AN ASSESSMENT OF KEY BIOLOGICAL RESOURCES IN THE DELAWARE RIVER ESTUARY

Versar INC.

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Submitted to:

Delaware Estuary Program
c/o U.S. Environmental Protection Agency
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EXECUTIVE SUMMARY

A review of information pertaining to the biological resources in and around the Delaware estuary was initiated at the request of the Delaware Estuary Program. Based upon an initial review of published information, key biological communities and species were identified for this estuary. Determinations of which communities and species were key resources were based upon ecological importance, significance to commercial or recreational fisheries, and designations of endangered, threatened, or protected status. Using these criteria, seven biological communities and 40 species were determined to be key biological resources within the Delaware estuary.

Using additional information from published and unpublished sources, the current status and historical trends for each community and species were described. Where possible, information was assembled and presented for three regions of the estuary which had distinct physical and chemical characteristics and different pollution histories. These regions were:

- Delaware Bay Region -- from the mouth of the bay (rkm 0) to Artificial Island (rkm ≈ 80); characterized as having waters with marine to brackish oligohaline salinities.
- Transition Region -- from Artificial Island (rkm ≈ 80) to Marcus Hook, PA (rkm ≈ 130); characterized as a low salinity, high turbidity region with a long history of repeated impacts from contaminant loadings.
- Tidal Fresh Region -- from Marcus Hook, PA (rkm ≈ 130) to Trenton, NJ (rkm ≈ 220); the fresh water portion of the estuary that is influenced by the tides.

Information was available to describe status and trends for the major biological communities in all three regions of the estuary. However, most of the longer term, more detailed studies were completed in the bay region of the estuary. Status and trends information for birds could not be presented by estuarine region because of their broader distribution around the estuary.

More information was available to describe status and trends for commercially important species and communities containing commercially important species than for other species and communities. Quantitative information to describe historical trends for fish and shellfish species, for example, were available back to 1880. Shorter-term (about 30 years) quantitative datasets were located for bird species.

Historical trends for the biological resources of the Delaware estuary are associated with human activities in and around the estuary. For example, overfishing and other fishery related activities appear to have been the cause of the decline in sturgeon at the turn of the century and oysters in the 1940's. Declining water quality as a result of intense urbanization and industrialization, mostly in the transition and tidal fresh regions of the estuary, are linked to reductions in anadromous fish stocks such as alewife and shad. Improvements in water quality in recent years (mainly dissolved oxygen concentrations) are associated with the return of these and other fish species to the estuary. Regulatory control of DDT and other chlorinated pesticides appears to be a principal cause of recent increases in raptors such as the bald eagle, osprey, and peregrine falcon, all of which suffered great declines in the 1960's.

This assessment suggests that nearly all of the biological communities living in or around the Delaware estuary are key biological resources and deserve attention. However, although all communities may be important, all species are not. Important species tend to be those that are valued by man specifically as a result of their 11commercial or recreational value, aesthetic qualities, or perceived importance.

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INTRODUCTION

The purpose of this report is to identify the key biological resources of the Delaware estuary and describe the current status of and historical changes in those resources. The report is based upon a synoptic review of available literature and unpublished datasets for the Delaware estuary and was completed for the Delaware Estuary Program.

The U.S. Environmental Protection Agency (USEPA) initiated the Delaware Estuary Program in 1988 at the request of the states of Delaware, New Jersey, and Pennsylvania (Castle et al. 1988). The program is conducting research to identify current problems in the Delaware estuary and the biological resources that are most impacted by those problems. This research is being conducted as background for the formulation of a Comprehensive Conservation Management Plan (CCMP) designed to improve overall environmental conditions within the estuary. The CCMP is intended to improve biological resources through direct management (e.g., seasonal limitations on shellfish harvesting) or indirect management to control pollutant loadings. To make such recommendations, it is imperative to identify which biological resources within the estuary are important and which need to be managed.

Reviews of the Delaware estuary as a biological system are rare. Noted exceptions are the reviews of Shuster (1959), Sharp (1983), Bryant and Pennock (1988), Castle et al. (1988), and Hargreaves and Kraeuter (1991). More commonly, publications on the estuary have focused upon specific biological communities (e.g., phytoplankton, benthos, fish) or species, without forming a synoptic picture of the estuarine ecosystem. Most individual studies have concentrated upon physical and chemical conditions in the estuary and how changes have resulted in water quality improvements (Albert 1988), or the recovery of biological resources. Consideration of what communities and species are important to the estuary in the context of an ecological system has not received much attention.

In this report, we identify the important biological communities and species in and around the Delaware estuary. Our study was limited to data from available publications and unpublished datasets. Our study was further limited to the estuarine portion of the Delaware Bay and River system, from the mouth of the bay to the head of tide in Trenton, NJ. Most of the data we reviewed pertains to the estuary proper, although information from selected tributaries was included.

The report is organized as follows: a brief description of the physical and chemical environment of the Delaware estuary, as background for the biology of the estuary; an overview of how information was collected and what criteria were used to identify important biological communities and species. The important biological communities and species are then presented along with data supporting the selection of each. The available data are used to describe the current status of the key biological resources in the Delaware estuary. Historical trends for those resources are also described. The report ends with a set of conclusions and recommendations potentially of use to the Delaware Estuary Program for management of the biological resources within the estuary.

PHYSICAL BACKGROUND

The Delaware estuary extends approximately 134 km from the mouth of the Delaware Bay at Liston Point, Delaware to the head of tide at Trenton, New Jersey (Figure 1). General descriptions of the estuary have concentrated on descriptions of the physical estuarine environment, its surroundings, or the physical and chemical conditions within the estuary itself (Sharp et al. 1982) For example, the Delaware estuary is one of the largest in the United States (approximately 1773 km^2), rivaled only by Chesapeake Bay and Long Island Sound. The estuary has the distinction of supporting one of the world's largest freshwater ports (Philadelphia Planning Commission 1982; Sharp 1986), one of the world's greatest concentrations of industry, and the second largest complex of oil-refining and petrochemical plants (Council on Environmental Quality 1975). Approximately 70% of the oil arriving at the nation's east coast ports moves through the combined Ports of Philadelphia, which include berths in all three states in the region. About 90 major municipal and industrial effluents discharge directly into the estuary, not including over 300 combined sewer overflows and various other pollution sources (Albert and Kausch 1988). Clearly, the Delaware estuary is exposed daily to a number of anthropogenic stresses.

Physically, the Delaware estuary is comprised of the Delaware Bay and the portion of the Delaware River to the head of tide (Table 1). Delaware Bay is usually described as the portion of the estuary from the mouth of the bay to a point below Artificial Island, where the estuary becomes narrower (Figure 1). Salinities in this region range from those typical of marine water at the mouth, to brackish oligohaline water at the head of the bay (Figure 2). The tidal riverine portion of the estuary begins just south of Philadelphia, PA near Marcus Hook, PA and runs to Trenton, NJ. Salinities in this region of the estuary are typically those of freshwater, but during low river flow periods, intrusions of brackish water from down river may occur (Figure 2). In between the bay and river regions is a transition zone, or low salinity, high turbidity region with a long history of repeated impacts from contaminant loadings (Albert 1988). Median concentrations of suspended solids are typically highest in this region for most of the year (Figure 3). Because the physical and chemical environments and the histories of these regions are very different, general patterns for the status and trends of the important biological communities and species will be presented for each.

The Delaware Bay portion of the estuary is the drowned valley of the Delaware River formed after seaward flooding, following the last glaciation. The ongoing marine transgression continues to effect the distribution of species within the estuary, particularly those in fringing marsh communities (Allen 1974). In the coastal Delaware area, sea level rise continues at a rate of about 6.2 cm/century (Belknap 1975). The mean depth of the bay is 9.7 m, but over 80% of the bay is less than nine meters deep. Deeper sections of the bay are located in the western portion, and the maximum depth is about 46 m. Unlike its southern neighbor, Chesapeake Bay, the Delaware Bay is well mixed, with very little long-term vertical stratification (Biggs 1978; Smullen et al. 1983). Short-term vertical stratification is common and is generally due to variations in river flow. There is a prominent horizontal salinity gradient along the north-south axis of the Delaware Bay, due to the mixing of seawater and freshwater (Figure 2).

The bay is fed by freshwater from the Delaware River and its major tributary, the Schuylkill River. Together, these rivers drain 65% of the 33,060 km^2 Delaware River Basin (United States Geological Survey 1982) and carry about 73% (400 m^3/s) of the total freshwater flow to the estuary. Fifty-eight percent of the freshwater flow is from the Delaware River, as measured at Trenton, NJ. Small tributaries supply the remaining freshwater flow (153 m^3/s) to the estuary (Smullen et al. 1983). The average flushing time for the estuary is about 100 days (range 60 to 120 days; Ketchum 1952).

The upstream extension of saline waters in the Delaware estuary has increased over the last fifty years (Smullen et al. 1983). Increased salinities may be due to a combination of rising sea level and upstream consumption and withdrawal of freshwater. The landward progression of saline waters caused the City of Chester, Pennsylvania to abandon the river as a source of freshwater in 1951. Since freshwater supply is a major controlling influence on the distribution of salt within the estuary, severe droughts continue to threaten other upstream municipal water supplies, including those to the city of Philadelphia, PA.

Historically, the most polluted region of the bay has been between Marcus Hook, PA and Philadelphia, PA, extending to Trenton, NJ in some years. A review of the history of water quality in the region was compiled by Albert (1988) (Table 2). Conditions were worst during the 1940's, when anoxia and hypoxia extended from Wilmington to Trenton, massive fish kills were common, and waters were mephitic and corroded the paint on ships berthed in the river. The region between Marcus Hook and Philadelphia, PA became known as a "dead zone," effectively obstructing the migration of anadromous fish through the estuary because of grossly depleted oxygen concentrations.

Conditions within the estuary have improved dramatically since the 1940's and 1950's due, in part, to the establishment of a federal, multistate, regulatory agency with broad responsibility for all facets of water resource management. Water quality improvements came about because this agency (The Delaware River Basin Commission - DRBC) adopted higher water quality standards at a time when federal funds became available to build or improve publicly owned treatment facilities. At present, water quality, particularly dissolved oxygen concentrations, has improved greatly (Albert 1988; Lee, pers. comm.) (Figure 4). However, water quality is still not adequate to support fishable/swimmable classifications along the entire reach of the estuary.

Table 1
Regions of the Delaware Estuary

	Geographical Range	DRBC River km*	Approximate Area (km^2)
Delaware Bay	Bay mouth to Artificial Island	0 to 80	1600
Transition Zone	Artificial Island to Marcus Hook, PA	80 to 130	118
Tidal Fresh	Marcus Hook, PA to Trenton, NJ	130 - 217	55

* From DRBC (1988), converting river mile to river km

Table 2
Delaware Estuary Water Quality History*

Approximate Period	General Water Quality Description
1800 - 1860	Increased incidence of pollution of local water supplies. Condition of Philadelphia harbor a concern. The first pollution survey was conducted (1799).
1880 - 1910	Increased population and pollution contributes to a rise in waterborne disease from consumption of river water.
1936 - 1960	Rapid degradation of water quality due to population and industrial growth and expansion of urban water and sewer systems. Descriptions of anoxic conditions, fish kills, mephitic waters abound. All time worst water conditions described for 1946.
1960 - 1980	Higher water quality standards adopted by the newly formed Delaware River Basin Commission and federal construction funds for treatment plants improve water quality throughout the river.
1980 -	Dissolved oxygen conditions, through improved, remain a problem along with the presence of toxics. Overall goal is to make the entire estuary fishable and swimmable.

* Compiled from Albert (1988).

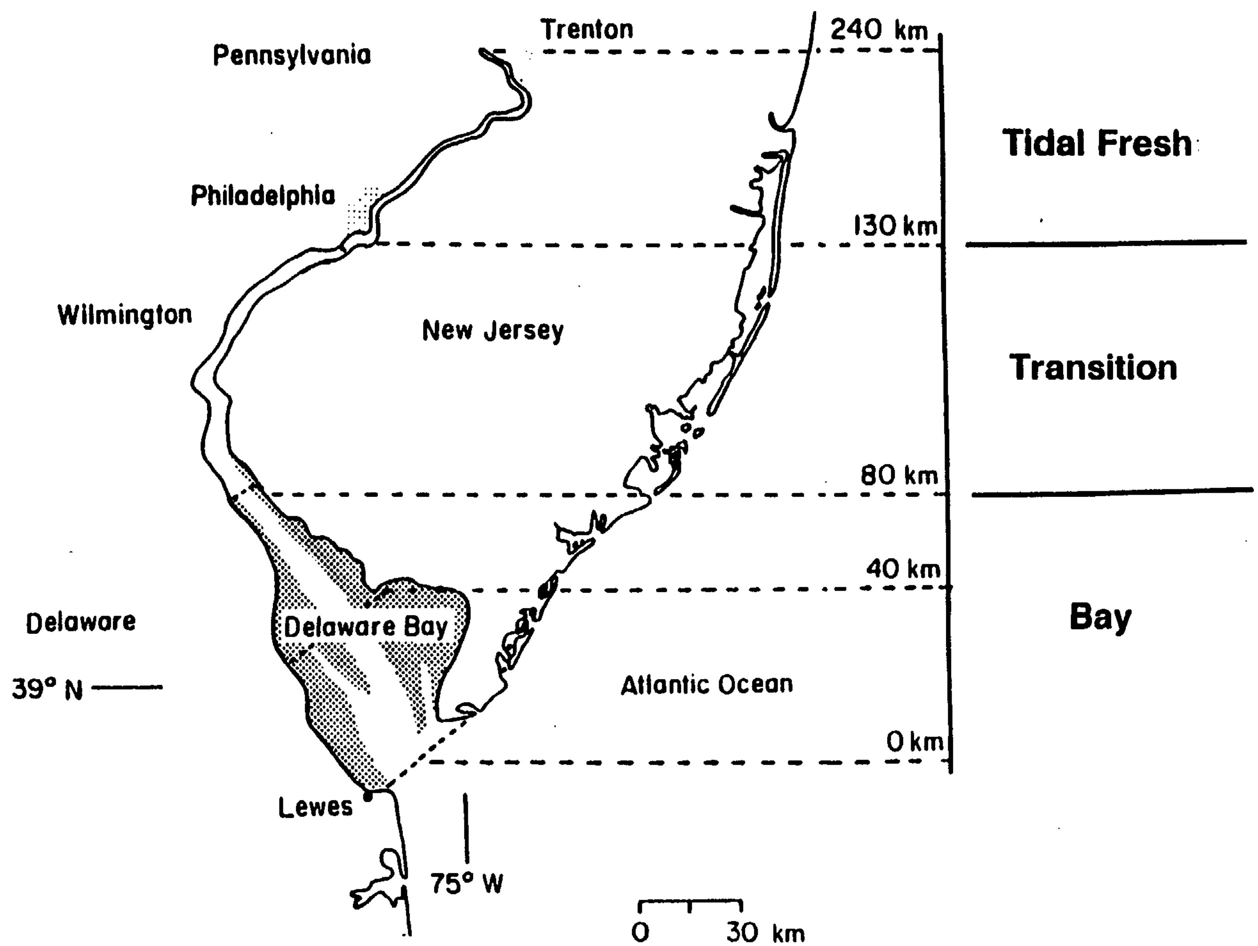
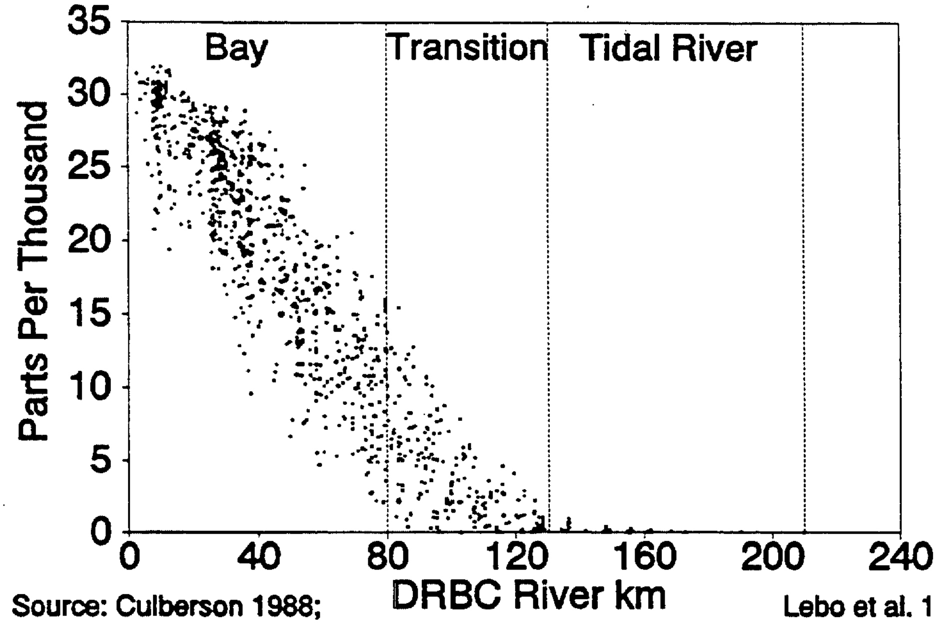


