leased by the South Jersey Port Corporation (SJPC) which is a public corporation of the State of New Jersey.

The SJPC was designated in the authorizing legislation of 1968 as the sole agency for port development in South Jersey, with purview over seven counties, overlapping in six New Jersey counties the mandate of the DRPA and in three New Jersey counties the interests of the DRBA. In its area of jurisdiction, the SJPC may acquire, construct, or operate marine terminals and such other facilities necessary for the accommodation of vessels, their cargo, and passengers, but it has confined its activities to the port of Camden.

In recent years the SJPC has extended its terminal wharf space, providing additional berths, and added a new multipurpose crane at a cost of $14 million through the use of revenue bonds. It is seeking to develop a coal export terminal in Camden through private enterprise, but it has no plans for exercising its mandate for port operations to other counties of New Jersey.

The dependence of the SJPC on the State of New Jersey is evident from the fact that the state has paid hundreds of thousands of dollars to the city and county governments in lieu of taxes from the SJPC and the state has sometimes subsidized the debt service of the revenue bonds issued by the SJPC when revenues have been inadequate. Although an independent entity with a seven-person board to manage affairs, the SJPC is administered through the Department of Labor and Industry, and all actions of the Board are subject to the veto of the Governor.

There is a major opportunity for collaboration between the SJPC and other agencies that are interested in planning and developing the marine transportation facilities on the Delaware Estuary through the constitutive statute of the SJPC. The SJPC is empowered to enter into contracts or agreements with the DRPA, or any other regional agency concerned with marine purposes, that would involve a joint participation between the SJPC and the other agency in any undertaking for marine terminal purposes.

The Port of Wilmington

The Port of Wilmington belongs to the City of Wilmington and is operated through its Department of Commerce. The city has the authority to plan, develop, and manage the port, although clearly the port serves not only the State of Delaware but also other states that import and export through it. Handling about three million tons of cargo a year, with good bulk storage and refrigerated space, special bagging facilities for bulk cargo, and convenient connections to rail and road, the Port has embarked on a modernizing and expansion course. Since 1976 the Port has spent more than $10 million in updating dock facilities and in 1982, with a new, efficient crane, began to seek containerized cargo on a larger scale (J.H. Doherty, personal communication).

Serious management issues confront the Port of Wilmington as they do the whole port system of the Delaware Estuary. Among the problems of this port are: (1) the necessity for regular dredging of the ever-silting Christina River and the challenge of moving the face of the port out to the deeper water of the Delaware Estuary; (2) the difficulty of obtaining spoil disposal permits for dredged materials due to environmental constraints and slow-moving bureaucracy in the federal government; and (3) the dependence on a relatively small base for financial commitments to the development of the Port. Although there has been support by the City of Wilmington for its ports, expansion plans call for capital investments of $50 to $60 million dollars a year; the City of Wilmington, with its limited population, plainly cannot support such financial needs (Doherty 1983).

MARINE TRANSPORTATION ISSUES

The maritime commerce of the United States and the ports serving oceanborne trade will have to face a variety of critical issues in the future that will challenge the resourcefulness of management. Without adequate planning, based upon sound research, and cooperative arrangements between government, industry, and labor and between shippers, carriers, and unions, there will be gross economic inefficiencies that will beggar all parties concerned and reduce the American standard of living.

Where a single river system nurtures proximate ports there will have to be a conscientious rationalization of trade and services to optimize a limited amount of waterborne commerce for the region.

All U.S. seaports are facing challenges to modernize their facilities to meet changing technologies in cargo packaging, handling, and distribution. There is an inexorable tendency toward larger vessels that are highly automated and reduce unit costs. In many regions the approach channels are poorly maintained or guidance facilities have become obsolete, if not unsafe. Harbor dredging has become an endemic problem, not only because of the costs, which the federal government would like to shift to users, but also because of the difficulty of disposing of the increasing amounts of dredge spoil. Small ports, in particular, are having difficulties in raising the capital requirements needed to improve pier space and warehousing, obtain modern lift equipment, and mechanized cargo handling-distribution equipment. Moreover, they suffer from the trend, as seen in airports, to concentrate traffic in major centers and avoid unnecessary stops and calls by vessels with small cargoes to unload. Finally, all ports must face up to the necessity of a complete, frictionless interfacing with land conveyances that provide rapid loading and unloading through terminals into swift distributional systems, thereby minimizing port delays and costly labor handling.

The ports on the Delaware Estuary must recognize and solve the problems posed for marine transportation in the next decades. This can hardly be done with piecemeal planning, fragmented jurisdictions, blind competitiveness, and a failure to realize the sound management decisions based upon research.

Another recent phenomenon in the shipping business that unmistakably will affect the economic life of many ports, including those on the Delaware Estuary, is the introduction of a single combined land-sea cargo rate by carriers for shippers. Essentially the marine carrier quotes a total rate from point of rail or road delivery right through by sea to the foreign port, or even beyond to the ultimate land destination abroad. Such a practice is open to intensive competition among the land transporters for the sea freight which might be carried to the closest port but also might go to another port if the price were right. Since railroads are regulated by the Interstate Commerce Commission and steamships by the Federal Maritime Commission, some complex questions on the effects of "landbridges" and "minibridges" need study. The answers will surely impinge upon management activities in the Delaware Estuary ports.

ROLES FOR THE DRBA IN UPPER ESTUARY PORTS

Statutory Authority and Potential Interest

The ten conferees appointed by the governors of Delaware and New Jersey in 1959 to recommend appropriate actions by both states to deal with the construction of an additional structure of the Delaware Memorial Bridge recognized in their report that "no matter how far-seeing the Conferees may be, it is folly to think that they have anticipated all problems for all times. New facets of problems, not now imaginable, are bound to arise in the future...." (DRBA 1975).