Figure 1
Delaware Estuary Salinity Regions

Figure 2

Salinity Distribution by River km

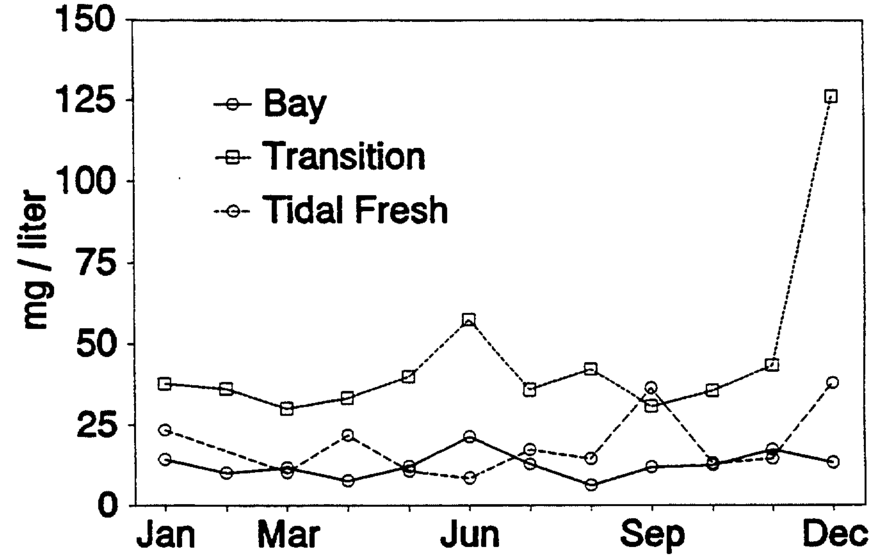


Source: Culberson 1988; Lebo et al. 1990

Figure 3

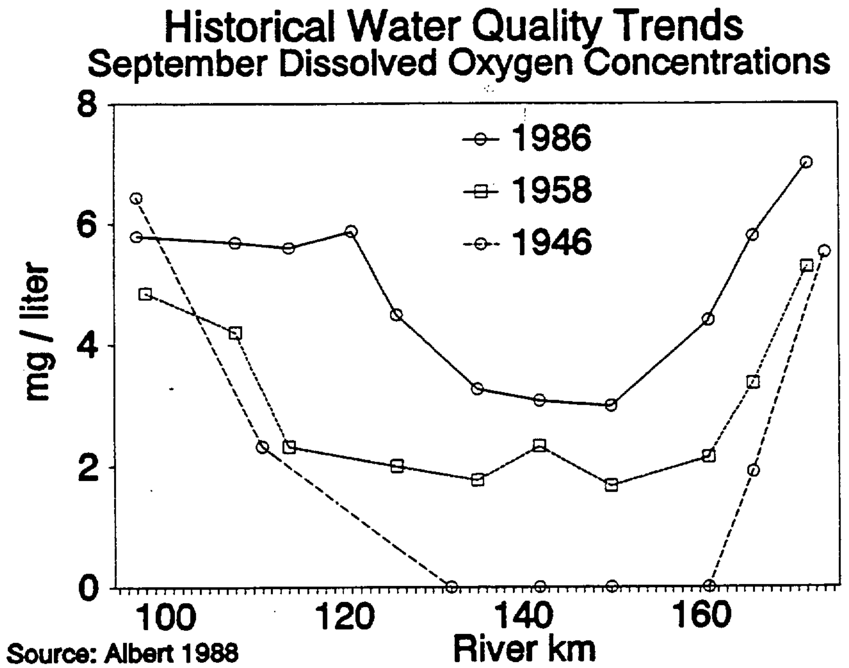
Annual Cycle of Suspended Solids

Median Concentrations



Source: Culberson 1988; Lebo et al. 1990

Figure 4


Historical Water Quality Trends
September Dissolved Oxygen Concentrations
1986
1958
1946
mg / liter
8
6
4
2
0
100
120
140
160
River km
Source: Albert 1988

IDENTIFICATION OF KEY BIOLOGICAL RESOURCES

The identification of key biological resources for the Delaware estuary required thorough review of the available information concerning the biology of the estuary. Based upon the review, important biological communities and species were identified and data were compiled to support the list of important biological resources.

The information reviewed for this project is catalogued in Appendix A (Annotated Bibliography of Existing Datasets). This catalog of publications and data sources was compiled through computer database searches and numerous contacts with federal, regional, state, and university staff with expertise pertaining to the biological resources in the Delaware.

A literature search was performed using DIALOG, a computer based, online system allowing access to summaries of articles and reports located by keywords. Three databases accessed by Dialog were searched (Aquatic Sciences Abstracts, NTIS, and America: History and Life) using the keywords Delaware River, Delaware estuary, and Delaware Bay, combined separately with the keywords plankton, phytoplankton, zooplankton, benthic or benthos, fish, and birds.

Additional published literature was found by reviewing citations in articles identified by the computer database search and through review of general publications concerning the Delaware estuary (Sharp 1983; Bryant and Pennock 1988; Castle et al. 1988; Majumdar et al. 1988). University libraries provided additional references. Rutgers University library in New Brunswick, NJ and the University of Delaware libraries in Newark and at the Marine Science Station in Lewes were visited to search for theses, dissertations, and other reports pertaining to the biological resources of the Delaware.

In addition to published data sources, unpublished datasets were located with the assistance of federal agencies and representatives from the states of Delaware, New Jersey, and Pennsylvania. Some agencies provided data in electronic formats to facilitate our analyses. Computerized datasets were obtained from the National Marine Fisheries Service (commercial fishing statistics), the U.S. Fish and Wildlife Service (annual breeding bird survey), and the Cornell University Orthinology Laboratory (Audubon Christmas bird counts).

Our initial investigation focused upon collecting basic descriptive information on biological communities within the Delaware estuary. This effort included a study of important pelagic and benthic communities, as well as specific species of shellfish, fish, and birds. Our objective in these initial investigations was to identify communities and species that are known to be or potentially are important species.

To limit overlap with other ongoing projects being conducted for the Delaware Estuary Program, we did not review the condition and areal extent of some habitats. Marsh and seagrass habitats were not treated, nor was the mapping of shellfish beds. Information encountered during our review concerning these resources was forwarded to the appropriate Delaware estuary research group.

The importance of communities and species was judged by assessing the overall ecological role they might have in the Delaware estuary. Communities and species were considered to be ecologically important if they:

- Produce significant quantities of organic matter for other resources within the estuary

- Are prey for other resources within the estuary

- Significantly control or modify the population levels or seasonal dynamics of other resources within the estuary by grazing, predation, or disturbance

- Control or modify some process (such as benthic nutrient regeneration) that influences other resources within the estuary.

Ecological importance was inferred in most cases, since energetic and biomass measurements were rare, and interactions between most species, particularly invertebrates, were largely unknown. Despite many uncertainties, attempts were made to estimate the importance of communities and species in terms of their general ecological importance in the estuary.

Species were also considered important if they contribute significantly to commercial or recreational landings or are classified as endangered, threatened, or protected by federal agencies or the states bordering the estuary.

Based upon the available published literature and unpublished data sources, seven types of biological communities and 40 species were identified as important biological resources within the Delaware estuary (Table 3). More literature and data sources were available for vertebrate communities (fish and birds) than for invertebrates and phytoplankton (Figure 5). Further, studies of the biological resources in the Delaware were not distributed equally between salinity regions (Figure 6). Studies of the fish and bird communities within the estuary were distributed approximately equally among bay, transitional, and tidal fresh regions. However, studies of zooplankton and benthic communities were conducted more commonly in the bay portion of the estuary. Ichthyoplankton studies were conducted more commonly in the transition and tidal fresh regions, mainly due to the large number of studies focused on striped bass.

Certain communities and groups of species were not included in our assessments because they did not meet our criteria for defining a key biological resource, or because insufficient information was available to assess ecological status and historical trends. For example, information concerning marine reptiles and mammals was limited to anecdotal accounts and occasional references to turtles caught in fish trawls.

Although these animals may be somewhat dependent upon the ecology of the estuary for food or habitat during specific seasons and certain periods of their life cycles, their influence on estuarine biological resources is probably insignificant. We realize, however, that some of these species are considered endangered by the states surrounding the Delaware. For example, the state of New Jersey lists four species of endangered reptiles (i.e., loggerhead sea turtle, leatherback sea turtle, hawksbill sea turtle, Kemp's Ridley sea turtle) and seven species of endangered marine mammals (i.e., right, sei, blue, finback, humpback, and sperm whales). The occurrence of endangered marine mammals in the waters of the Delaware is occassional and rare.

Aquatic reptiles and terrestrial mammals were not included in the bibliographic survey or assessments of status and trends for this project. Although these animals are somewhat dependent upon the ecology of the estuary, their influence on estuarine biological resources is probably insignificant.

Table 3
Important Biological Resources In the Delaware Estuary

Communities

Phytoplankton	Parabenthos
Zooplankton	Fish
Ichytyoplankton	Birds
Benthos	

Species

Benthic Invertebrates
American oyster - *Crassostrea virginica*
Hard clam - *Mercenaria mercenaria*
Blue crab - *Callinectes sapidus*
American lobster - *Homerus americanus*
Horseshoe crab - *Limulus polyphemus*

Fish
Striped bass - *Morone saxatilis*
American shad - *Alosa sapidissima*
Blueback herring - *Alosa aestivalis*
Alewife - *Alosa pseudoharengus*
White perch - *Morone americana*
Atlantic sturgeon - *Acipenser oxyrhynchus*
Shortnose sturgeon - *Acipenser brevirostrum*
Weakfish - *Cynoscion regalis*
Bluefish - *Pomatomus saltatrix*
Summer flounder - *Paralichthys dentatus*
Atlantic menhaden - *Brevoortia tyrannus*
Bay anchovy - *Anchoa mitchilli*
Spot - *Leiostomus xanthurus*
Scup - *Stenotomus versicolor*

Birds

Raptors
Bald eagle - *Haliaeetus leucocephalus*
Osprey - *Pandion haliaetus*
Peregrine falcon - *Falco peregrinus*
Northern harrier - *Circus cyaneus*

Waterfowl
Black duck - *Anas rubripes*
Canvasback - *Aythya valisneria*
Wood duck - *Aix sponsa*

Shorebirds
Semipalmated sandpiper - *Calidris pusilla*
Ruddy turnstone - *Arenaria interpres*
Dunlin - *Calidris alpina*
Black bellied plover - *Pluvialis squatarola*
Sanderling - *Calidris alba*
Piping plover - *Charadrius melodus*
Red Knot - *Calidris canutus*

Wading Birds
Black crowned night heron - *Nycticorax nycticorax*
Great blue heron - *Ardea herodias*
Green-backed heron - *Butorides striatus*
Snowy egret - *Egretta thula*
Great egret - *Casmerodius albus*

Gulls and Terns
Laughing gull - *Larus atricilla*
Least tern - *Sterna antillarum*

Figure 5

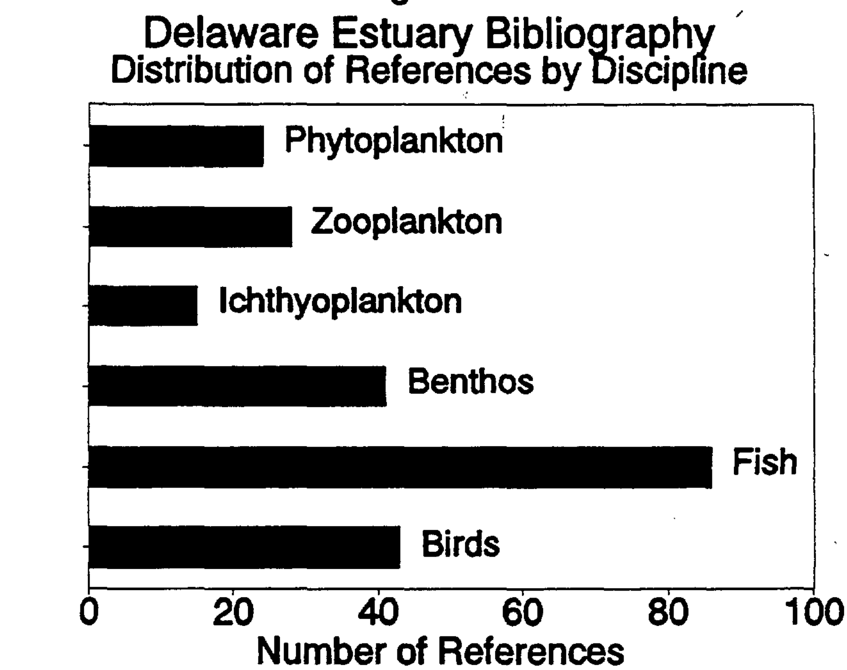
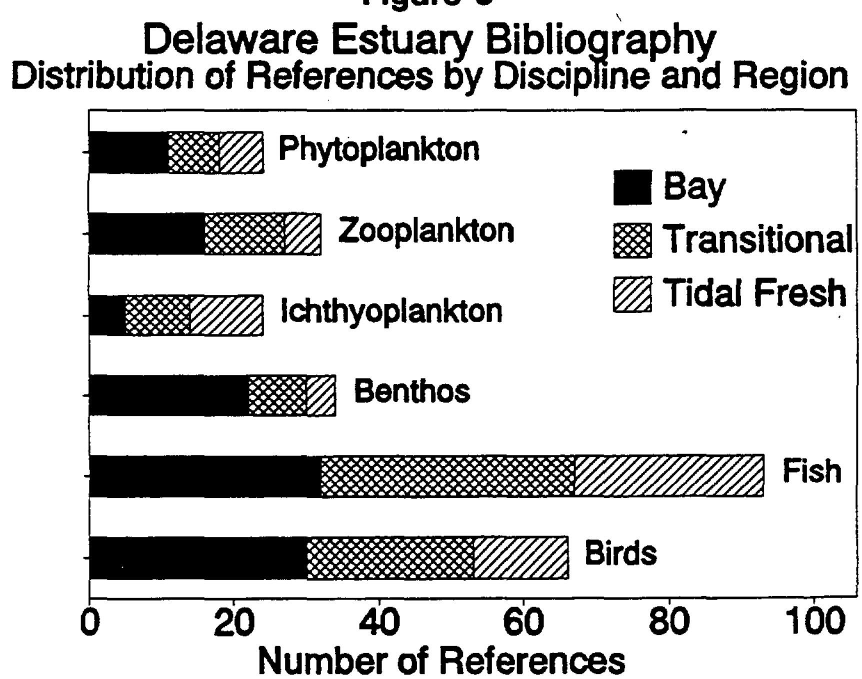


Figure 6



Phytoplankton Community

Like most temperate estuaries along the East Coast (Nixon 1983), the Delaware estuary is a phytoplankton-based system. Phytoplankton are microscopic, single-celled plants that drift passively with the tides and currents and produce organic matter photosynthetically. This organic matter forms the base of the Delaware estuary food web and is, ultimately, the dominant source of organic matter for most major biological communities. Other sources of organic matter within the estuary are thought to be of minor importance for use by biological communities. These other sources mainly produce detritus and include vascular plants (seagrasses and other attached macrophytes), exported organic matter from fringing marshes, detritus from upstream, and production from benthic algae.

No data could be found to estimate vascular plant production in the Delaware. Macrophyte production is generally limited in the estuary due to high turbidity, but the greater dominance and importance of macrophytes centuries ago cannot be discounted. It has been suggested that the supply of sediments to the estuary has increased two to four times due to urbanization (Mansue and Commings 1974). Although the magnitude of the impact has been questioned by other researchers, the relationship between sediment loads and urbanization is one that is generally accepted (Biggs and Beasley 1988).

The amount of organic matter exported from tidal marshes that fringe estuaries is still largely unknown, though recent studies suggest that this export is less than originally thought (see review by Nixon 1980). Several studies have shown that 20% to 45% of the primary production of a salt marsh, including organic matter from vascular plants, submerged aquatic vegetation, and edaphic algae, is exported to adjacent estuaries (Mitsch and Gosselink 1986). Isotopic tracer studies of the use of salt marsh organic matter, however, show that only certain invertebrates actually use this food source (Peterson et al. 1986). No hard data concerning the export of organic matter from Delaware estuary marshes could be located. Nonetheless, marshes are generally believed to be the most important source of detrital matter to food webs in the Delaware (Pennock 1988). No information concerning the use of detrital carbon from upstream sources could be found.

There is not likely to be a significant amount of autotrophic benthic production in the Delaware estuary, due to the high turbidity present throughout the estuary. The sedimentary environment, except in a few of the shallowest portions on the flanks of the estuary, is largely heterotrophic and dependent upon production from phytoplankton in the water column.

In the absence of better data, we assume that phytoplankton are the major source of organic matter to consumers within the Delaware estuary. Therefore, phytoplankton as a community were considered to be a key biological resource of the Delaware.

The current status and historical trends for phytoplankton were assessed by reviewing the available data for phytoplankton biomass, as measured by chlorophyll *a* concentrations in the water column. Additional assessments were made from measurements of the rate of primary production, although these data were generally less available than chlorophyll data.

Phytoplankton abundance data were generally not reviewed. Estimates of phytoplankton abundance are influenced significantly by differences in sample collection, preservation, and preparation. Additionally, it is difficult to assess the taxonomic expertise available when these studies were completed. Because of these problems, abundance was used only to identify dominant phytoplankton species to assess historical changes in community composition over time. Shifts in phytoplankton species composition, particularly shifts to smaller forms (e.g., flagellates vs diatoms), may have far greater impacts on the overall trophic structure of the system than changes in abundance (Steele 1974; Officer and Ryther 1980; Ryther and Officer 1981).

Zooplankton Community

As the primary consumers of the phytoplankton, the zooplankton are generally believed to be a critical component of the Delaware estuary food web (Pennock and Herman 1988). Crude estimates suggest that copepods in the lower bay potentially consume 90% of the planktonic primary production (Herman and Hargreaves 1988). Since consumption by bacteria is thought to be about 20% of phytoplankton production (Cole et al. 1987; Coffin and Sharp 1987), and benthic respiration measurements in the lower bay account for about 10% of primary production (Seitzinger 1988), it is unlikely that the consumption of phytoplankton by zooplankton is that high. Nevertheless, the number demonstrates that zooplankton as a community are potentially significant primary consumers in the estuary.

The zooplankton community is comprised of tiny organisms most of which have limited swimming ability and are transported primarily by tides and currents. The zooplankton includes organisms that spend their entire life in the plankton (holoplankton) and organisms that spend some portion of their juvenile lives in the plankton (meroplankton). Examples of the former are such diverse groups as copepods, cladocerans, and jellyfish. Meroplanktonic groups include the larvae of benthic invertebrates and fish (ichthyoplankton). Therefore, because of their role as major consumers of phytoplankton, and because the juveniles of many commercial and recreational species are transient members of the zooplankton, this group was included as a key biological resource of the Delaware estuary.

Status and trends assessments were completed using information available for zooplankton abundance and biomass. Far more data were available for abundance than for biomass. Due to problems in assessing the taxonomic quality of various studies and to the scope of this project, only totals for abundance and biomass were reviewed. With the exception of the larvae of selected benthic and fish species, specific species of zooplankton were not treated separately. However, abundance data were used to identify dominant zooplankton species to assess historical changes in community composition.

Ichthyoplankton

The ichthyoplankton, although a temporary member of the zooplankton community, were considered separately as key biological resource in the Delaware estuary. Larvae and eggs of many commercially and recreationally important finfish are represented in the ichthyoplankton. The overall success of each year-class of individual finfish species is dependent upon successful spawning by adults and the survival of these sensitive life stages. Therefore, the number of eggs and larvae in the water column may be an indicator of spawning success and survival and can be an indicator of general water quality conditions.

Benthic Community

The benthic community includes invertebrates living on or in the bottom of the estuary, associated with bottom sediments, or attached to solid substrates. Like the zooplankton, these bottom dwelling organisms are significant consumers and provide an important link between the primary producers and higher trophic levels. These organisms are the chief prey for many of the more important species in the estuary, including crabs, demersal fish, and certain birds. Many benthic invertebrates such as crabs, oysters, and clams are commercially or recreationally important species themselves. Because they are less mobile and generally live longer than communities in the plankton, benthic communities are believed to be sensitive, long-term integrators of water quality and pollution stress (Pearson and Rosenberg 1978; Boesch and Rosenberg 1981). Therefore, studies of benthic communities are an integral part of most environmental monitoring programs (Holland 1985; Bilyard 1987). For these reasons, benthic communities were considered a key biological resource in the Delaware.

Assessments of the current status and historical trends for benthic communities were made with abundance data, despite many methodological differences between studies. Few estimates of benthic biomass and very few estimates of benthic secondary production were found and these were for the lower bay only.

Assessments were limited to studies of benthic macrofauna: invertebrates large enough to be caught on 500 or 1000 μm sieves. Smaller metazoans (meiofauna) and protozoans (e.g., foraminiferans) generally are not as well studied and were not included in this review.

Except for the specific commercially or recreationally important species listed below, specific benthic species were not treated separately. However, abundance data were used to identify dominant benthic species to assess changes in community composition over time.

Parabenthic Communities

Some invertebrates are active swimmers, able to make vertical migrations into and out of the sediments, thus spending part of the day as members of the zooplankton and part of the day as members of the benthos. These vertically active invertebrates are referred to as parabenthos and include mysids, shrimp, and to a lesser extent, amphipods. These animals are generally not well sampled because of their habitat plasticity. However, the available data support the general consensus that these groups are important as secondary consumers in the estuary, feeding on both zooplankton and benthos (Herman and Hargreaves 1988). These groups may be very important prey for various fish in the bay (Shuster 1959; PSE&G 1984b,c); therefore, the parabenthos may play a significant role in the energy flow of the Delaware estuary.

Important Benthic Species

In addition to the benthic community as a whole, five benthic species were identified as key biological resources for the Delaware. These species were:

- American oyster — *Crassostrea virginica*
- Hard clam — *Mercenaria mercenaria*
- Blue crab — *Callinectes sapidus*
- American lobster — *Homerus americanus*
- Horseshoe crab — *Limulus polyphemus*.

These species were chosen because of their current or historical importance as commercial species (Table 4). The oyster, hard clam, and blue crab provide the principal commercial shellfisheries in the Delaware estuary (McHugh 1981; Price et al. 1983; Haskin et al. 1983), although in this century the importance of the oyster as a fishery has decreased and the importance of blue crabs has increased. American lobster and horseshoe crabs each contribute smaller amounts to the Delaware estuary commercial shellfish landings. The hard clam and blue crab also contribute significantly to the recreational fisheries (Miller 1987).

Ecologically, the importance of these species in the Delaware estuary system is unknown. Since these species are estuarine and marine, their distribution is mainly limited to the bay, although blue crabs can live and support recreational fisheries in freshwater (Tagatz and Hall 1971). The lobster and blue crab are generally believed to be omnivores (Cobb and Phillips 1980; Williams 1984), but estimates of the amount of organic matter processed by these two species were not available. As filter feeders, oysters and clams likely filter significant quantities of water in the bay, although no estimates of their filtration capacities have been made for the Delaware. In other estuaries, filter feeders are thought to be responsible for controlling phytoplankton dynamics (Cloern 1982) and potentially to decrease total suspended solids concentrations (Newell et al. 1988).

Horseshoe crabs, formally referred to as king crab (Table 4), are a significant biological resource within Delaware Bay (Shuster and Botton 1985). Each spring, horseshoe crab spawning in the lower estuary coincides with the arrival of thousands of migratory shorebirds. The Delaware Bay is a critical shorebird feeding area primarily as a result of the abundant food source in the form of horseshoe crab eggs. These shorebirds are dependent upon the horseshoe crab eggs to fuel the remainder of their northward migration (Dunne et al. 1982; Roberts 1989; Meyers 1987).

Most of the information available to make assessments of the current status of and the historical trends for these benthic species has been taken from the long-term fisheries landings records maintained by the National Marine Fisheries Service (NMFS). For these assessments, only landings data (i.e., pounds landed per year) were reviewed. However, market value data were also reviewed to help identify important species (Table 4). Problems associated with using the NMFS Fisheries landing data will be discussed in a subsequent section.

Table 4 Dominant Benthic Invertebrate Species of Commercial Importance (Top 5 species listed: 99% of landings)			
1921		1980	
Dominance by Pounds Landed	Dominance by Dollar Value	Dominance by Pounds Landed	Dominance by Dollar Value
King Crab*	Hard Clams	Blue Crab	Oyster
Hard Clam	Oyster	Oyster	Blue Crab
Oyster	King Crab	Lobster	Lobster
Squid	Squid	Horseshoe Crab	Hard Clam
Hard Crabs	Hard Crabs	Hard Clam	Conch

* King crab = Horseshoe crab
\+ Cumulative percent of total shellfish landing
Source: NMFS fisheries landings data

Fish Communities and Important Fish Species

The fish communities in the Delaware estuary are important biological resources because of their importance as secondary consumers and because many of the commercially and recreationally important species of the Delaware are members of this community. Various surveys conducted by federal and state agencies were used to assess fish community status. These studies and data from the National Marine Fisheries Service (NMFS) fisheries landings database were used to assess status and trends for individual species. Many of the fish species identified as important in terms of commercial or recreational catch or value are also ecologically important to the estuary.

Based upon survey data and the fisheries landings records, the following fish species were chosen as key biological species in the Delaware estuary:

- Striped bass — *Morone saxatilis*
- American shad — *Alosa sapidissima*
- Blueback herring — *Alosa aestivalis*
- Alewife — *Alosa pseudoharengus*
- White perch — *Morone americana*
- Atlantic sturgeon — *Acipenser oxyrhynchus*
- Shortnose sturgeon — *Acipenser brevirostrum*
- Weakfish — *Cynoscion regalis*
- Bluefish — *Pomatomus saltatrix*
- Summer flounder — *Paralichthys dentatus*
- Atlantic menhaden — *Brevoortia tyrannus*
- Bay anchovy — *Anchoa mitchilli*
- Spot — *Leiostomus xanthurus*
- Scup — *Stenotomus versicolor*

These species constitute the majority of the commercial and recreational fisheries within the Delaware estuary (Tables 5 and 6).

The Delaware estuary provides important spawning habitat and nursery areas for many of these fish, especially the anadromous species. Anadromous species include American shad, alewife, blueback herring, striped bass, white perch (semi-anadromous), and sturgeons. In the Delaware estuary, changes in the abundance of anadromous species have been linked to a decline in available spawning habitat due to obstructions in waterways (e.g., dams, pollution blocks) that impede their ability to reach historical spawning locations, and overall water quality (Ellis et al. 1947; Sykes and Lehman 1957; Walberg and Nichols 1967; Chittenden 1969, 1971; Miller et al. 1982).

Species characteristic of more saline waters also are very important to the Delaware estuary. Historically, weakfish, bluefish, and summer flounder have contributed significantly to Delaware estuary sport and commercial fisheries (Miller, 1978; Seagraves, 1981; McHugh, 1981). They are also important top level consumers

Table 5
Delaware Estuary Commercial Fisheries Landings*
Percent contribution of top 5 species collected.

Species	1901	1921	1945	1960	1970	1980	1989
Shad	66						
Alewife	10						
Weakfish	8	12	2		25	31	10
Menhaden	3	62	91	96	20		
Butterfish	3			<1			
Scup		7	2	1		22	14
Croaker		7					
Bluefish		3					
Striped Bass					12		
American Eel					20		
White Perch					9		
Mackerel			1			8	39
Summer Flounder			1	1		17	14
Silver Hake				<1			
Whiting						7	
Black Sea Bass							5
Cumulative Total	90	91	97	99	86	85	82

* Source: NMFS fisheries landings data. Estimated from county data. Data reported by waterbody for 1947 to 1977 suggest scup, black sea bass, and mackeral are probably over-represented in 1980 and 1989 numbers.

within the ecosystem (Hildebrand and Schroeder 1928; Smith and Daiber, 1977; Mercer 1983).

Species such as Atlantic menhaden and bay anchovy constitute a large proportion of fishery biomass within the estuary. They are also significant secondary consumers and

Table 6
Marine Recreational Fisheries Statistics*
Percent contribution of top 5 species collected.

Species	1979	1980	1983	1985	1986	1987	1988	1989
Weakfish	12	9	11		6	10	7	
Bluefish	22	18	14	11	9	22	11	22
Summer Flounder	28	19	28	29	18	30	37	
Black sea bass			11	9	34			16
Atlantic mackerel	7			6		6		6
Winter flounder	8			19			6	
Silver hake		26						
Tautog								7
Searobins		8	10		12	9	9	9
Cumulative %	77	80	74	74	79	77	70	60

* Source: National Marine Fisheries Service, Marine Recreational Fishery Statistics Survey, Atlantic and Gulf Coasts, 1979-1989.

an important link in the food web from phytoplankton and zooplankton to higher consumers. Spot and scup were chosen as key species because they are opportunistic feeders on smaller invertebrate and fish species, and they are also components of the commercial and recreational fisheries of the Delaware estuary.

Parameters chosen to assess the status and trends of fish communities include:

- For commercial fisheries data - examination of pounds landed for each species over time
- For recreational fisheries - examination of numbers of individuals caught over time and location
- For fisheries surveys - examination of species distribution throughout the estuary, changes in species composition, and estimates of relative abundance over time (generally measured as catch/haul, or by density estimates- number/square meter, number impinged/volume water).

Since 1871, commercial fisheries landings statistics have been collected by various state and federal agencies. These data are the most extensive long-term database available for examining trends in fisheries. However in some instances landings records may not reflect actual abundance of species in the estuary. Problems associated with commercial landings statistics include 1) lack of effort to standardize data , 2) crediting pounds caught to port where landed when fish were harvested offshore or in other regions (data from 1950 to 1977 report landings by water body, avoiding this problem), 3) lack of adjustments or standardization for gear changes, changes in target species, and seasonal closures.

For the Delaware estuary, combined landings for counties that border the estuary were examined. This included all reported landings from Pennsylvania and Delaware and seven New Jersey counties (Mercer, Burlington, Camden, Gloucester, Salem, Cumberland and Cape May). For the years of 1950 to 1977, water body designations that assigned landings data to the Delaware Bay, Delaware River, and associated large tidal tributaries were used in addition to county landings data.

No long-term records of recreational harvest of fish and shellfish exist for the entire Delaware estuary. General surveys of recreational finfish harvest in waters of the state of Delaware were conducted between 1967 and 1978 (Miller 1980). No comprehensive recreational finfish surveys from New Jersey and Pennsylvania waters were available. Similarly, few surveys of recreational shellfish harvest have been conducted. The National Marine Fisheries Service (NMFS) initiated a marine recreational fishery statistics survey (MRFSS) in 1976 in recognition of the nearly complete lack of data on recreational marine fish harvest. However, these data are reported by state and not readily available by specific water body or coastal county.

Valuable fisheries information was also provided by fishery independent surveys. Standardized juvenile finfish surveys are ongoing and have been conducted since 1980. The state of New Jersey conducts an annual seine survey in the transitional and freshwater region of the estuary, and Delaware conducts a trawl survey primarily in the lower bay region. Other studies have been directed specifically at anadromous species, including estimates of adult American shad available from 1976 to the present.

A combination of studies, using a variety of gears, were necessary to examine status and trends of Delaware estuary fish species thoroughly. General patterns in species abundance and distribution were identified for each region. Apparent distribution and relative abundance of species within each region was dependent upon the gear used. Bottom trawls were more efficient in capturing demersal and mid-water species, seines frequently captured more pelagic species and those more characteristic of surf zones, and gill nets collected larger species, such as sturgeon and catfish, that frequently avoid other gears. An intensive seine survey conducted by Versar during September and October of 1990 as part of DRBC's striped bass mark-recapture program provided valuable information on relative abundance and distribution of species in the freshwater and transitional zone (S. Weisberg, pers. comm.).

The Delaware estuary occupies a rather unique geographic location in relation to fisheries distribution. June and Reintjes (1957) reported that the offshore fisheries in the vicinity of Delaware, New Jersey, and Maryland were located in the center of the distribution of migratory fish stocks that range from Cape Cod to Cape Hatteras. They determined that this area was the southern limit of more northern fish stocks and the northern limit of many fish stocks that migrated from the south seasonally. This central location between warm temperate and cold temperate species ranges contributes to annual fluctuations in species abundance. They also found that these waters were some of the most productive in North America. McHugh (1981) found that the species of Delaware Bay were composed of three general classes of fish: 1) endemic species more or less restricted to the region, or restricted in their migrations, such as the mummichog, *Fundulus heteroclitus*; 2) boreal species that migrate into the region in the winter such as Atlantic cod, *Gadus morhua*, and 3) temperate species that migrate north in the spring and summer like the weakfish, *Cynoscion regalis*.

In addition to geographic location, fishery populations in the Delaware estuary are influenced by climatic and anthropogenic factors. Climatic changes include air and water temperature, freshwater runoff, salinity changes, and coastal circulation. Anthropogenic changes include nutrient input, pollution and overfishing (Price and Dinkins 1986). Daiber (1988) reports that the Delaware estuary's fisheries have exhibited general downward trend since the turn of the century. Evidence suggests that overfishing throughout the mid-Atlantic region, in conjunction with habitat destruction and deterioration of the environment in the Delaware, are responsible for recent fluctuations, as well as this decline. However, the relative importance of anthropogenic versus climatic factors is unknown.

Bird Communities and Important Bird Species

The following birds were chosen as key biological species in the Delaware estuary. These species were selected because they are dependent on the estuary for breeding, overwintering and staging habitats.

- Bald eagle — *Haliaeetus leucocephalus*
- Osprey — *Pandion haliaetus*
- Peregrine falcon — *Falco peregrinus*
- Northern harrier — *Circus cyaneus*
- Black duck — *Anas rubripes*
- Canvasback — *Aythya valisneria*
- Wood duck — *Aix sponsa*
- Semipalmated sandpiper — *Calidris pusilla*
- Ruddy turnstone — *Arenaria interpres*
- Dunlin — *Calidris alpina*
- Black-bellied plover — *Pluvialis squatarola*
- Sanderling — *Calidris alba*
- Piping plover — *Charadrius melodus*
- Red Knot — *Calidris canutus*
- Black-crowned night heron — *Nycticorax* nycticorax

- Great blue heron — *Ardea herodias*
- Green-backed heron — *Butorides striatus*
- Snowy egret — *Egretta thula*
- Great egret — *Casmerodius albus*
- Laughing gull — *Larus atricilla*
- Least tern — *Sterna antillarum*

The species were grouped according to general life history characteristics to examine population trends over time. These groups included: raptors (bald eagle, osprey, peregrine falcon, northern harrier), waterfowl (black duck, canvasback, wood duck), shorebirds (ruddy turnstone, semipalmated sandpiper, red knot, sanderling, black-bellied plover, piping plover and dunlin), wading birds (great blue heron, green-backed heron, black-crowned night heron, snowy egret, great egret, and gulls and terns (laughing gull and least tern).

The choice of birds to be included in our review was difficult and inexact because many species use the resources of the Delaware. Certain migratory species were chosen because of their dependance on the estuary as a temporary feeding ground. The estuary is a vital component of the Atlantic Flyway, an important flight corridor for numerous migratory bird species, and is the largest spring staging site for shorebirds in the eastern United States (Stein et al. 1983). Because of this the Delaware estuary has been included in the Western Hemisphere Shorebird Reserve Network (WHSRN) since 1985. This network includes critical habitats located along primary migratory routes.