The conferees recommended the passage of the legislation by both states and the U.S. Congress to create a bistate agency with power primarily to operate the existing bridge and construct a second or additional crossing of the Delaware River as well as provide for a Cape May-Lewes ferry. The conferees also recommended the authority to plan, develop, and operate related transportation facilities and projects within those areas of both states that border on or are adjacent to the Delaware River south of the boundary line between Delaware and New Jersey as extended across the river.

The interstate compact, establishing the Delaware River and Bay Authority finally approved by the U.S. Congress in 1962, and incorporating the recommendations of the conferees, also provided in Article VII that the DRBA would be entitled "To exercise all other powers not inconsistent with the constitutions of the two States or of the United States which may be reasonably necessary or incidental to the effectuation of its authorized purposes" (Delaware-New Jersey Compact 1962).

There can be no doubt about the interest of the DRBA in all ports and terminals in the area bordering or adjacent to the Delaware Estuary south of the New Jersey-Delaware border. With respect to crossings, the DRBA has exclusive jurisdiction; with respect to all other ports and terminals, or any facilities associated with them, it may be given exclusive or concurrent jurisdiction by agreement of the legislatures of both New Jersey and Delaware.

Apart from its actual crossings responsibilities, however, and its general interests in ports and terminals as well as the trade and vessels utilizing such ports and terminals, there are roles that the DRBA ought to consider seriously, for the need is obvious.

Maritime Planning and Development Agency

There is no single planning and development agency for ports and terminals or for marine trade and transportation either in the area served by the DRBA or in the upper Delaware Estuary area north of the New Jersey-Delaware boundary. To be sure informal consultations among the several agencies concerned with Delaware Estuary ports and trade have occurred; for example, lobbying before Congress on dredging issues or cooperation in advertising trade advantages, activities that could benefit all terminals in the region, have been loosely coordinated. But this is very different from a permanent, institutionalized arrangement.

The DRBA might consider taking the initiative in exploring the creation of an arrangement that would regularly bring together the several authorities for ports (the Philadelphia Port Corporation, the South Jersey Port Corporation, the Delaware River Port Authority, and the Port of Wilmington) to plan, consult, compare, and analyze their activities. The DRBA might consider its role as host and secretariat for such meetings, helping to organize the agenda, prepare administrative and research reports, and collect files.

While an institutionalized planning and development agency for marine transportation might be an ultimate outcome of initiative by the DRBA (see Chapter 15), there are a number of specific problems that need addressing by the several ports and require cooperative effort and particularly leadership.

Dredging and the disposal of dredge spoil is an activity that affects the entire estuarine system and its competitive position in foreign trade. It is a problem that is not going to disappear in the near future, and it is a problem racked by the divergent political values placed upon economic development and environmental amenities. The inadequate depth of the estuarine channel for deep-draft vessels, the continuous silting, and the lack of suitable sites for spoil disposal all inhibit the development of the Delaware Estuary ports. Concerted pressure on state and federal legislatures and agencies to appreciate the needs of the ports, and the community that benefits from their prosperity, is essential. However, money alone will not solve the problem unless there is adequate research and planning to overcome the physical difficulties and the social concerns of those who are alarmed about deterioration of the environment.

Indeed, various studies of dredging and spoil disposal have been made by the academic community and by federal agencies, notably the U.S. Army Corps of Engineers. Still the need is for a broadly based, representative body of the managers of port and terminal activities to collect, reflect, and recommend.

The DRBA might consider taking the initiative with representatives from all interested port agencies to: (1) conduct research on the scientific, economic, and legal aspects of the subject; (2) receive reports from the public agencies involved in permitting, dredging, and disposing of spoils; and (3) conduct hearings from the interested public on the economic and environmental consequences of alternative policies for dredge spoil disposal. The DRBA has already established itself as a supporter of environmental research and, by this very report, a purveyor of environmental research information.

In sum, the role for the DRBA in marine transportation is, first, catalytic, flexing the inherent powers of its legislative mandate without an immediate need for additional statutory authority and, second, leading the several agencies, public and private, that must have goals, direction, and a cooperative spirit if their port and terminal activities are to survive the next decade. Activity of the DRBA as an organizer of the several port authorities and as the lead agency in dredge spoil investigations would be compatible with its larger role as a bistate planning and development agency.

Chapter 19

A DEEPWATER PORT IN THE LOWER DELAWARE ESTUARY

W.S. Gaither

INTRODUCTION

The Delaware Estuary has been used extensively for maritime commerce since the first colonists arrived in the 17th century. The cities of Trenton, Philadelphia, Camden, and Wilmington soon were established centers of industry, depending on ocean shipping for much of their vitality. During the succeeding decades, these cities also were linked with the interior by barge canals, roads, and railroads (URS 1980).

The natural channel in the Delaware River was of adequate depth to accommodate early sailing ships. However, as steam power and steel ships were developed in the 19th century, ship size and loaded draft increased, requiring that navigation channels be deepened. These larger ships carried cargo at a lower unit price and were less vulnerable to loss at sea.

As the size and capacity of ships have continued to increase, so has the need to accommodate them in the Delaware Estuary. Ports and terminals in the upper estuary are the subject of Chapter 18. What follows in this chapter is a discussion of the nature of the problem and the larger opportunities that could come with a national deepwater port located in the lower estuary. After presenting two options for constructing such a port and the many related factors to be considered, this chapter addresses the regulatory and management issues and specific roles that the Delaware River and Bay Authority (DRBA) could assume in such development.

THE NEED FOR A LOWER ESTUARY PORT

During the first half of the 20th century, the channel to Philadelphia was dredged to a maximum navigable depth of 40 feet, measured at mean lower water. This channel accommodated the largest commercial and military vessels in use at the end of World War II. Part of this channel passed through a reach of bedrock requiring drilling and blasting under water, a costly undertaking.