Our choice of bird species was also based upon which might best be used as indicators of ecological change, since these species occupy levels within the ecosystem ranging from primary consumers to top level predators. Birds are very susceptable to alterations in environmental quality within the ecosystem (Custer and Osborn 1977), and fluctuations in their abundance are often related to environmental degredation caused by factors such as habitat alteration or chemical introduction. As a result of environmental degradation and habitat alteration, the abundance of some species has become so low that the species has been designated as threatened or endangered. Species so designated were also included in our assessments.

Some of the bird species were chosen because of current or past recreational or commercial value. The avian resources of the Delaware estuary have contributed to the economy of the region. Historically, most of these key species were hunted commercially for food or millinery purposes (Mellon 1990). Today, they are the focus of recreational activities such as birdwatching and hunting (gamebirds only).

Status and trends for these key bird species were assessed by examining changes in population abundance and distribution in the Delaware estuary. Two long-term computerized databases were obtained during the literature search. These include the United States Fish and Wildlife Service Breeding Bird Survey (1966 to 1989), and the National Audubon Society Christmas Bird Count (1961 to 1988). In addition, recent data concerning the current breeding status of many species were obtained from

Delaware and Pennsylvania. Methods used to standardize each of these studies are summarized below. In addition to these studies, many other sources of historical and recent data were obtained and analyzed.

The purpose of the U.S. Fish and Wildlife Services Breeding Bird Survey is to detect changes in populations of all bird species encountered along the routes by establishing a yearly index that can be used to determine trends (USFWS 1979). Routes were chosen randomly, and observers follow standardized procedures. Twenty-four routes adjacent to the Delaware estuary were chosen for trend analysis (Figure 7). A potential limitation of these data was that all routes were not used each year. Thus, these data were better suited to species that have a more random distribution. Biases may result when attempting to examine trends in species that have clumped distributions.

The Audubon Christmas bird surveys are conducted from count circles (7.5 mile diameter). Nineteen count circles in the Delaware estuary were chosen for trend analysis (Figure 8). Count methods were standardized, and information such as number of hours of observation were recorded to allow data to be standardized between years. Fluctuations in winter counts may be affected by factors such as populations or conditions in other areas and annual climatic variability. Therefore, counts are used only as an index to general population levels and are inappropriate for rigorous trend analysis (L. Niles and K. Clark, pers. comm.).

In recent years, Pennsylvania (1984-1988), Delaware (1983-1987), and New Jersey (1981-1985) have conducted standardized breeding bird surveys. The purpose of these studies was to identify and plot the distribution of species that breed within that state. Each state was divided into geographic areas using U.S. Geological Survey topographic maps. Each topographic map was divided into six blocks, and surveys were conducted within each block. Surveys identified species breeding within that block and whether breeding was possible, probable, or confirmed depending on certain characteristics. Results of these surveys are now in press; however, it was possible to obtain some preliminary results on breeding status and distribution within each state (PA-Brauning in press; NJ-Hughes pers. comm.; and DE-West et al. in press).

Figure 7
USFWS Breeding Bird Survey Routes

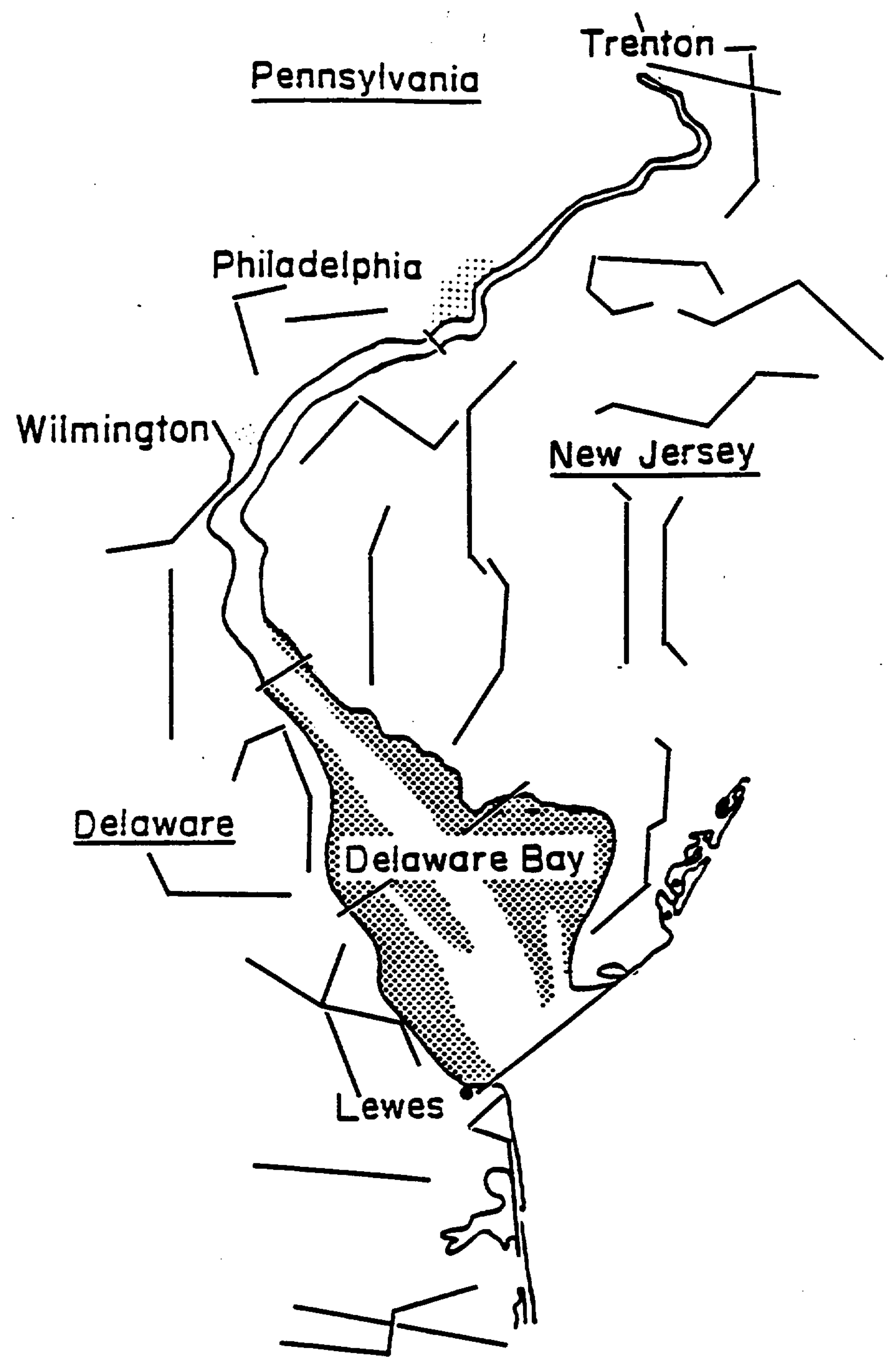
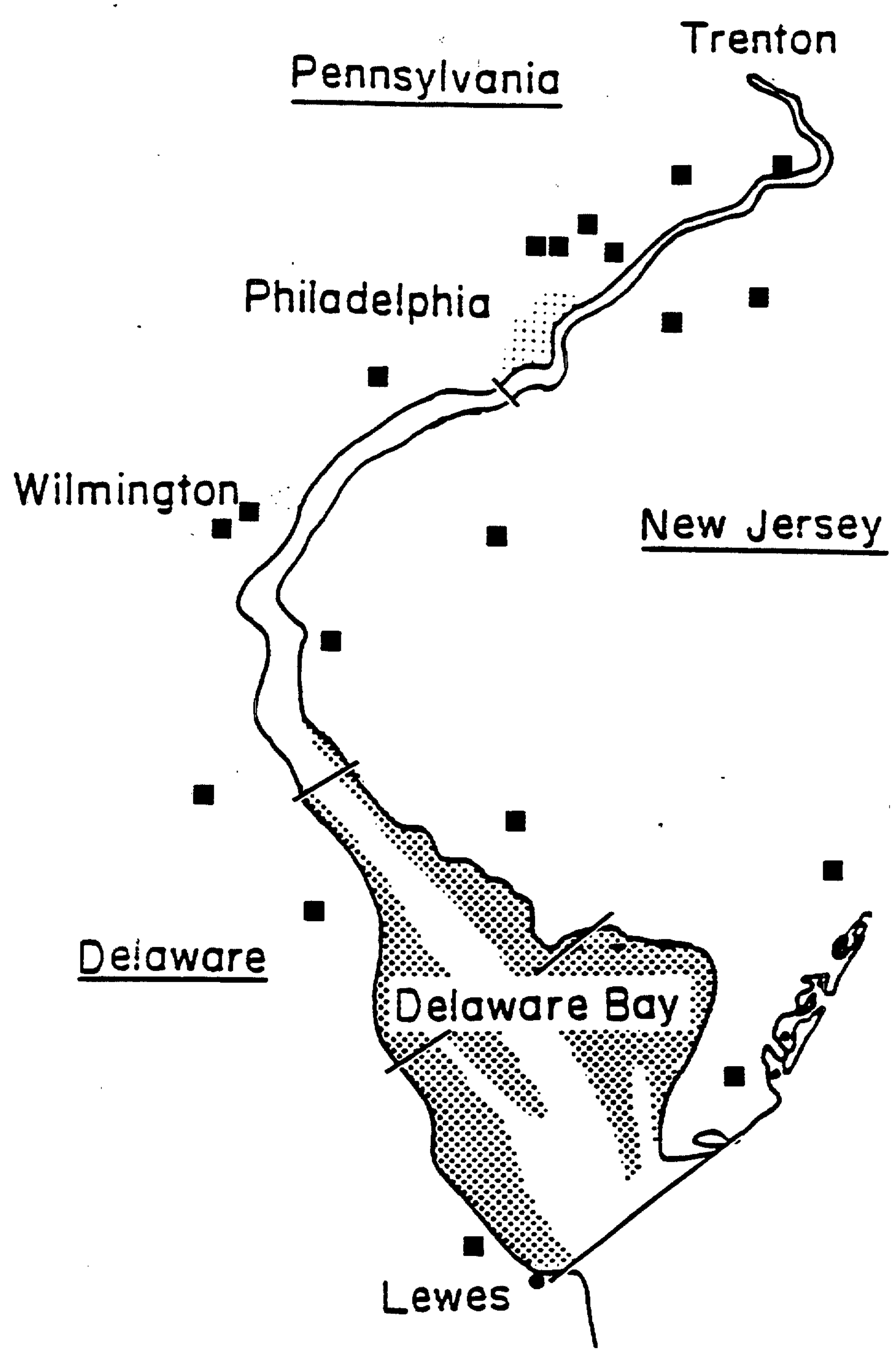


Figure 8
Audubon Christmas Bird Count Sites



STATUS AND TRENDS FOR BIOLOGICAL RESOURCES

Phytoplankton Community

The status and trends for phytoplankton in the Delaware estuary were assessed using chlorophyll *a* concentrations as a measure of phytoplankton biomass. Rates of primary production were used as a measure of photosynthetic activity. These parameters were used because other measures of the phytoplankton (i.e., abundance and species composition) were not available for the entire estuary and were limited in temporal extent. Additionally, methodological differences such as collection method, sieve size, and preservation made comparison of species data collected at different times, by different investigators difficult.

The bay portion of the estuary (Table 7) is dominated by marine and estuarine phytoplankton species. In the spring, phytoplankton blooms are dominated by the diatoms *Skeletonema costatum, Leptocylindrus* sp. and *Thallasiosira* sp. Species dominance shifts from these diatom populations to flagellates in the summer and fall (Watling et al. 1979). In the tidal fresh region of the estuary, freshwater species dominate, represented chiefly by species of *Cyclotella, Closterium*, and *Melosira* (Walton et al. 1973).

Chlorophyll *a* and primary production measurements were available for the entire length of the estuary from a series of cruises conducted by researchers at the University of Delaware. Data for these parameters were also available seasonally, and sometimes monthly, from 1977 to 1988 (Culberson 1988; Lebo et al. 1990). Chlorophyll data collected back to 1967 were available from the EPA database STORET. However, these data were not used for this assessment of status and trends. Preliminary inspection of the STORET database revealed problems with spurious values and mislabeled data columns. After finding these problems, we considered it outside of the scope of this project to attempt refinement of the STORET data.

Phytoplankton biomass and production in the Delaware are spatially and temporally variable. Numerous studies published during the past ten years have focused on the factors driving this variability (Pennock 1985; Pennock and Sharp 1986; Harding et al. 1986; Fisher et al. 1988). Data used for the studies by Pennock (1985) and Pennock and Sharp (1986) were part of the Delaware Bay database described by Culberson (1988) and were collected during various cruises to monitor water quality throughout the bay (Culberson et al. 1987a, b, c). Pennock's (1985) study was limited to the period 1980 to 1983, whereas Pennock and Sharp's (1986) study included 1980 to 1985 data. The studies of Harding et al. (1986) and Fisher et al. (1988) each used the same data, although these data were not included in the Delaware Bay database.

Our assessment of status and trends focused on describing general, broad-scale patterns in the estuary. For this assessment, 1977 to 1985 data from Culberson (1988) were combined with 1986 to 1988 data from Lebo et al. (1990). Using these data, median values for salinity, suspended solids, chlorophyll *a*, and phytoplankton production were calculated for each of the three salinity regions of the estuary (bay, transition, and tidal fresh) and for each 10 km segment of the estuary. Median values were used instead of means for our analyses. Data for suspended solids, chlorophyll *a* concentrations, and production were not normally distributed. The distributions of values for these parameters were strongly skewed towards higher values; therefore, median values were more appropriate measures of central tendency and were used so that estimates of spatial and temporal patterns would not be unduly influenced by extreme values.

The combined data from Culberson (1978) and Lebo et al. (1990) were used to characterize chlorophyll concentrations and phytoplankton production in the three regions of the estuary. However, data were not available from all 10 km segments of the estuary for all months (Figure 9). In general, a greater number of samples were available from the bay region than from the tidal fresh region, and more samples were taken during the spring and summer than during the winter. Further, an equal number of sample points was not available for each of the years represented in the combined dataset. This temporal and spatial distribution of sample points potentially biases the median values we calculated for chlorophyll and production.

Overall median chlorophyll biomass for the period 1977 to 1988 was similar in the three regions of the estuary (Figure 10). Production was lowest in the transition region and highest in the tidal fresh region. Published descriptions of production in the estuary (Pennock and Sharp 1986) have attributed the production minimum in the transition region to light limitation. This region of the bay has high concentrations of suspended solids (Figure 10) and highest turbidity. Higher production in the tidal fresh portion of the estuary has been attributed to large nutrient loadings from sewage effluents, combined sewer overflows, and other sources.

Our estimates of daily production rates suggest that phytoplankton production in the tidal fresh region of the Delaware is higher than production in the bay region. This is contrary to the pattern described by Pennock and Sharp (1986) and may be due to the use of a larger dataset (1977 to 1988 vs. the 1980 to 1985 data used by Pennock and Sharp) or differences in analytical approaches. Pennock and Sharp (1986) integrated production values to estimate average annual areal production (Figure 11). For the entire estuary, the average production rate was 307 g C m^{-2} yr^{-1}. Values for specific areas of the estuary ranged from 70 g C m^{-2} yr^{-1} in the turbidity maximum zone to 392 g C m^{-2} yr^{-1} in the middle of the bay region. Using these average annual rates, Pennock and Sharp also estimated the percent of total production in the Delaware estuary that can be attributed to various areas of the estuary. These estimates are shown as a cumulative frequency plot in Figure 11.

Summarizing these data using overall median or integrated annual values simplifies an otherwise comlex dataset. Across the estuarine salinity gradient, both chlorophyll concentrations and phytoplankton production rates were extremely variable (Figures 12 and 13). Despite this variability, the same overall patterns are shown; higher chlorophyll and production values are found in the bay and tidal fresh regions and lower values in the transition region. The highest chlorophyll concentrations were found in the middle of the bay region, where there is an adequate supply of nutrients and less turbid waters (Harding et al. 1986).

A portion of the variability shown in the long-term datasets for chlorophyll and production can be attributed to seasonal variations. As in many temperate estuaries, the phytoplankton of the Delaware undergo marked seasonal cycles (Smayda 1973; Harding et al. 1986; Fisher et al. 1988). To illustrate these changes, the combined datasets of Culberson (1988) and Lebo et al. (1990) were subdivided into four seasons and median values calculated for each season and each 10 km segment of the estuary. Winter (December, January, and February) is characterized by relatively low biomass and production throughout the estuary (Figure 14). Small blooms of diatons may occur in the lower bay, but chlorophyll concentrations are typically less than 10 μg/liter. Low winter production has been attributed to low irradience and temperature (Pennock and Sharp 1986).

Following the relatively inactive winter months, phytoplankton biomass in the bay region builds during the later winter-early spring typically reaching peaks around mid-March. In the bay region, this rise in chlorophyll concentrations is accompanied by increased production (Figure 15). In the tidal fresh region, increased rates of primary production are not accompanied by increased chlorophyll biomass.

Phytoplankton blooms appear to progress up the estuary through the year. In the bay region, maximum chlorophyll concentrations and production rates characteristically occur in the spring. In the tidal fresh region, however, maximum chlorophyll concentrations and production rates typically occur in the summer (June, July, and August). During summer, extended phytoplankton blooms are observed over a large portion of the upper estuary (Figure 16). In this region, peak biomass and production is centered around river km 180, approximately where the Rancocas Creek enters the Delaware River. This peak in both biomass and production may be due to nutrient input from the sewage treatment plant on the Rancocas, but this was not confirmed by review of nutrient concentration data for this portion of the river.