In the 1950s, as Japanese and European shipyards modernized, the capacity of liquid- and dry-bulk ships increased rapidly from 100,000 to over 500,000 deadweight tons (DWT). These largest vessels have a loaded draft in excess of 90 feet and hull dimensions on the order of 1350 feet length, 220 feet beam, and 130 feet moulded depth (Frankel and Marcus 1972).

Only a few bulk commodities move in these huge and highly mechanized ships with crews of only 25 to 30 people. The cargoes are principally coal, ore, grain, and crude oil. In the Delaware Valley, crude oil is consumed by refineries at the rate of approximately 900,000 to 1 million barrels per day. To the north, in the Bayonne and Port Elizabeth areas, another 600,000 to 700,000 barrels per day are being delivered to refineries through a 45-feet deep channel.

To take advantage of the lower unit transportation cost available by delivering crude in the larger ships, refining companies began bringing oil into the lower bay in ships that had a loaded draft of 55 feet, even though the channel to the upriver refineries was only 40 feet deep. They did this by taking advantage of the naturally sheltered deep channel (Figure 19-1) which runs in a northwesterly direction straight up the Delaware side of the bay some 12 miles from the ocean. There, these large ships would anchor to wait for barges to come alongside so that part of the cargo could be pumped off and the

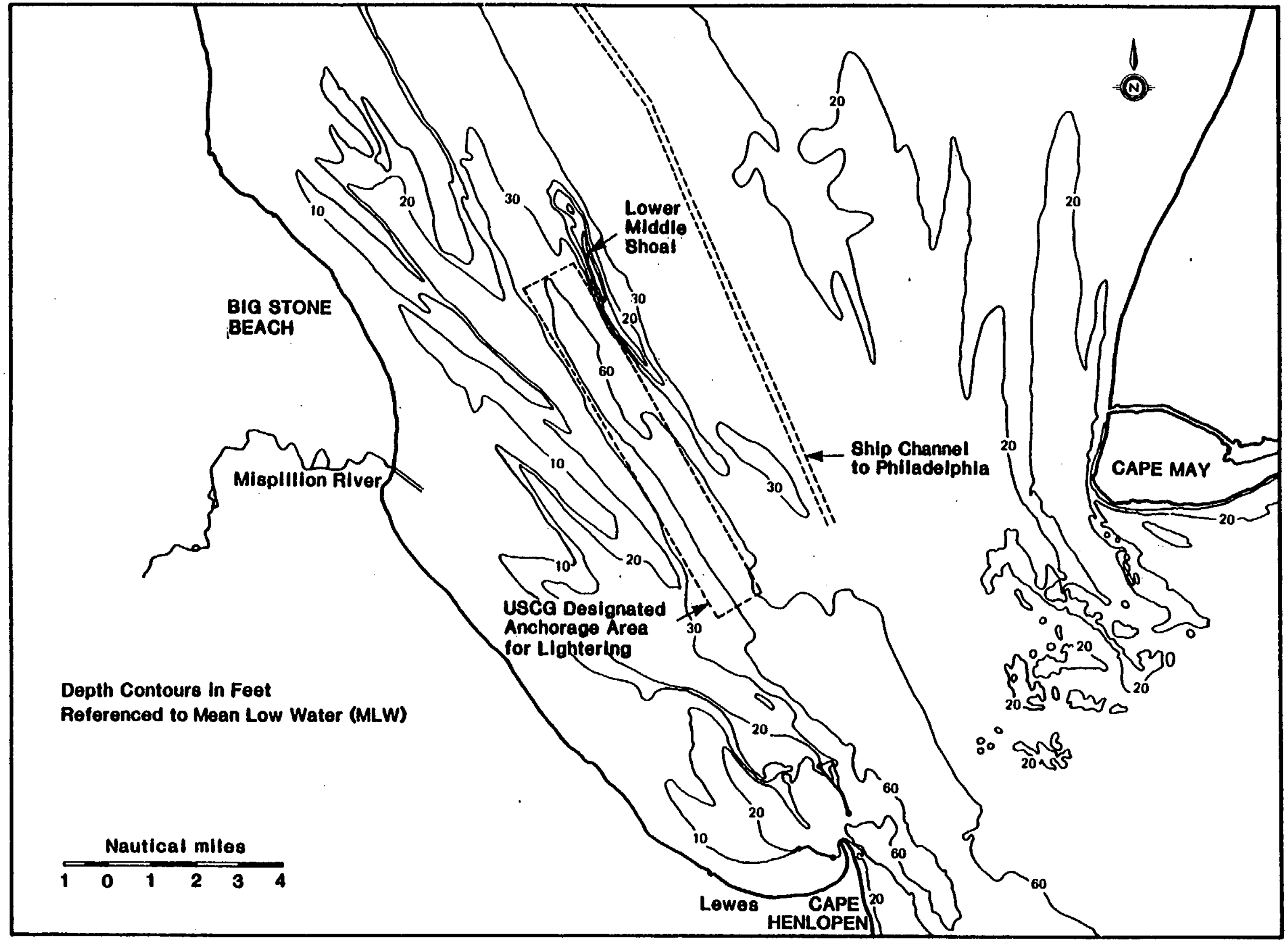

Figure 19-1. Bathymetry (bottom depths) at and above the mouth of Delaware Estuary.

ship "lightered" to a draft of 40 feet or less. These barges or lighters, and the partially loaded ship, would then proceed up the dredged channel to the refinery dock where they would unload their cargoes.

The naturally deep channel is ideal for lightering in that it is wide, straight, has a soft bottom for easy anchoring, and is sheltered from ocean swell by the shoals which extend across a substantial part of the bay mouth from Cape May. Much of the channel is considerably deeper than the 55 feet allowed by the U.S. Coast Guard (USCG) as a maximum ship draft. Several areas exceed 100 feet in depth. Minimal investment was required to mark a lightering area with buoys for use by the large ships, barges, and tugs needed to move the barges. Little monitoring and environmental oversight accompanies the lightering operation since only the U.S. Coast Guard (see Chapter 16) has authority over this activity. Considerable investment was required by private organizations to build tugs and barges to construct docking facilities to accommodate both ships and barges at the refinery sites. No dredging was required for the deep channel, as it naturally maintains a minimum depth of 60 feet. By this means, a de-facto deepwater port was established in the lower Delaware Bay drawing little public attention and no federal opposition.

In the latter part of the 1960s the oil refining companies combined to form the Delaware Bay Transportation Company (DBTC). It was the responsibility of this closely held company to build the first permanent port facilities in the lower bay, an oil-unloading structure on the Delaware side of the deep channel. This facility was to include two deepwater tanker berths and four barge berths as well as a pipeline to an onshore tank farm also owned by the DBTC (Descon 1968).

Shortly after the proposal to build a permanent deepwater crude oil port was made by the DBTC, a second proposal was advanced by the Zapata-Norness Company to build a 250-acre rectangular island on the Delaware side of the deep channel to accommodate coal transshipment. Their plan was to bring coal from existing piers at Norfolk, Virginia, by a fleet of 30,000-DWT barges and store it on the island in piles segregated by grade. Colliers of 250,000-DWT capacity would be loaded with coal which was blended as it was withdrawn from storage on the island. One goal was to reduce the use of railroad cars for coal storage in marshaling yards at Norfolk, as was and still is the practice, by providing larger and more efficient storage on the manmade island. Two sets of docks were to be built beside the island: one to unload barges requiring a draft of approximately 30 feet, and the other to load coal ships requiring a draft of approximately 65 feet (Zapata Bulk Systems, Inc. 1971).

In 1969, Delaware Governor Russell W. Peterson declared a moratorium on all development along coastal areas of the state touched by tidal waters and in the adjacent waters controlled by Delaware. He then appointed a Task Force on Marine and Coastal Affairs to study this matter and make recommendations. Shortly after the Governor's Task Force issued its preliminary report on 18 February 1971, legislation was written and quickly passed that defined a series of highways, the boundaries of a "Coastal Zone," and prohibited many commercial activities, particularly heavy industry and the construction and operation of a deepwater port. A final report of the Governor's Task Force was completed on 1 July 1972 which restated the conclusions of the preliminary report (GTF 1972).

Shortly after the Coastal Zone Act was passed, the 120th General Assembly, by Joint Resolution 18, instructed the Governor to appoint an Oil Transport Committee to "study the logistics of transport of oil to and from Delaware River and Bay port facilities and to prepare within one year a recommendation for developing and operating oil terminal facilities that would provide for much increased protection from spills and thereby safeguard our Coastal Zone and its recreational potential."

This committee employed the Bechtel Corporation of San Francisco to provide necessary technical expertise to compare feasible options and develop comparative cost data. The committee issued its final report on 15 January 1973. In brief, it recommended that the state prohibit additional refineries; regulate petroleum transfer operations; protect private property owners from spill damage; and examine regional port options outside Delaware Bay to supply needed crude oil to Delaware Valley refineries. Failing that, it recommended that the state construct and operate a lower bay terminal with a pipeline to the refineries; and consider the defense of a deepwater port if located in the lower bay. The committee's findings were presented in a Summary Report (Delaware Bay Oil Transport Committee 1973a) and technical report (Delaware Bay Oil Transport Committee 1973b). No new legislation resulted immediately from the report.

Between 1969 and 1973, business and federal interest in constructing a downbay deepwater port was great. Other projects were proposed including a crude oil port immediately outside the bay mouth in federal waters (Soros and Hakman 1973) and a project inside the bay for crude shipment and resort development (Hudson 1973).

The effect of the two study committees appointed by Governor Peterson, as well as the public concern for environmental quality, was to discourage further planning for the use of the deepwater channel in the lower bay for commercial purposes for the next decade. The practical result was that lightering continued as before with operational oversight by the U.S. Coast Guard, and navigation and channel maintenance by the U.S. Army Corps of Engineers. The State of Delaware made no serious attempt to regulate or to collect fees on crude oil lightered in state waters.

Presently (i.e. 1982-83) considerable interest is growing for a coal-transfer operation in the same area as that used for oil lightering (Silberman 1983). The operation would involve barge transfer to large coal colliers and would also have operational oversight by the Coast Guard (Silberman 1983).

RECOGNIZING THE LARGER OPPORTUNITY

Several other factors need to be identified, discussed, and fitted into an overall regional, national, and international picture to better explain the importance of a lower estuary port.

The first factor is shipping and industrial safety in the upper estuary. During the 1970s several shipping accidents occurred in or along the Delaware River, due in part to restricted operating conditions and in part to the dangerous nature of petroleum cargoes. Two of the major accidents were the explosion and sinking of the MV Elias on 9 April 1974 with the loss of 13 lives (USCG 1977a), and the collision of the SS Edgar M. Queen and the S/T Corinthos on 31 January 1975 with the loss of 26 lives (USCG 1977b). A number of lesser accidents also occurred.

The second factor is the transformation of the ports of Philadelphia and Camden from growing commercial centers to declining ports with waterfront areas being converted from shipping to residential and recreational uses. Examples include Penns Landing, covered piers used for indoor sports, and proposed high-rise apartment complexes built on abandoned pier sites.

The third factor is the problem of dredging. The 100-mile plus channel to Philadelphia is now maintained by dredging at an operating depth of 40 feet mean low water (MLW) at an annual cost of approximately $30 million, roughly 10% of the nation's total budget for maintaining all of its ocean ports and channels on the Atlantic, Gulf, and Pacific coasts. Dredge disposal areas onshore are nearly full. Deepening the channel, even by five feet, would cost hundreds of millions of dollars.