During the fall (September, October, and November), small phytoplankton blooms may occur throughout the estuary (Figure 17). These blooms are smaller than those that characterize the spring and summer periods, but larger than chlorophyll concentrations and production rates observed during the winter.

The seasonal changes for chlorophyll concentrations and primary production rates for the three main regions of the estuary are summarized in Figures 18 and 19. Figure 18 clearly shows the seasonal progression of phytoplankton blooms up the estuary. Paterns for phytoplankton production do not parallel those for phytoplankton biomass. Peak production rates for the phytoplankton in the lower bay generally occur in late summer, five months after the spring biomass peak (Figure 19). Maximum production rates for the phytoplankton in the transition zone follow the spring biomass maximums for this region. Pennock (1985) has shown that this bloom results from an increase in the average light intensity of the mixed surface layer caused by vertical stratification during the spring freshet. In the tidal fresh portion of the estuary, maximum production rates occur in early summer and precede the peak in phytoplankton biomass.

A measure of the photosynthetic efficiency of phytoplankton is the ratio of production to chlorophyll biomass (P/B). Phytoplankton populations that have adequate nutrient supplies and are in log phase growth typically have high P/B ratios, whereas nutrient starved or otherwise limited phytoplankton have low P/B ratios. Median P/B ratios for phytoplankton show stronger and more consistent trends along the estuarine gradient than either chlorophyll or production (compare Figure 20 with Figures 14 through 17). P/B ratios were lowest in the transition salinity region, where the concentration of suspended solids is highest. In this region, phytoplankton production is limited by light because the high concentration of suspended solids retards light penetration through the water column. P/B ratios are highest in the bay and in the middle reach of the tidal river, below Trenton. In these regions, nutrients are generally in adequate supply to support phytoplankton activity. The finding that high P/B ratios exist to the mouth of Delaware Bay is consistent with Harding et al.'s (1986) conclusion that nutrients were never depleted at this end of the estuary.

The Delaware Bay Database (Culberson 1988; Lebo et al. 1990) thus far has been used to describe the current status of the phytoplankton in the estuary by grouping all years. These data were also used to look for broad temporal trends during the period 1978 to 1988. Interannual variability is quite high for both chlorophyll biomass and phytoplankton productivity. The eleven year record for chlorophyll does not suggest that there have been substantial changes in any of the three salinity regions of the estuary (Figure 21). However, there is a certain degree of consistency between salinity regions. In years characterized by large phytoplankton blooms (1987 and 1989 for example), large chlorophyll biomass peaks were observed in all three salinity regions. Similarly, low chlorophyll numbers were recorded for all three regions during years when chlorophyll concentrations were generally low (1983, 1989, 1986, for example). Pennock (1985) has shown that at least some of the interannual variations in chlorophyll concentration are due to river flow.

In contrast to the absence of a trend for chlorophyll, phytoplankton production appears to be increasing (Figure 22). Trends are most apparent for the bay portion of the estuary, where production appears to have nearly doubled during the last ten years. This increase in production may be related to the increase in phosphorus loadings documented by Najarian (1991). Production in the tidal river portion of the estuary may also have increased, but fewer data were collected in this region at the beginning of the record to make adequate comparisons. There does not appear to be a trend in production for the transition region of the estuary.

Table 7

Phytoplankton Community Composition	
Delaware Bay Region	
Winter-Spring Dominants	Thallasiosira sp. Cyanophyceae sp. Guinardia flaccida Cryptomonad sp. Asterionella glacialis Skeletonema costatum
Spring Dominants	Gyrodinium sp. Skeletonema costatum Leptocylindrus minimus Thallasiosira sp. Chaetoceros sp. Pyramomonas sp.
Summer Dominants	Cryptomonas acuta Calycomonas ovalis Prasinophyte sp. Rhizoselenia fragillisima Cerataulina pelagica Chrysochromulina sp. Katodinium rotundum
Fall Dominants	Navicula sp. Navicula septentrionalis Gyrodinium spirale Cryptomonad sp. Nitzschia seriata Leptocylindrus danicus
Mid - Estuary Region	
	Skeletonema costatum Asterionella sp. Cyclotella spp. Melosira spp. Chlorella sp. Closterium sp. Scenedesmus sp.
Tidal Fresh Water Region	
	Cyclotella menghiniana Closterium sp. Melosira sp. Nitzschia sp. Scenedesmus sp. Pediastrum sp.

Figure 9

Temporal and Spatial Distribution of Primary Production Data

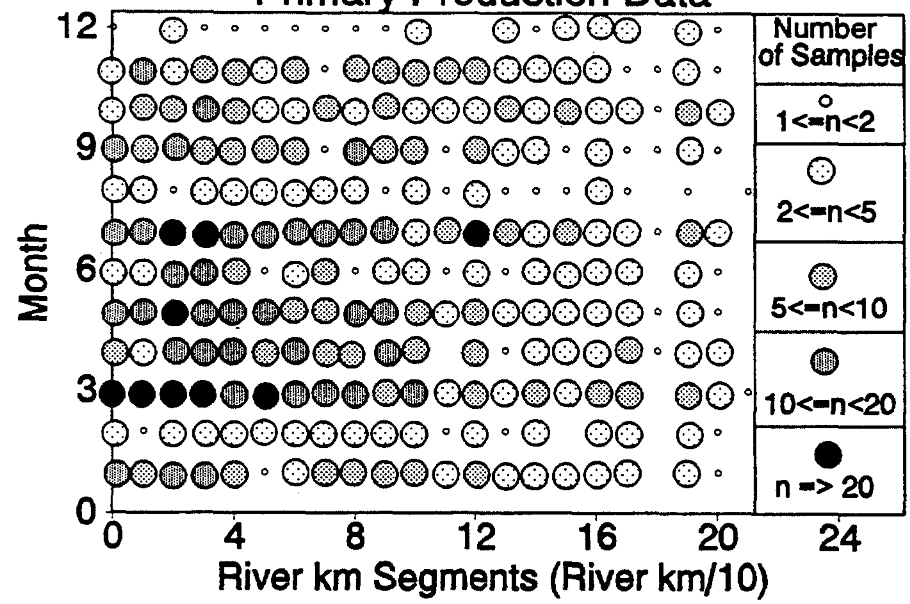
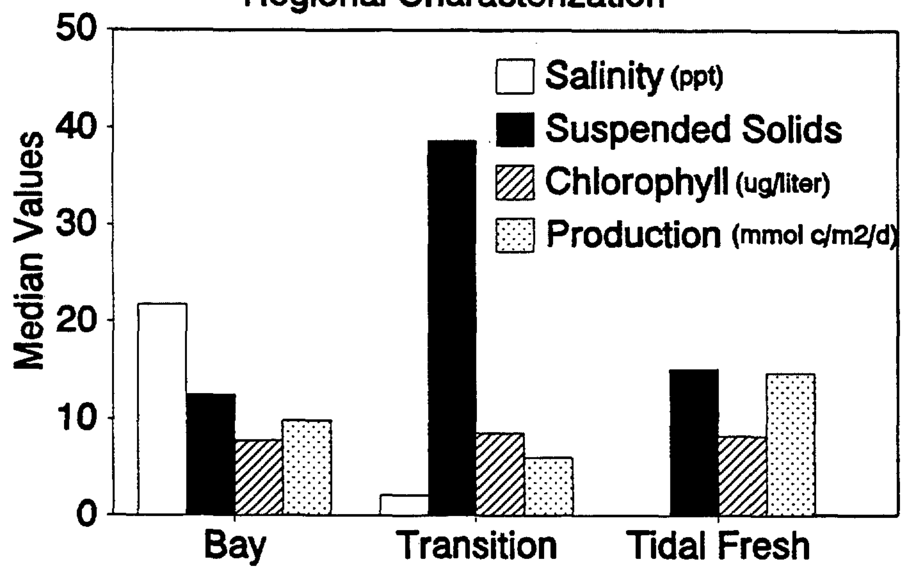


Figure 10

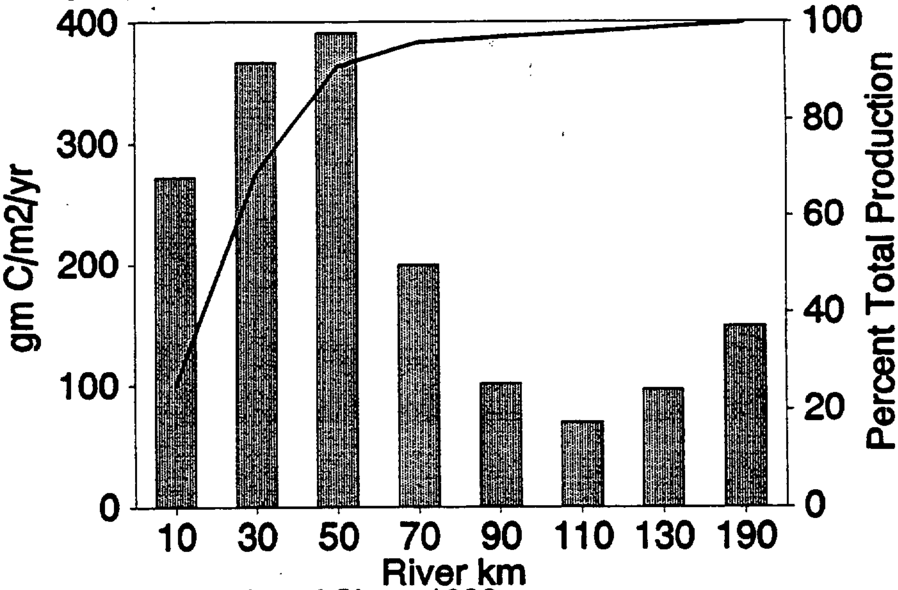
Delaware Estuary
Regional Characterization



Source: Culberson 1988; Lebo et al. 1990

Figure 11

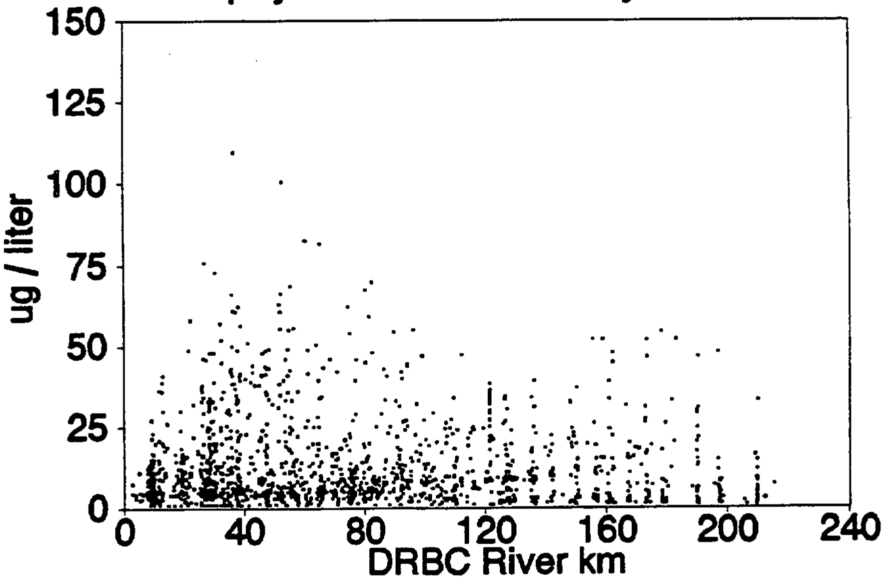
Phytoplankton Production for Estuarine Regions



Source: Pennock and Sharp 1986

Figure 12

Chlorophyll Concentration by River km



Source: Culberson 1988; Lebo et al. 1990

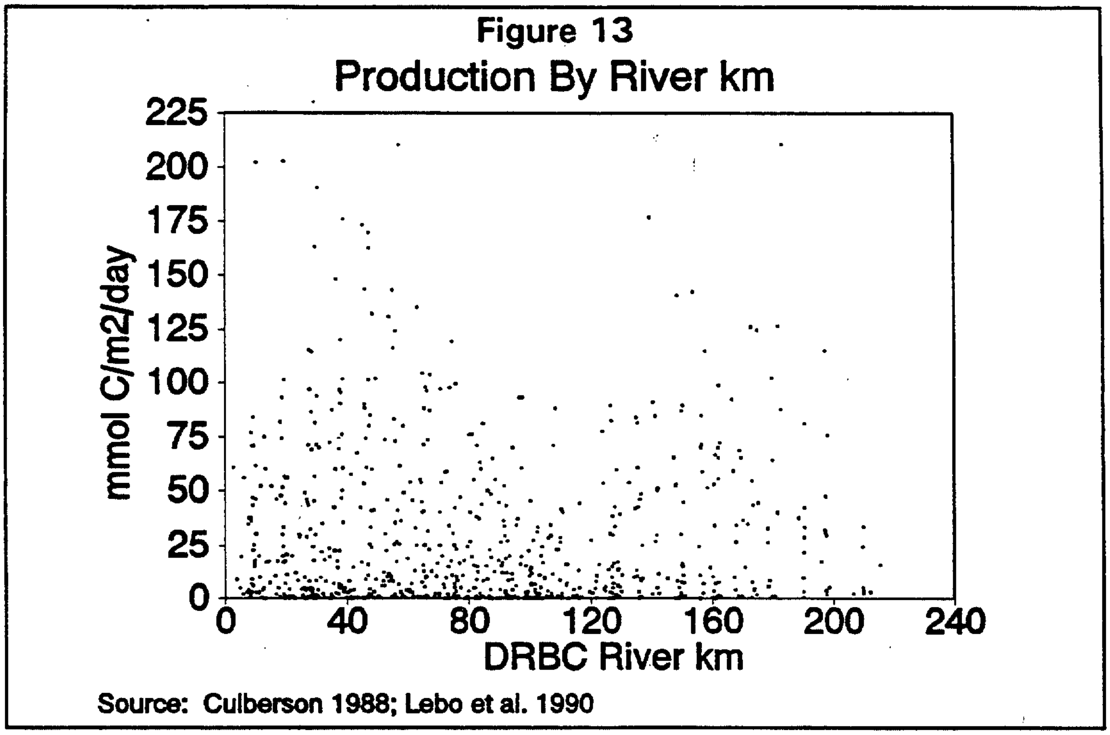


Figure 13
Production By River km
225
200
175
150
125
100
75
50
25
0
mmol C/m2/day
0
40
80
120
160
200
240
DRBC River km
Source: Culberson 1988; Lebo et al. 1990

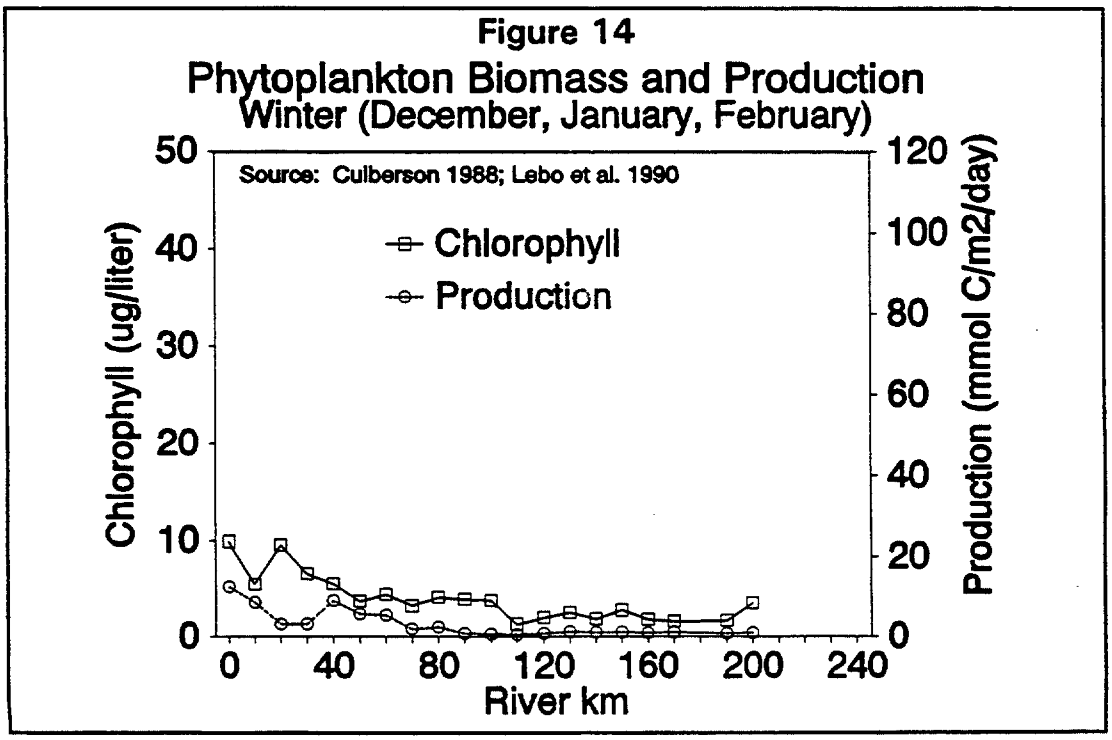


Figure 14
Phytoplankton Biomass and Production
Winter (December, January, February)
Source: Culberson 1988; Lebo et al. 1990
Chlorophyll
Production
Chlorophyll (ug/liter)
50
40
30
20
10
0
120
100
80
60
40
20
0
Production (mmol C/m2/day)
0
40
80
120
160
200
240
River km

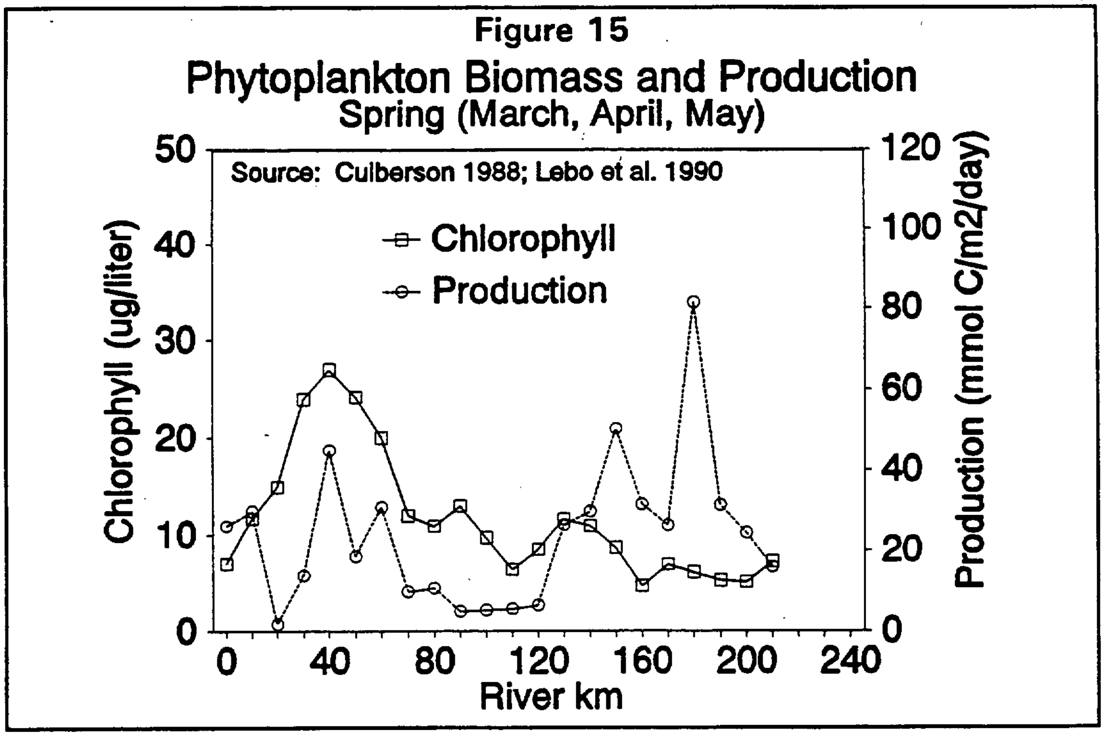


Figure 15
Phytoplankton Biomass and Production
Spring (March, April, May)
Source: Culberson 1988; Lebo et al. 1990
Chlorophyll
Production
Chlorophyll (ug/liter)
Production (mmol C/m2/day)
River km
0
10
20
30
40
50
0
20
40
60
80
100
120
0
40
80
120
160
200
240

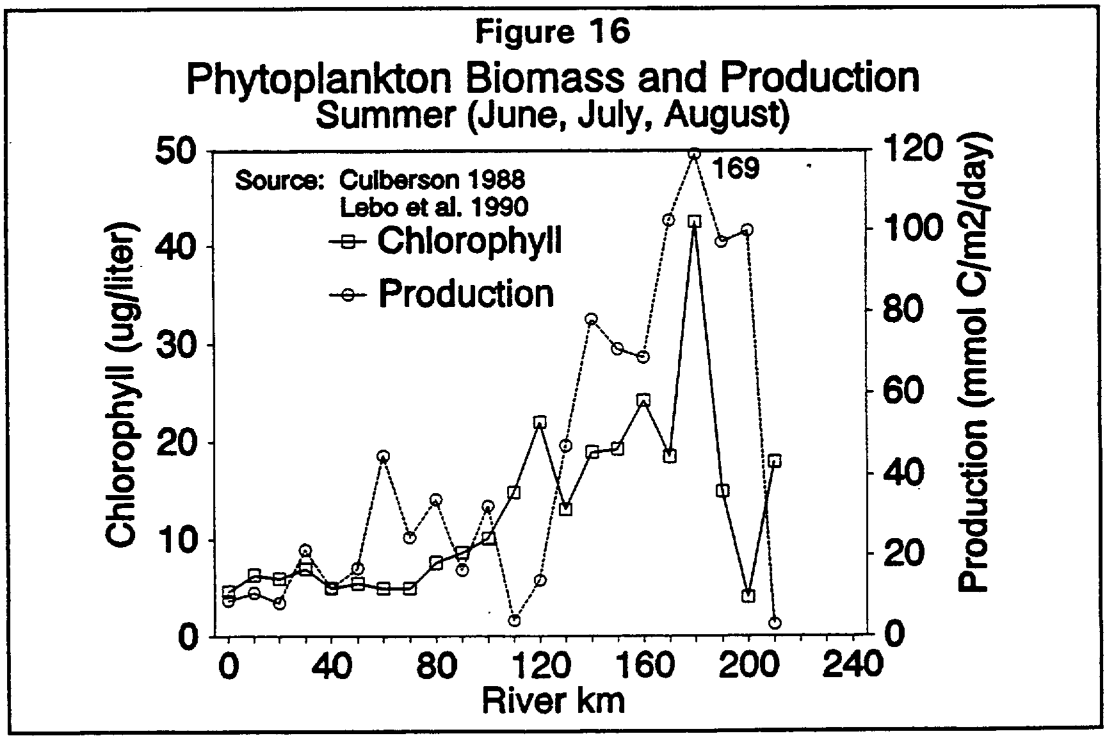


Figure 16
Phytoplankton Biomass and Production
Summer (June, July, August)
Source: Culberson 1988
Lebo et al. 1990
Chlorophyll
Production
169
Chlorophyll (ug/liter)
Production (mmol C/m2/day)
River km
0
10
20
30
40
50
0
20
40
60
80
100
120
0
40
80
120
160
200
240

Figure 17

Phytoplankton Biomass and Production

Fall (September, October, November)

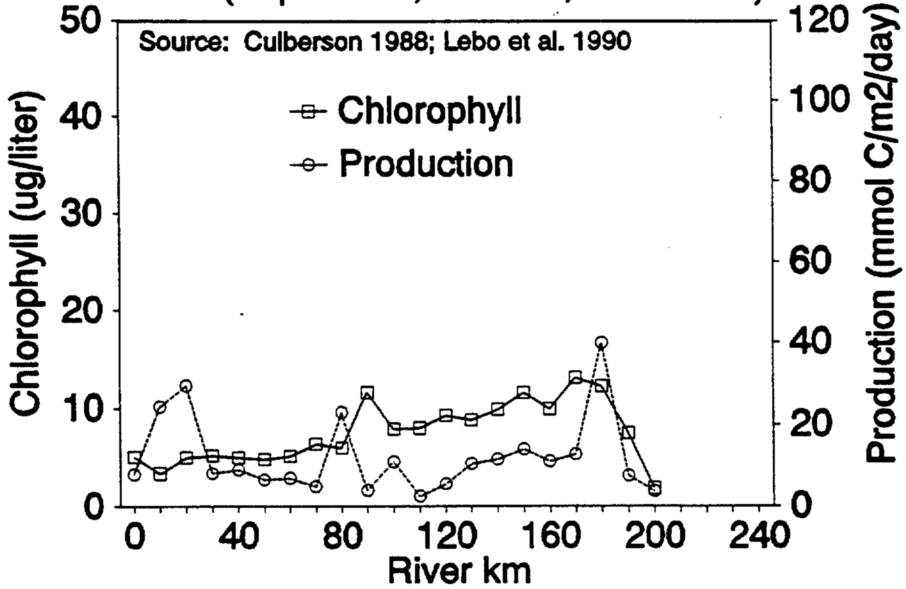
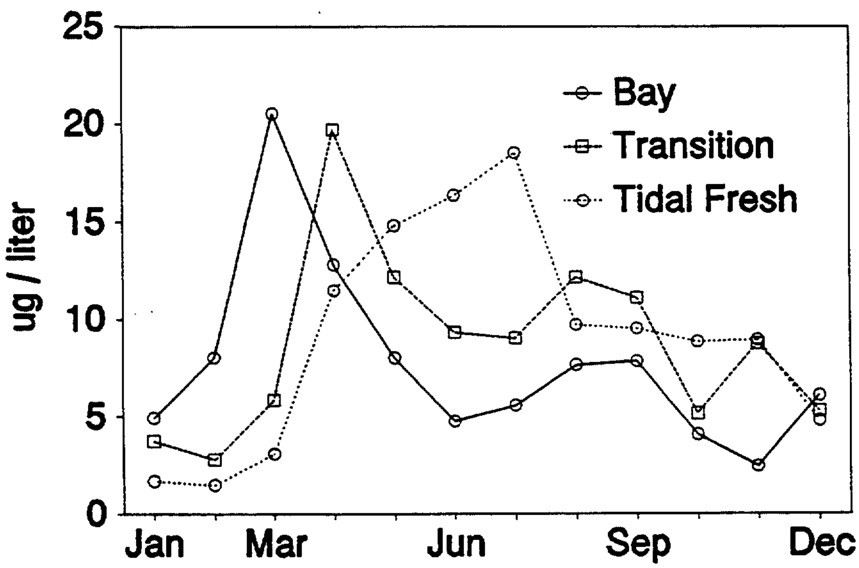


Figure 18

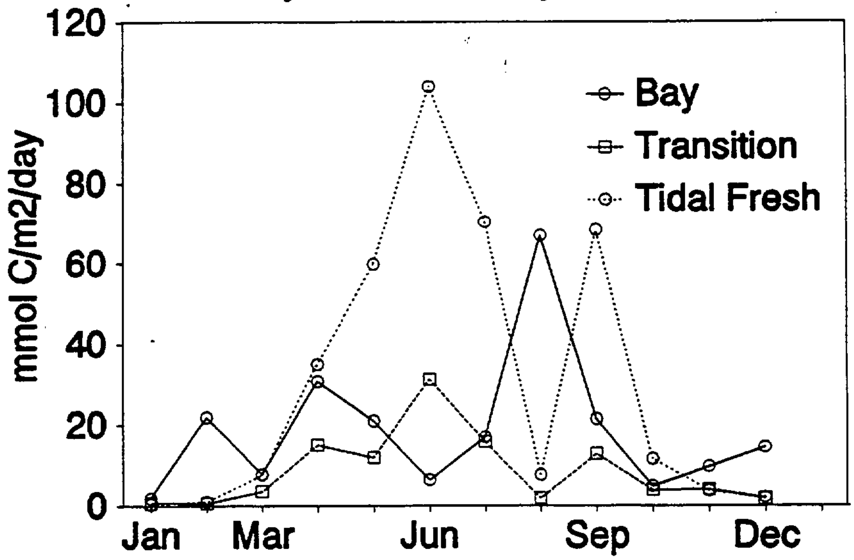
Annual Cycle of Chlorophyll



Source: Culberson 1988; Lebo et al. 1990

Figure 19

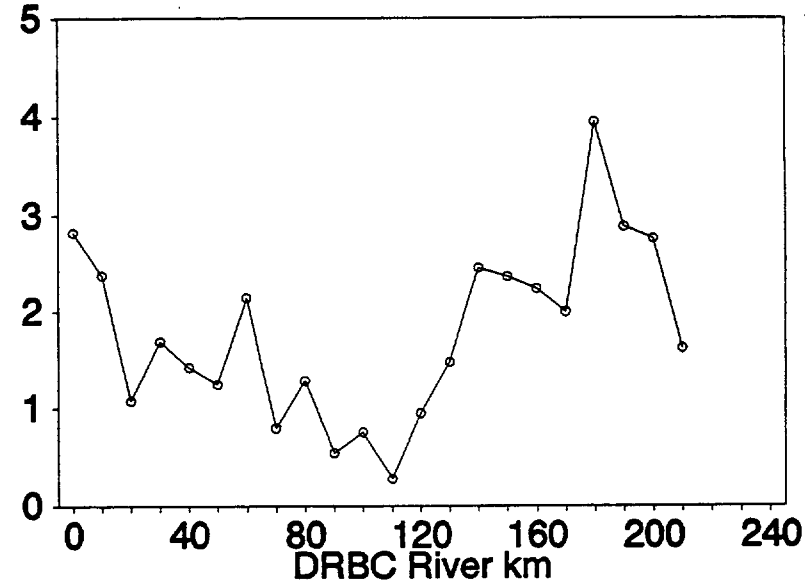
Annual Cycle of Primary Production



Source: Culberson 1988; Lebo et al. 1990

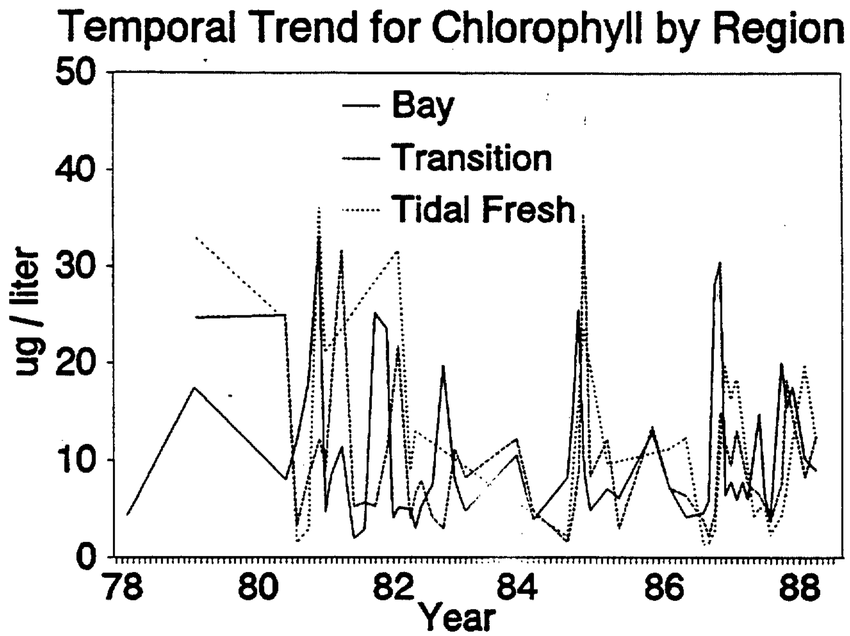
Figure 20

Production to Biomass Ratio by River km



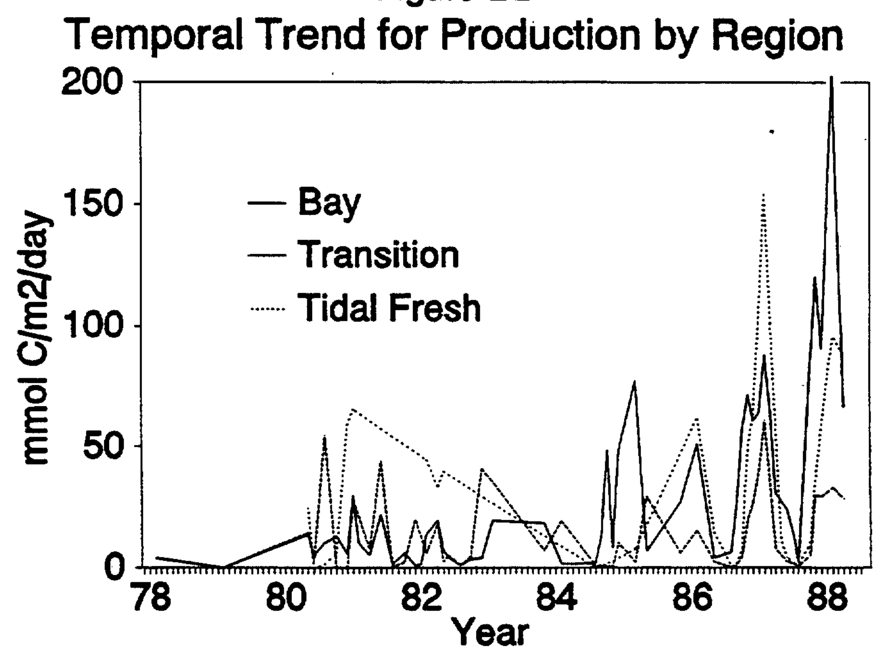
Source: Culberson 1988; Lebo et al. 1990

Figure 21



Source: Culberson 1988; Lebo et al. 1990

Figure 22



Source: Culberson 1988; Lebo et al. 1990

Zooplankton Community

Known studies of the zooplankton in the Delaware estuary date back to 1929. Early data (1929 to 1935) were well summarized by Deevey (1960) and focused upon comparing the zooplankton community in the lower bay with the community offshore and along the southern New Jersey shore to Townsend Inlet. After this early interest in the zooplankton, no studies were initiated until 1951, when a two year study of the zooplankton from the mouth of the bay to approximately Philadelphia commenced (Cronin et al. 1962). This study is most frequently cited to describe patterns of zooplankton community composition along the length of the estuary. The field surveys of Cronin et al. (1962) were followed by more intensive investigations of mysids in the bay by Hulburt (1957) and Hopkins (1958). Since these early studies, others have collected information on the zooplankton in and near the Chesapeake and Delaware Canal (Ferrante 1971; Raytheon 1975), in the lower bay (Mauer et al. 1978, Herman et al. 1983; PSE&G 1980), and in the adjacent coastal waters (Van Engel and Tan 1965; DuPont et al. 1972; Sandine and Swiecicki 1975). Other investigators have completed comparative studies of the zooplankton in various East Coast estuaries, including the Delaware (Jeffries and Johnson 1973; Nixon 1973). Relatively few studies of the zooplankton in the tidal freshwater portion of the estuary have been completed (Walton et al. 1983).