The fourth factor is the indisputable evidence that the United States has fallen behind other major maritime nations of the world in providing modern port facilities to stimulate international trade and provide shippers access to the most modern and cost-effective transportation systems to import and export goods.

Fifth, earlier proposals for deepwater port facilities in the lower bay have been devoted to handling a single commodity such as crude oil or coal. These specialized facilities possess no flexibility to accommodate alternate cargoes. Should demand for the particular commodity for which the facility was designed decline below some break-even point, the facility would be closed or abandoned by its owner, or be removed if provisions had been made to do so when permission was given for its installation. In other words, no consideration has been given by any commercial organization proposing to install permanent deepwater port facilities in the lower bay to meet the need for more universal and flexible port facilities for international commerce many decades into the future. Defining that broader need is the responsibility of public organizations and governments, both state and national.

A NATIONAL DEEPWATER PORT

The natural, sheltered deepwater channel located in Delaware waters of the lower bay is unique on the East Coast in that it is geographically central to the dense Boston-to-Norfolk population belt; it enjoys substantial subaqueous land areas on both sides of the channel on which port facilities could be developed; its construction and maintenance costs could be minimized while enjoying sheltered water with immediate access to the ocean; with relatively modest expense onshore connections to supporting infrastructure could be made; and a major cargo handling facility could be developed onshore and in the bay that could offer the option of sea and air shipment with great flexibility to respond to changing cargo and commodity mixes in the future.

Fundamentally, there are two generic design options that can be considered for a national deepwater port in the lower bay that make full use of the existing deepwater channel. Fortunately, these options are not mutually exclusive and could be developed sequentially over the coming century.

The two options presented below have emerged as logical outgrowths of the extensive conceptual engineering studies cited before. Option 1 was synthesized from the large number of concepts explored by the Oil Transport Committee (Delaware Bay Oil Transport Committee 1973a & b) and an analysis of the related resources such as the Dover Air Force Base as well as considerations of environmental and quality-of-life values of the citizens of Delaware. This concept was first presented at a luncheon talk to the Wilmington (Delaware) Rotary Club in April 1977 by this author (Gaither 1977) and later elaborated on (Murray et al. 1977, Gaither 1981). Option 2 is a synthesis of the proposals described by Descon Engineers (1968), Zapata Bulk Systems, Inc. (1971), and Hudson (1977).

Option 1: Construction of a Port Island On Lower Middle Shoal

Lower Middle Shoal, shown in Figure 19-1, is a natural feature that extends for nearly five miles along the outboard (northeast) sides of the deepwater channel. Preliminary seismic surveys (Weil 1977) indicate that this shoal is a stable structure, probably made up of granular material with fines interspersed, quite suitable to support heavy foundations. There is no evidence from the sketchy evidence, or from geologic conjecture, that unconsolidated organic material (peat and other recent marsh materials) are layered into the shoal structure. This however is an important issue to clarify.

Option 1 would be to construct a port-island using the existing Lower Middle Shoal as its core in the location shown in Figure 19-2. This shoal is attractive in that it provides shallow water immediately adjacent to deep water, thus minimizing the cost of dredging and filling. The ultimate dimensions of the port island would be on the order of five miles in length and one-half to three-quarters of a mile wide. It could be constructed in several stages so that additional capital investment would be made only after demonstrated use of the previous stage. The objective would be to construct high-value industrial-port land by filling to an elevation of 14 to 16 feet above mean sea level. Two advantages enjoyed by this option are: (1) Ship access could be provided on both sides of the island, with 40 feet mean low water (MLW) on the side nearer the existing channel and as deep as 90 feet MLW on the deep channel side. (2) Less cut and fill would be required, thus reducing the capital, and probably the maintenance costs.

All-weather access would be provided from shore by a trestle carrying at least two rail tracks, a four-lane highway, an open pipe rack, and power transmission lines. Thus while nominally an island it would, in reality, be an extension of the land.