Cronin et al. (1962) present the best description of zooplankton in the entire estuary using data collected during the period 1951 to 1953. Then, the estuary supported a diverse assemblage of zooplankton species. However, averaged over the entire estuary, zooplankton were dominated by three copepod species -- *Acartia tonsa, Eurytemora hirundoides,* and *Eurytemora affinis* (Cronin et al. 1962). These three species constituted 84% of all zooplankton. Because of differences in average individual weight between species, weight dominant species were different than numerically dominant ones. Cronin et al. (1962) did not measure biomass but did estimate volume for zooplankton species and groups. By volume, five species (*Gammarus fasciatus, Acartia tonsa, Eurtemora hirundoides, E. affinis,* and *Neomysis americanus*) constituted 89% of the zooplankton in the entire estuary.

The primary factor influencing the distribution of specific zooplankton species in the estuary was salt. The lower bay was dominated by marine species and estuarine species tolerant of saline waters (Figure 23). Calanoid copepods were most abundant, and zooplankton assemblages often included offshore species that had been swept into the bay. In the tidal freshwater portion of the estuary, cyclopoid copepods, cladocerans, and gammarid amphipods dominated. Rotifers were also more prominant in the tidal freshwater region (Walton et al. 1973). These assemblages overlapped in the transitional zone of the estuary. The greatest densities of zooplankton were supported in the lower transitional zone of the estuary south of the Chesapeake and Delaware Canal and extending into the upper reaches of the bay to Ship John Light. Throughout the estuary, the copepod *Acartia tonsa* was the most numerous, persistent, and euryhaline copepod in the estuary.

More recent studies suggest that the composition of zooplankton within the Delaware estuary has not changed significantly since Cronin et al.'s (1962) analysis of data from 1951 to 1953. However, the more recent studies focus only on zooplankton in Delaware Bay and the lower portion of the transition zone. Copepods continue to account for 90% or more of all zooplankton, and *Acartia tonsa* continues to be the dominant zooplankton species in this portion of the estuary (Mauer et al. 1978; Herman et al. 1983; Herman and Hargreaves 1988). Herman et al. (1983) and Herman and Hargreaves (1988) also described *Oithona* spp. as a dominant in the lower bay zooplankton. This was a species that Cronin et al. (1962) did not include in their published species list. This is unlikely to represent any real change in the composition of the zooplankton community, since *Oithona spp.* are relatively small, and Cronin et al. (1962) used a coarser net (0.37 mm) than that used by Herman and Hargreaves (1988) (0.158 mm). For similar reasons, and as discussed by Aurand and Daiber (1976), it is unlikely that the occurrence of the cyclopoid *Halicyclops fosteri* in low salinity waters of the Delaware and its tributaries represents a newly introduced species to the Delaware.

The abundance and composition of zooplankton in most estuaries along the east coast of the United States are seasonally dynamic (Nixon 1973). The Delaware estuary is no exception. Cronin et al. (1962) describe spring and summer peaks for zooplankton volume. Other studies report seasonal changes for bay zooplankton only. Deevey (1960) used 1929 to 1935 data to describe a seasonal cycle in which peak abundances occurred in the winter-spring period. Mauer et al. (1978), reporting on data from 1974 and 1975, showed highest abundances in the winter and spring period and relatively low numbers in late summer. High spring zooplankton numbers were also noted by Herman et al. (1983) and Herman and Hargreaves (1988), who used 1982 data.

The general pattern that emerges from these studies is that in the lower estuary, high zooplankton densities are more likely found in the spring than in other seasons. This pattern does not preclude the existence of secondary abundance peaks during other times of the year. Zooplankton numbers from Mauer et al's (1978) Station 1 in the lower bay suggest that zooplankton may sustain three major peaks (spring, summer, and fall), and data collected by Radiation Management Corporation (1979) in the vicinity of Artificial Island show a late summer abundance peak (Figure 24).

Accompanying the seasonal dynamics in abundance are changes in the composition of zooplankton assemblages. Although present throughout the year, *Acartia tonsa* is more dominant in winter and summer samples (Cronin et al. 1962; Mauer et al. 1978). Mauer et al. (1978) used cluster analysis techniques to group bay zooplankton species into five separate seasonal assemblages (Table 8). The dominant species in these seasonal assemblages agreed well with data from other studies (Herman et al. 1983). In the upper reaches of the estuary, seasonal dynamics was dominated by spring peaks for cladocerans and *Cyclops viridis*, and spring-summer peaks for gammarid amphipods. Dominance by the warm-water, brackish cyclopoid *Halicyclops fosteri* may occur in the summer (Aurand and Daiber 1976), but samples are generally inadequate to assess their presence north of the Chesapeake and Delaware Canal (Lindsay 1974).

Long-term changes in the zooplankton of the Delaware River are difficult to assess due to methodological and taxonomic difficulties. Deevey's (1960) study mainly looked at composition, whereas Cronin et al. (1962) reported most data in terms of zooplankton volume and used a course plankton net. Reliable abundance measurements are available mainly from the early 1970s on.

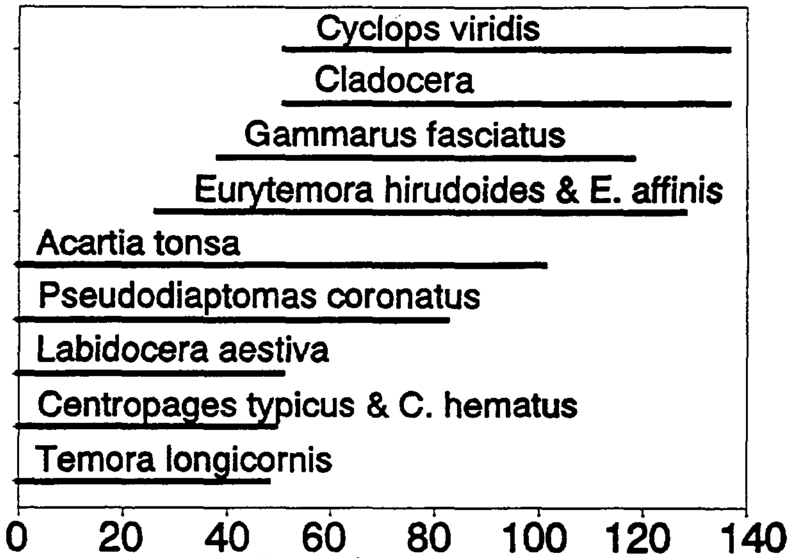
Available data suggest there have been no significant changes to the overall abundance or composition of the zooplankton since the turn of the century. However, it is hard to believe that the changes in water quality that have occurred in the transitional and tidal freshwater portions of the estuary during this century (Albert 1988) did not have some effect on the zooplankton. Crustaceans, for example, are quite sensitive to low dissolved oxygen conditions -- a long standing water quality concern in this region. Low oxygen concentrations and the presence of toxics also would have limited the presence of zooplankton predators such as fish (see subsequent section on the status and trends for fish), potentially causing additional changes in zooplankton structure (Carpenter et al. 1985, 1987). Unfortunately, data are not available to substantiate that the zooplankton assemblage in this region of the bay did change as a result of ambient water quality.

Table 8

Zooplankton Species Assemblages	
Time - Group	**Characteristic Species**
June	*Podon* sp. *Acartia tonsa* *Pseudodiaptomus coronatus* *Centropages hamatus*
July - August	*Acartia tonsa* *Pseudodiaptomus coronatus* *Neopanope sayi* (zoea) *Pinnixa sayana* (zoea) *Copepodites*
September - November	*Oikopleura* sp. *Paracalanus* spp. Veliger larva Polychaete larva
December	*Acartia tonsa* Veliger *Acartia* copepodite
January - May	*Centropages hamatus* *Centropages* copepodites *Temora longicornis* *Pseudocalanus minutes*
Source: Maurer et al. 1978.	

Figure 23

Delaware Bay Zooplankton Species

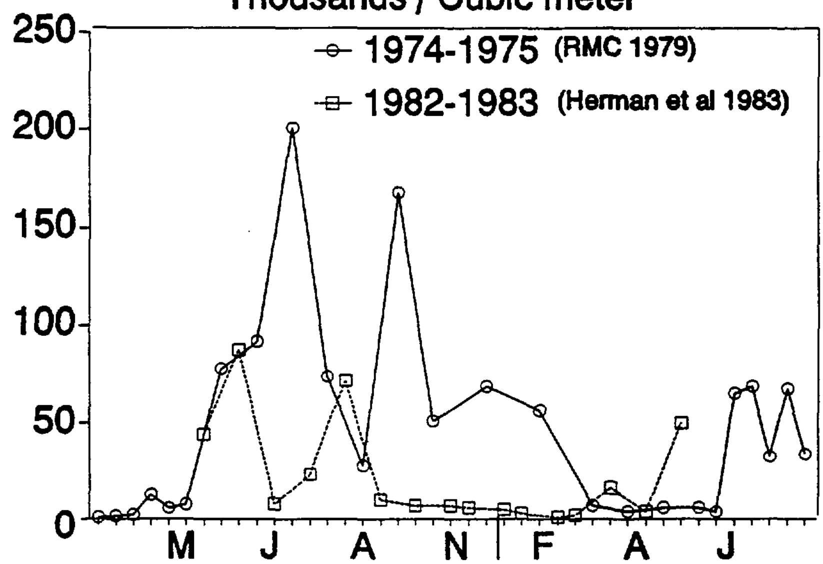


Source: Cronin et al. 1962

Figure 24

Delaware Bay Zooplankton Abundance

Thousands / Cubic meter



Ichthyoplankton

Fish eggs and larvae are referred to collectively as ichthyoplankton. The presence of ichthyoplankton in an area may signify the location of spawning. However, because many fish eggs are buoyant, they may be transported considerable distances from actual spawning locations by tides and currents (Norcross and Shaw 1984).

Ichthyoplankton surveys conducted in the Delaware estuary identified spatial and temporal distributions of eggs and larvae. Information on ichthyoplankton were collected using two methods: 1) measuring entrainment rates at water intake screens and 2) collecting samples with fine mesh nets. Data collected using both methods were used in our assessment of status and trends.

Two types of ichthyoplankton studies have been conducted in the Delaware estuary. Most ichthyoplankton data has been collected as part of ecological studies directed at assessing the environmental impacts of power plant intake and effluent or dredging activities. The majority of other ichthyoplankton studies deal primarily with striped bass, and weakfish although other species may be included.

Finfish spawning, and thus ichthyoplankton abundance in the Delaware estuary, generally peaks during spring and summer, although some species such as spot and Atlantic menhaden spawn offshore during early fall and winter (Rogers and Van Den Avyle 1989; Wang and Kernehan 1979). The anadromous species such as American shad, blueback herring, alewife, striped bass, white perch (semi-anadromous), and sturgeons typically undergo extensive annual spawning runs into the freshwater reaches of the Delaware estuary during spring and early summer.

In the tidal freshwater region, ichthyoplankton abundance is dominated by the Alosids, (family Clupeidae) (Anselmini 1974; Himchak 1982; Weisberg et al. 1987). Near Mercer Generating Station (rkm 129 to 131) eggs were most commonly collected during May, and were primarily comprised of blueback herring and alewife. Larvae of these species were collected from late-April to July. During 1972 to 1973, approximately 80% of larvae were bluebacks and alewives. White perch were the second most numerous larvae and averaged 7.5% of the annual catch (Anselmini 1974). Recent ichthyoplankton studies between rkm 174 and 214 documented similar results (Weisberg et al. 1987; Table 9).

Ichthyoplankton surveys were conducted during 1977 to 1982 in the transitional and lower bay regions as part of an ecological assessment in the vicinity of Artificial Island (Marden et al. 1976, 1977; Marden and Randle 1977; PSE&G 1984a). Faculty and students in the University of Delaware's Marine Science Department have been involved recently with weakfish ichthyoplankton research in the lower Delaware Day. Results of these studies are currently being prepared for publication (K. Price and C. Epifanio, pers. comm.).

Ichthyoplankton studies conducted in the transitional region identified the bay anchovy as the most abundant species. Species diversity was greatest during the spring and summer months. Bay anchovy comprised greater than 77% of ichthyoplankton samples collected during 1970 to 1977, and other common species included naked goby, blueback herring, alewife, Atlantic menhaden, weakfish and silversides (PSE&G 1980). Bay anchovy eggs comprised 96.0 to 99.9 percent of annual egg samples in this region. Studies near Delaware City, DE during 1977 to 1978 found 86 percent of larvae collected were comprised of five species or species groups, including: bay anchovy (76%), river herring (bluebacks and alewives (6.5%)), naked goby (6%), and silversides (5%) (Ichthyological Associates 1979a). Similar results were reported for samples collected in this region during 1978-1981 (PSE&G 1984; Table 10). One obvious difference is the lack of river herring in the latter samples. However, these species were collected during 1990 ichthyoplankton sampling in the upper transitional region (Biosystems Inc. 1990). White perch, striped bass, and weakfish larvae were collected infrequently during these studies.

Many ichthyoplankton surveys in the Delaware estuary were directed at assessing egg and larval striped bass distribution and abundance. Murawski (1969) provided the earliest information on the distribution of striped bass eggs and larvae. He found eggs distributed from Oakwood Beach, N.J. (rkm 93) to Bridgeport, NJ (rkm 127) and larvae between Fort Mott State Park and Newbold Island (rkm 98 to 201), although few were collected between rkm 151 to 172. He speculated that the low concentrations of dissolved oxygen near Philadelphia and Wilmington may explain the absence of ichthyoplankton in this area. Ichthyoplankton surveys conducted from Reedy Island to Lambertville, NJ during 1980 to 1981 reported very few striped bass eggs or larvae north of the Delaware Memorial Bridge (Himchak 1982). Numerous impact-assessment studies conducted during the mid- to late-1970s documented the abundance of striped bass eggs and larvae in the transitional region. In these studies, egg and larval striped bass were restricted to areas down river of Philadelphia, whereas recently, striped bass eggs and larvae have been collected throughout the freshwater tidal region (Weisberg and Burton 1989). The more upriver distribution in 1988 may be a reflection of a reduced pollution block in the Philadelphia region (Weisberg and Burton 1989).

Table 9

Total Number of Ichthyoplankton in Spring 1987 Plankton Tows in the Tidal Freshwater Portion of the Delaware River

	Total Number	Percent of Total
Larvae:		
Clupeidae (alosids)	61,891	69
White perch (yolk-sac)	2,575	3
White perch (post yolk-sac)	23,425	26
Percidae (perches)	740	0.8
Catostomidae (suckers)	477	0.5
Ictaluridae (catfish)	120	0.1
Cyprinidae (minnows)	88	<0.1
Anguillidae (elvers)	21	<0.1
Cyprinodontidae (killifish)	5	<0.1
Unidentified larvae	323	0.4
TOTAL	89,741	
Eggs:		
Small (< 1.0 mm)	33,001	99
American Shad	353	1
TOTAL	33,354	
GRAND TOTAL	123,095	

Source: Weisberg et al. 1987

Table 10

Species Composition of Ichthyoplankton Entrainment Samples at the Salem Generating Station, 1978-1981*		
Species	**Average Species Composition (%)**	**Overall rank**
Eggs:		
Bay anchovy	99.5	1
Silversides	0.4	2
Weakfish	<0.1	3
Unidentified fish	<0.1	4
Hogchoker	<0.1	5
Atlantic silverside	<0.1	6
Rough silverside	<0.1	7
White perch	<0.1	8
Striped bass	<0.1	8
Atlantic needlefish	<0.1	10
Mummichog	<0.1	10
Larvae:		
Bay anchovy	76.8	1
Gobies	17.0	2
Silversides	2.5	3
Weakfish	2.1	4
Hogchoker	1.1	5
Unidentified fish	0.3	6
Sand lances	<0.1	7
Atlantic croaker	<0.1	8
White perch	<0.1	9
Mummichog	<0.1	10
* Top 10 species in each category listed.		
Source: Public Service Electric and Gas Co. 1984		

Benthic Community

Initial descriptions of the animals inhabiting the sediments in the Delaware Bay area data back to the late 1800s with the work of J. Leidy and A.E. Verrill. These initial investigations focused on qualitative and taxonomic descriptions of benthic fauna, chiefly from offshore regions. Additional qualitative descriptions of fauna were completed by Richard (1929) working in the Cape May region. Maurer et al. (1978) report that the first truly quantitative study of the benthos in Delaware Bay was that of Amos in the 1950s. Unfortunately, this work remains unpublished.

Published quantitative reports of the Delaware benthos are available from the 1970s, starting with the paper by Maurer and Watling (1973) describing the benthic assemblages associated with oyster beds. At about the same time, other quantitative studies were being conducted in restricted areas near the mouth of Delaware Bay (Kinner et al. 1974; Watling et al. 1979), and throughout the bay (Maurer et al. 1978). Additional benthic studies have focused upon specific benthic groups such as amphipods, hydroids, pelecypods, isopods, gastropods, and polychaetes (Watling and Maurer 1972a,b; Maurer et al. 1974; Watling et al. 1979; Leathem and Maurer 1975; Kinner and Maurer 1978). All of the above mentioned studies focused upon the benthic communities in the bay. Fewer studies have been conducted in the transition region (Ichthyological Associates 1974) and the tidal fresh water region of the estuary (Fuller and Powell 1973; Crumb 1977).

The distribution of benthic species in the Delaware estuary is, as in most estuaries, primarily controlled by salinity. Sediment type (Crumb 1977; Maurer et al. 1976) and the presence of poor water quality (Ichthyological Associates 1974) secondarily influence the distributional patterns imposed by the estuarine salinity gradient (Table 11).