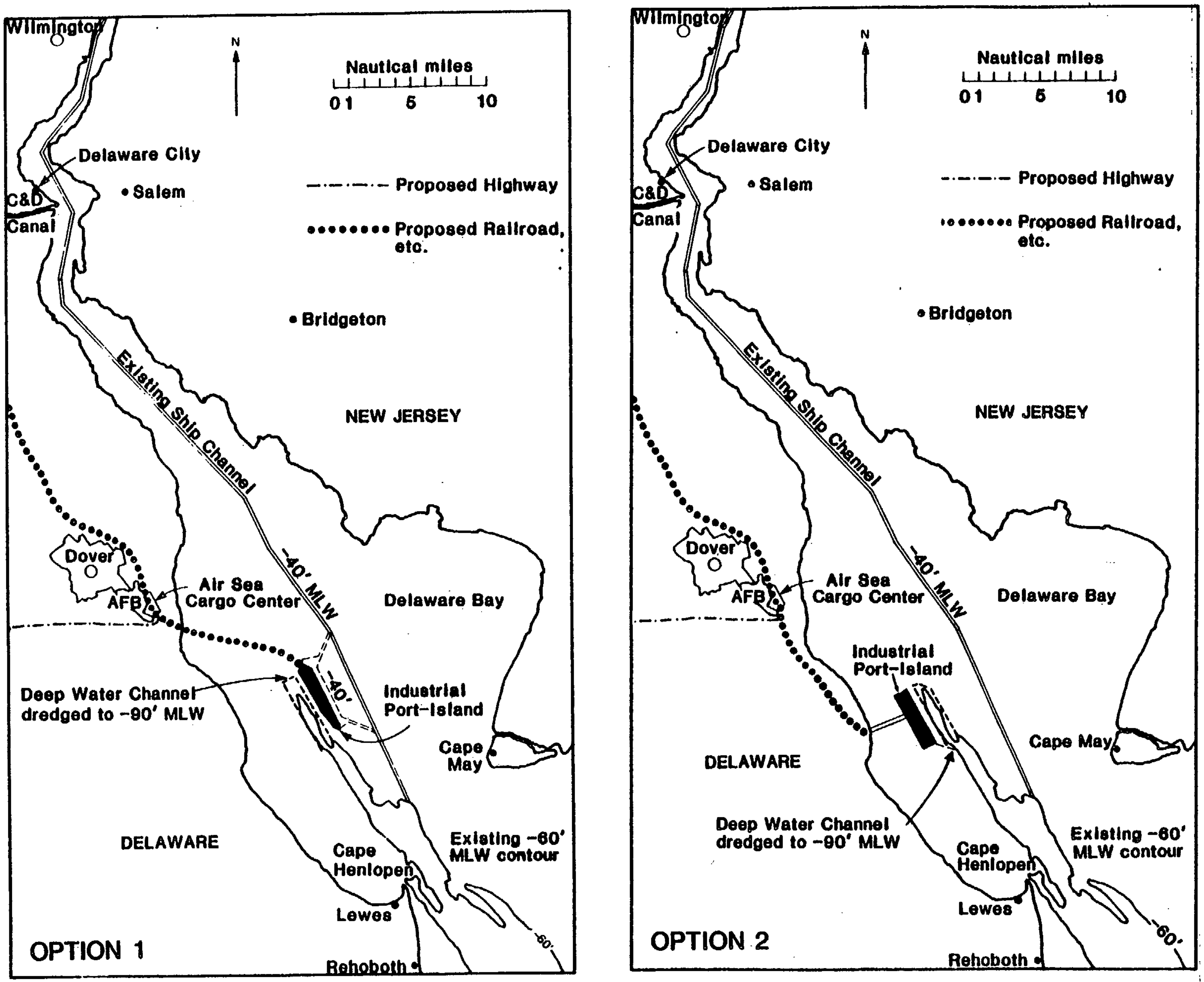

Figure 19-2. Two options for the lower estuary deepwater port.

The shore end of the trestle would terminate in an air-sea cargo center immediately adjacent to the Dover Air Force Base. Shared use of the base would permit shippers to enjoy the option of either containerized sea cargo or, if economics dictated, containerized air cargo carried by jumbo jet freighters.

Option 2: Construction of a Port Island on the Landward Side of the Deep Channel

The existing deepwater channel and lightering area is located approximately four miles from the nearest point on the Delaware coast. This section of coast is lightly populated due to the geologic feature of a thin line of barrier sand dune which is constantly moving landward over the marshes. The marshes also retreat landward due to the apparent sea-level rise which has been documented for many centuries. In one location known as Big Stone Beach, several miles of bay coast comprise solid headland soils which extend to the bay shore. A tract of 1800 acres was acquired by the Delaware Bay Transportation Company as a suitable place to construct a tank farm needed to service their proposed oil dock located four miles across the shallows at the edge of the natural deep channel.

It would be technically feasible to construct a diked containment structure several miles offshore from the Big Stone Beach property to contain fill for port development. These dikes would be located so that the volume of dredge material taken from the bay bottom to provide an access channel would equal the volume of fill material required to raise the land behind the dikes to a suitable elevation for port operations. This elevation would probably be within 14 to 16 feet above mean sea level. One possible configuration for such a project is shown as Option 2 in Figure 19-2 with a trestle or causeway connected to shore.

The advantages of this option are that it would permit the construction of a very large port area that could be extended up and down the coast over a long period of time. Also, access would be provided by a shorter causeway or trestle than required by Option 1. The initial area shown in Figure 19-2 is approximately five square miles.

Disadvantages of this option are that it would create a substantial disturbance in the configuration of the lower bay with attendant alteration in current patterns. Further, it would encourage the development of an industrial complex in lower Kent and upper Sussex Counties, creating substantial changes in shoreline use away from the traditional recreation and agricultural uses now widely accepted and enjoyed. Finally, this configuration would not be as amenable as Option 1 to providing access to the existing 40-feet MLW channel on one side and the deepwater channel on the other side.

HOW PREDICTIVE MODELS CAN BE USED

The use of the predictive models will play a key role in evaluating either option described above. How will these mathematical or analog models be used? First, and most obvious, is the use of models to predict altered water movements caused by the filled structures and the location of sedimentation as well as scour areas. Physical models of sediment transport would allow the prediction of dredging effects on estuarine biology and probable maintenance dredging locations. These modeling efforts would be of crucial importance in the designing of structures in planning construction sequences, and in obtaining public acceptance. The investigations being carried out under the DRBA/Sea Grant Delaware Estuary Project are of great importance as forerunners to later site-specific and structure-specific studies focused on the effects of potential designs. Background information must be gathered and the estuary understood from a scientific point of view so that later engineering studies employing predictive models can be carried out with confidence.

To predict onshore effects, models would also play an important role. Transportation models of total shipping systems are necessary to accurately compare alternative port sites for various cargoes (Gaither and Sides 1969). Of central importance would be operational models of the island complex and the air-sea cargo center. Economic models of the impact of a national deepwater port in the lower estuary should be constructed to predict effects on: (1) the Dover area and Kent County, (2) the State of Delaware, (3) the Delaware Valley Region, and the eastern United States tributaries to the port. Regional economic models of this type already exist and no doubt could be expanded to include the effects of the proposed port options (Latham and Black 1981, Brucker and Hastings 1983).

The reliablity of mathematical models varies with the complexity of the problem and the understanding of how the system functions. Scientists, engineers, and economists do not understand all systems equally well. Several types of models have been discussed briefly above. Each has a different degree of sophistication and reliability.

Economic models of transportation systems are reliable in that they incorporate cost and facility components which can be defined with considerable precision. Shipping rates per ton-mile can be specified. The capital cost of facilities that are not yet to be constructed, such as ports, highways, and pipelines, can be estimated with considerable confidence if designed and carried to the point where engineering quantities and construction procedures can be accurately estimated. However, such estimates can be a problem when inflation rates are difficult to predict. These models must also include estimated costs of capital and future interest rates which are more difficult to predict. The degree to which these future variables affect the accuracy of model output depends to considerable extent on how many of the major capital and operating costs can be fixed early in the project and thus make the model less sensitive to these future fluctuations. Models of regional economic effects are less well understood because they involve human behavior patterns which respond to various economic and social stimuli.

A second class of model is hydrodynamic, concerned with water current directions and velocities. Here also considerable experience is available and known techniques are being applied presently to the hydrodynamic models of Delaware Estuary (see Chapter 3). Yet the Delaware Estuary is complex. It is not a simple system to model. Its currents are governed by tides which reverse twice daily and its bottom topography is quite unique, causing transient features known as fronts or convergence zones to form and disappear during each tidal cycle. To model these features accurately is a challenge. There is reason for confidence, however, because of the current measurement and modeling research in the Delaware Estuary Project.

The least reliable models, yet very important, are those that deal with relationships between marine organisms and the chemical soup in which they live. This situation should not be a cause for alarm or abandonment, but rather a warning that the results of these models will not be available or yield dependable results as soon as those which are constructed of well understood and easily quantified relationships. It is into this class of model that the greatest effort is now going in the Delaware Estuary Project. It is accurate to observe that until a phenomenon is understood well enough to be modeled, it is not understood well enough to be explained. That is why the early and major effort in the Delaware Estuary Project are on acquisition of field data and experimental rate measurements of chemical changes and biological food web relationships.

ECONOMIC ISSUES

The economic issues connected with a national deepwater port in the lower estuary fall into several categories including construction financing; operating cost policy; local, state, and regional economic impact; effects on competing East Coast ports; transportation pricing policy; and effect on industrial activity in the United States.

Construction Financing

Very preliminary estimates of project construction are $2 to $3 billion to build the port-island, access trestle, and the air-sea-cargo center (Murray et al. 1977). An additional $2 to $3 billion will be needed to build and upgrade roads and railroads necessary to provide efficient access to the port. More definitive designs and cost estimates will be needed before a reliable construction cost estimate can be prepared.

The three sources of capital to build the project are private, public, and foreign. In the private category are the industries that would benefit directly from access to lower-cost imports and exports which could be carried in larger ships. The use of commercial lending sources to raise construction capital would place a substantial interest-cost burden on port operations. Due to the general purpose of the proposed port-island, constructed and operated to promote a cost-effective import-export economy in the United States, it is not immediately evident that using private capital would promote optimum use of the facility.

Public financing of the capital costs could be undertaken in a variety of ways. The simplest and most direct would be to obtain a federal appropriation. The rationale for this action by the federal government would be that the project serves a "public purpose" and thus should be financed by tax revenues. This would place the minimum operating-cost burden on the completed port-island and should allow operational rates to be set at a level low enough to stimulate port use. Other options include low-interest bonds issued by a public or quasi-public body.

Foreign financing might be arranged for all or part of the capital cost. Candidate nations and corporations would be those that trade extensively with the United States, particularly Japan and northern European countries.

Operating Costs

Operating costs will include capital debt retirement, if any, port administration, contribution to a reserve fund for port-island and infrastructure upkeep, and dredging costs to maintain access from the ocean to the port-island. These costs should be met by the lease charges made to island tenants and organizations licensed to provide needed services. Lease terms should require financial and legal provision for the tenant to remove all facilities on the port-island as well as dock facilities serving the site at the conclusion of the lease period.

Area Economic Inputs

The presence of the proposed national deepwater port would add substantially to the economic base of the State of Delaware, the Delaware Valley region and the eastern United States. Not only would the facility provide new industry to the mid-Delaware area but also, and importantly, it would protect the Dover area from the negative effects of possible reduced military use of the Dover Air Force Base in the future.

Personnel associated with all aspects of air or sea shipping and onshore service would be of well trained semiprofessional and professional categories. Due to automated ship operations and cargo handling the ratio of officers to seamen is rising rapidly. This means that the educational level, and thus the general quality, of personnel associated with the port and air sea-cargo center would be high.

Effect on Competing East Coast Ports

On first examination it might be assumed that opening a national deepwater port in the lower Delaware Estuary could have a detrimental effect on the ports of New York, Philadelphia, Wilmington, Baltimore, and Norfolk. This need not be the case if care is taken to involve those ports in the process of planning the proposed deep-draft port. First, it must be remembered that the objective of constructing a national deepwater port and air-sea-cargo center is to increase U.S. imports and exports by reducing transoceanic transportation costs. With the new national deepwater port in lower Delaware Estuary, the existing ports enumerated above could be served by barge and shallow-draft ships while at the same time saving on dredging costs. Planning from the outset to use these existing ports as feeders for the deep-draft port would permit them not only to maintain, but also to increase, their level of industrial activity dependent on movement of materials and commodities in world trade. If, on the other hand, these existing East Coast ports do not plan aggressively to benefit from the new deep-draft port in the lower Delaware Estuary, then indeed their commercial sector, dependent on low-cost transoceanic shipping, could decline.

Transportation Pricing Policy

A transcontinental land bridge linking the Atlantic and Pacific Oceans by high-quality rail service and efficient hinterland access to the port for shippers of the eastern United States will be important. This will require national policy to insure attractive rail and highway rates and use charges so that maximum benefit will be realized by the nation in return for its investment in the proposed deep-draft port and air-sea-cargo center.

Effect on U.S. Industrial Activity

As stated eariler, the national objective to be achieved through construction and operation of the proposed deep-draft facility is to stimulate commercial activity in the United States by reducing the transportation cost component of international trade. This goal should be foremost in guiding the design, financing, and operation of the project.

REGULATORY AND MANAGEMENT ISSUES

The most serious issue now confronting a deepwater port plan is the lack of a single agency or constituency to coordinate and promote planning of a national deepwater port in the lower estuary. Once a focal agency is recognized it will be possible to address the regulatory and management issues.

Regulatory issues will include rail and trucking rates for interstate commerce, permits for constructing and operating the proposed lower bay deep-draft port, and Jones Act restrictions on shipping systems available to service the port.

On the management side the most critical issue is the lack of a widely accepted, financially sound, and administratively experienced organization designated to plan, construct, and operate the proposed port and air-sea-cargo center. The designation or creation of such an agency is essential to the further exploration which, if favorable, will lead to the implementation of the project.

To create or designate a management agency to lead the development of this project will require legislation, certainly at the state level and probably at the national level. Legal changes fall into three categories: authorization, financing, and regulation.

Authorization

At present there is no organization authorized to construct a deep-draft terminal comprising fixed facilities in the lower Delaware Bay. The DRBA which was established through the Delaware-New Jersey Compact (1962) clearly envisioned that it would, at some future date, be authorized to undertake such a role. Article IV (b) of the Compact gives as the second purpose of the DRBA: "The planning, financing, development, construction, purchase, lease, maintenance, improvement and operation of any transportation or terminal facility within those areas of both States which border on or are adjacent to the Delaware River or Bay south of the aforesaid line and which in the judgement of the States is required for the sound economic development of the area...."

If concurrent authorizing legislation were approved by Delaware and New Jersey then the DRBA could be empowered to undertake the design, financing, construction, and operation of a deep-draft port in the lower Delaware Estuary.

Regulation

The proposed national deepwater port in the lower Delaware Bay, being in the territorial waters of the State of Delaware does not come under the jurisdiction of the National Deepwater Port Act. Present permitting procedures following approval of applicable federal, state and local agencies are adequate to accommodate all construction authorization. Existing regulatory procedures of the U.S. Coast Guard are adequate to accommodate all navigation requirements. The agency authorized to construct and operate such a port would no doubt develop suitable regulations to define special construction and operational requirements.

ROLES FOR THE DRBA IN A DEEPWATER PORT

As stated above, the intent of the authors of the Delaware-New Jersey Compact creating the DRBA was that first, it would be responsible for crossings (Article IV (a)) and, second, it would be responsible for transportation or terminal facilities (Article IV (b)). The DRBA has proven itself a capable operator of bridge and ferry crossings of the bay. It is an organization with substantial financial resources and it controls revenue-generating facilities. In light of these accomplishments to date, it is logical that the DRBA assume a larger role in ensuring the sound economic development of the area. Specific roles which could be played by the DRBA include the following.

Enlarge Authorized Role of the DRBA

In light of the successful installation and operation of the twin bridges and the Cape May-Lewes Ferry, defined in Article IV (a) of the Compact, it is logical that next the states of Delaware and New Jersey, authorize the DRBA to undertake duties envisioned in Article IV (b). There is a clear and constructive role for the DRBA in carrying ahead the exploration of the national deepwater-port project described in this chapter.

How much could the DRBA do without further authorization and how much could be carried out under their present roles defined by the bistate compact? Clearly, detailed planning and construction of a port would require concurrent legislation in New Jersey and Delaware. However, studies of the port concept could be accomplished. There are precedents for the DRBA to support feasibility studies (Latchum 1967, Biondi and Babiarz 1978, Biondi 1982). The other two roles discussed below are such studies. It is not suggested that DRBA seek legislation relating to the deepwater port; rather study on the estuary and examination of the deepwater port concept should be done first. Then, and only if a major deepwater port appears to be economically feasible and ecologically sound, should the DRBA seek legislation. On the other hand, since present oil transfer and proposed coal transfer are a de-facto deepwater port, the DRBA should seek a permitting role in these activities which would require legislation (this was discussed in Chapter 16).

Continue Scientific Study of the Delaware Estuary

For the DRBA to be granted the enlarged role suggested in the preceding section, the citizens of Delaware and New Jersey will need to feel confident that the DRBA possesses a thorough understanding of the estuary and that it could accurately predict the consequences of any alteration of the estuary to accommodate a national deepwater port. A good beginning has been made with the DRBA/Sea Grant Delaware Estuary Project. An important role for the DRBA is to establish itself as the undisputed authority on the hydrography, chemistry, and biology of the estuary through continued and integrated studies. This can be accomplished, and public confidence in the DRBA enhanced, by supporting subsequent phases of this project in order to prepare persuasive documentary evidence describing how the estuary works and how changes will affect it. This is a finite and possible task in the coming five to eight years. Through careful attention to providing the public with timely and comprehensible information, the suggested scientific efforts can swing public confidence to support an expanded role for the DRBA.

Examine the Deepwater Port Concept

Port interests in the upper Delaware Estuary recognize the need to examine the concept of a deepwater port in the lower estuary and, in particular, determine how such a new port can benefit the entire region. An international conference focusing on this issue is now being planned for the spring of 1984 by Drexel University, the University of Delaware, and Princeton University. A prominent role in the sponsorship of this conference, and in publishing its proceedings, would be appropriate for the DRBA.

Several years may be required to obtain public support for the expanded role of the DRBA suggested above. During that time, a research and educational project in marine transportation, using the national deepwater port as a case study, could be carried on at the University of Delaware College of Marine Studies. This effort would build on over a decade of attention to this subject at that institution. The suggested project would encompass graduate education and public awareness. This approach will permit solid progress to be made while the DRBA is seeking necessary authorization to proceed on its own in exploring the concept of a national deepwater port.