Benthic species in the bay include those limited to more saline regions in the lower bay and at the bay mouth (e.g., the surf clam *Spisula solidissima*), estuarine species that are found throughout most of the bay (e.g., the razor clam *Ensis directus* and the polychaete *Heteromastus filiformis*), estuarine species that favor lower salinity waters in the upper end of the bay (e.g., *Gemma gemma*), and species that are found only in the oligohaline region at the head of the bay and into the transition region (e.g., *Rangia cuneata*) (Maurer et al. 1974; 1978) (Table 11). In general deposit feeders comprised the dominant feeding type throughout the bay portion of the estuary.

The distribution of benthic fauna in the bay is secondarily influenced by sediment type. Maurer et al. (1978) used multivariate techniques (cluster analysis) to identify specific benthic assemblages within the bay. Five assemblages were identified using data from 1972, and four assemblages were identified using data from 1973. These assemblages were differentiated according to salinity and sediment type (Table 12). Differentiations between assemblages were not always distinct, leading Maurer et al. (1978) to describe the benthic communities of the bay as "a mosaic of animal assemblages, some of which have relatively sharp boundaries similar to classical level bottom type communities, whereas the boundaries of others are almost impossible to detect, and these represent species distributed along an environmental continuum."

Salinity and sediment type influenced not only species composition but density as well. Infaunal densities were positively correlated with salinity for both years of Maurer et al.'s (1978) study. During the first year, infaunal densities were also positively correlated with median grain size, and negatively associated with percent clay, percent silt, water content, and percent volatiles.

Average macrobenthic densities in the Delaware Bay appear to be low compared to densities in other East Coast estuaries. The overall average density reported by Maurer et al. (1978) was 722 individuals/m^2 and abundances of over 1000 individuals/m^2 were recorded at only 14 out of 207 stations. Abundances tended to be highest along the east side of the lower bay, and most samples were dominated by one or two species. These density measurements led Mauer et al. (1978) to conclude that benthic secondary production in Delaware Bay must be low.

Estimates of secondary production for the benthos in any estuary are rare. However, benthic secondary production in the Delaware Bay was estimated using data collected during the Northeast Monitoring Program sponsored by NOAA (Howe and Leathem 1984; Howe et al. 1988). Monthly macrobenthic production at a station in the lower bay was estimated to be 24 g C m^{-2} hr^{-1}. Three bivalve species (*Ensis directus*, *Mytilus edulis*, and *Tellina agilus*) accounted for 40%, and one polychaete species (*Asabellides oculata*) accounted for 49% of the annual benthic production at this station. From these numbers, Howe and Leathem (1984) concluded that the secondary production of the macrobenthic community in the Delaware was comparable to that reported from other estuaries.

Benthic communities in the tidal fresh region of the estuary (Crumb 1977) are dominated by species typical of most North American rivers (Hynes 1970) and include tubificid worms, chironomid larvae, spaerid clams and unionid mussels. The benthic fauna in this portion of the estuary have been the least studied of that in any part of the estuary. Benthic communities here are influenced by numerous contaminant inputs from point and non-point sources. Crumb's (1977) study focused on the area of the river between Burlington and Trenton. It is not known how well this 16 km segment represents the status of benthic communities throughout the tidal fresh region of the estuary. Crumb (1977) found that 90% of the benthic community was comprised of oligochaetes of the genus *Limnodrilus*, of which 90% were one species, *Limnodrilus hoffmeisteri*. This nearly monogeneric composition of tubificids suggests that the river is exposed to organic pollution, simple eutrophication, or some combination of both (Brinkhurst 1970). No estimates of benthic secondary production have been made for this portion of the estuary.

Table 11

Benthic Community Composition by Region		
Bay	**Transition**	**Tidal Fresh**
Bivalves *Tellina agilis* *Ensis directus* Polychaetes *Glycera dibranchiata* *Heteromastus filiformis*	Oligochaetes (Presence noted, species composition and abundance not recorded) Amphipods *Gammarus daiberi*	Oligochaetes *Limnodrilus* sp. Chironomids *Procladius culiciformis* Bivalves *Corbicula manilensis*
Maurer et al. 1978	Ichthyological Associates 1974	Crumb 1977

Table 12

Delaware Bay Benthic Assemblages		
Assemblage	**Species**	**Description**
1	*Tellina agilis* *Glycera dibranchiata* *Heteromastus filiformis* *Protohaustorius wigleyi* *Glycera capitata* *Nephtys picta*	Polyhaline environments with fine to medium sand
5	*Tellina agilis* *Nucula proxima* *Paraphoxus spinosus* *Aricidea cerruti* *Glycera americana* *Cancer irroratus* *Pagurus longicarpus*	
8	*Melita nitida* *Polydora ligni* *Neopanope sayi* *Nereis succinea* *Corophium simile* *Paracaprella tenuis* *Parapleustes aestuarius* *Crepidula plana* *Eurypanopeus depressus* *Sabellaria vulgaris*	A distinctly epifaunal assemblage found in scattered localities throughout the bay
10	*Mulinia lateralis* *Mya arenaria*	Mesohaline to lower polyhaline environments with fine sand and silt
From: Maurer et al. 1978		

Parabenthos

The term parabenthos refers to fauna living next to and associated with the surface of subtidal sediments. These fauna are also sometimes referred to as epifauna. Parabenthos are distinguished from epifauna in that they are also widely found in the water column due to diel vertical migrations. Thus, epifauna are found strictly on or just above the sediment, whereas parabenthos are epifaunal forms with the ability to make periodic excursions into the water column.

The parabenthos in the Delaware estuary are represented by three groups of fauna:

- Mysids, or oppossum shrimp
- Sand shrimp
- Amphipods.

Mysids

Mysids were identified as one of the key biological resources of the Delaware estuary because they are potentially important predators of both plankton and benthos and are important prey for carnivorous fish (PSE&G 1984). Thus, mysids function as an important link between trophic levels. The dominant mysid species in the bay is *Neomysis americana* (Hulbert 1957; Cronin et al. 1962; PSE&G 1989), a species that has been described as the most common and abundant mysid inhabiting estuaries and the nearshore ocean of the northeastern coast of the United States (Wigley and Burns 1971).

Neomysis is present year around and is one of the more common species sampled during zooplankton surveys (Cronin et al. 1962). This shrimp is an estuarine species having peak abundances in the upper bay and lower abundances at the mouth of the estuary and in the transition region of the estuary. *Neomysis* is commonly found up to the four parts per thousand isohaline (Hulbert 1957), but can penetrate up-estuary to waters of less than one part per thousand (Cronin et al. 1962). This species is more abundant in the deep-water portion of the bay than in near-surface or shallow water. It is a strong vertical migrator, more concentrated near the sediments during the day and dispersed through the water column at night (Herman 1963).

No quantitative estimates have been made of the importance of *Neomysis* as a predator on pelagic and benthic communities. However, due to their abundance and biomass, in the estuary, and their common occurrence in the diets of many fish, their influence on pelagic and benthic communities is potentially significant.

As prey, *Neomysis* is a very important food supply for fish. The oppossum shrimp may be the most important food item for weakfish (Shuster 1959; De Sylva et al. 1962; Thomas 1971). Shuster (1959) found that *Neomysis* was the most frequently found prey item in weakfish and estimated that approximately two-thirds of the annual weakfish harvest, by weight, was due to predation on zooplankton, particularly

Neomysis. *Neomysis* is also a dominant prey item for white perch (Meadows 1976) and anchovy (Stevenson 1958; Meadows 1976).

Sand Shrimp

Sand shrimp (*Crangon septemspinosa*) is also a dominant macroinvertebrate in the Delaware estuary system. Whereas mysids are more common in deeper portions of the estuary, sand shrimp are more common in shallow waters. *Crangon's* penetration into the upper reaches of the estuary is restricted to waters having salinity greater than four parts per thousand (Price 1962).

Crangon are thought to fill an ecological niche similar to that of mysids by forming a link between invertebrate benthic and zooplankton communities and carnivorous fish. Recent evidence suggests that in some systems, *Crangon* may be a dominant predator of the benthos, able to influence the structure and abundance of benthic communities (Frithsen et al., Unpublished manuscript).

Amphipods

Amphipods are found throughout the Delaware estuary system. However, they are a dominant member of the macroinvertebrate species assemblage in the transition region (PSE&G 1984), primarily represented by the genus *Gammarus*. Like mysids and *Crangon*, *Gammarus* is an important link between benthic communities and carnivorous fish (PSE&G 1984). Since these three groups are separated by salinity, amphipods in the freshwater region of the estuary may have the same ecological role as mysids and *Crangon* in mesohaline regions of the estuary.

Important Benthic Species

Five benthic invertebrate species of current or historical importance as commercial species were identified as key biological resources for the Delaware estuary. Status and trends for these species are presented below.

American Oyster

The American oyster, *Crassostrea virginica*, is a significant ecological and economic component of the Delaware estuary. Additionally, the oyster may be a sensitive indicator of environmental degradation in the estuary (Maurer and Watling 1973). Oysters range from Cape May to north of Arnolds Point (rkm 67.5), although maximum development of natural seed beds extends from Woodland Beach (rkm 65) to Port Mahon (rkm 47) on the Delaware side and Egg Island Point (rkm 35) to north of Arnolds point on the New Jersey side (Maurer et al. 1974). Oyster beds in the Delaware Bay were first surveyed by the U.S. Bureau of Fisheries in the early 1900s (USFWS 1979). Today, most of the beds still occupy virtually the same areas reported in the original surveys (Beck 1978; Sullivan pers. comm.). The state of Delaware periodically conducts oyster surveys to inventory Delaware's natural oyster beds. The objectives of this study are to evaluate population trends, collect recruitment data, determine mortality rates, and estimate overall stock densities on each bed (Cole et al. 1984).

Oysters form the nucleus of a benthic assemblage that contains many species (Maurer et al. 1974), and the diversity of this associated fauna communities declines with decreasing salinity (Maurer and Watling (1973a). These species benefit from association with oysters primarily due to the filter feeding activity of oysters that transports organic matter from the water column to the sediments. The fauna in this benthic assemblage also modify oyster populations. Oysters in the bay, for example, are subject to more predation by oyster drills (*Urosalpinx cinera*), the principal predator of oysters (Haskin et al. 1983), than oysters in lower salinity regions, because drills are more commonly found in high salinity waters. Other factors influencing oyster occurrence and abundance are also related to the estuarine salinity gradient. For example, the incidence of oyster diseases, particularly MSX, is lower in low salinity regions of the bay and transition regions (Haskin et al. 1983)

The commercial oyster industry is based on native oyster populations that extend from the Hope Creek beds, below Artificial Island, to the vicinity of Brandywine Shoals in the lower bay (Haskin et al. 1983). Over a century ago, fisherman began transplanting oyster from seed beds in the upper bay to down bay growing sites. Transplantation activities were designed to maximize growth and minimize losses from predation and disease. By keeping juvenile oysters in low salinity regions, losses from predation and disease were minimized. Upon reaching a certain minimum size, oysters were less vulnerable to predation and could be transported down bay to grow to a marketable size (Haskin et al. 1983). An account of the oyster industry in Delaware Bay has been presented in the excellent monograph by Miller (1962).

Oyster landings in the Delaware estuary during the late 1800s to early 1900s ranged from approximately five to 15 million pounds (Figure 25). A sharp decline in oyster seed production was apparent in the early 1950s and was probably due to overfishing the seed beds (Haskin et al. 1983). Other factors that may have contributed to the initial decline in landings were: siltation in the watershed, heavy industrialization of the Delaware River, industrial effluent and oil spills, mosquito control practices, and closure of harvested areas caused by sewage contamination (McHugh 1981). In 1957, disaster struck the Delaware estuary oyster population. A parasitic organism called MSX (*Haplosporidium nelsoni*) had seriously affected the oyster stocks. It was estimated that in three years 90% to 95% of all oysters on the planted grounds, and about 60% of the stocks on the seed beds, were killed by this disease (Haskin et al. 1983). Oyster populations have made a gradual comeback since that time, although stocks are still reduced. Commercial fishing for oysters in the Delaware estuary has been severely reduced since 1988.

Blue Crab

The blue crab, *Callinectes sapidus*, is an important component of the Delaware estuary commercial and recreational fisheries and, in the 1980s, became the principal shellfishery, constituting over 85% of the entire Delaware estuary shellfish catch.

With the reduction of oysters as a fishery in 1988 and 1989, the blue crab fishery accounted for approximately 95% of the shellfish industry. During the late 1800s to 1930s very few blue crabs were harvested (Figure 26). Since that time, and especially in the early 1950s, landings have risen dramatically, although large annual fluctuations are apparent. McHugh (1981) cites possible reasons for these fluctuations. Chief among these is that the blue crab in the Delaware may be near the northern limits of its range and thus may be sensitive to small fluctuations in temperature caused by climatic factors. The reported range for the blue crab is along most of the East Coast north to Chesapeake Bay where it supports a major fishery. From Delaware north it appears less abundantly; its occurrence is irregular, but is reported as far north as Nova Scotia (Williams 1984). The great variations in availability from Delaware Bay north are probably explained on the basis of environmental fluctuations, the major element of which is water temperature.

Blue crabs undergo extensive seasonal migrations within the Delaware estuary, beginning with larval stages (Dittel and Epifanio 1982; Epifanio et al. 1984). Crabs are caught nearshore in the lower bay during early spring and toward summer. As temperature increases, the fishery moves up the estuary into the transitional and freshwater region. They were reported from as far upstream as rkm 174 to 195 (Pennsylvania Fish Commission, unpublished data). As temperature declines during fall months, blue crabs return to the Delaware Bay region, where they burrow under the sediment to overwinter (Shuster 1959).

In the Delaware Bay region, annual trawl surveys have been conducted since 1977 to document the recruitment of juvenile blue crab (R. Cole, pers. comm.). These data are collected by the Delaware Department of Natural Resources, Division of Fish and Wildlife and published in annual reports. However, it was beyond the scope of this project to acquire and analyze these data.

Blue crab populations in the Delaware are apparently healthy and sustainable. Although annual fluctuations in catch are relatively large, there is no indication that the stock is overfished (Price et al. 1983).

Hard clam

The hard clam, *Mercenaria mercenaria*, no longer supports a significant commercial fishery, but historically was an important component of the Delaware estuary shellfisheries (Figure 27). Since peak landings in the 1940s, landings have fluctuated greatly, with very little reported landings after 1974. Large differences in state and estuarine landings suggest that the bulk of this species is harvested offshore. In the estuary, hard clams range from Woodland Beach, DE (rkm 65) to the Atlantic Ocean, although greatest abundance occurs from the lower bay, south of Port Mahon (rkm 47) to Broadkill Beach (rkm 3) (Keck et al. 1972; cited from Maurer et al. 1974).

Horseshoe crab

The horseshoe crab, *Limulus polyphemus*, occurs in great numbers in the Delaware estuary, and its distribution is limited to the bay. Horseshoe crab spawning and distribution patterns have been examined in the Delaware estuary (Shuster and Botton 1985; Finn et al. 1990), and its abundance appears to be spatially and temporally aggregated. Horseshoe crab spawning migrations are presumably initiated by increasing daylight hours in late spring that stimulates adults to move shoreward from deep bay and coastal waters. These crabs spawn primarily along the Cape May Shore of New Jersey, although the Delaware shoreline is also used. Crab numbers on New Jersey beaches are four times higher than on Delaware Beaches (Finn et al. 1990). Most adults appear in shallow water in April. Peaks in breeding occur during May and June spring tides; however, they may spawn on high tides throughout the lunar cycle (Botton 1982). After June, spawning activity declines, and adults disperse to deeper water. Up-bay spawning is limited by fringing salt marsh and peat banks. In New Jersey this species ranges from the mouth of the bay to Arnolds Point (rkm 67). Population estimates during 1977 were approximately 222,000 males and 51,000 females (4.3 males:1 female) (Shuster and Botton 1985). Recent surveys suggest that populations have increased since 1977. Finn et al. (1990) estimated peak 1990 spawning populations at 1,240,700 and suggested that populations have not been at this level since the 1920s.

Horseshoe crabs contribute significantly to the ecology of the Delaware Bay. The large numbers and seasonal activity of these horseshoe crabs may play an important role in controlling the composition and abundance of benthic invertebrates (Maurer et al. 1978; Botton 1984). Additionally, their eggs provide a rich energy source for migratory shorebirds. The great abundance of these eggs is a primary reason that the Delaware estuary ranks as one of the largest migratory shorebird staging areas in North America (Stein et al. 1983; Myers 1987).

Horseshoe crabs have been a minor component of Delaware estuary fisheries. Commercial landings of horseshoe crabs reached a peak in the late 1800s (Figure 28). They were harvested for fertilizer and animal feed (Fowler 1908; Shuster 1960). Landings declined steadily through the 1900s, and the fishery ceased during the 1960s (McHugh 1981).

Very little data is available on status of horseshoe crab populations in the Delaware estuary. Studies that have examined population trends suggest that, although the current spawning population is several fold greater than in the 1960s, the population is far from approaching the numbers and spawning intensity reported a century ago (Shuster and Botton 1985; Finn et al. 1990).

Lobster

The American lobster, *Homarus americanus*, supports a limited commercial fishery in the Delaware estuary. The majority of American lobster in the Delaware Bay area are caught in offshore waters, and this is reflected in the drastic differences in the state and estuary landings (Figure 29). Lobster have a limited distribution in the Delaware estuary. They are located only in the Delaware Bay region of the estuary and range from the mouth of the bay to approximately 13 km north. They are most common on hard sand and rocky bottoms and in deeper channels (Leathem and Maurer 1980).

Figure 25

Oyster

Thousands of Pounds Landed

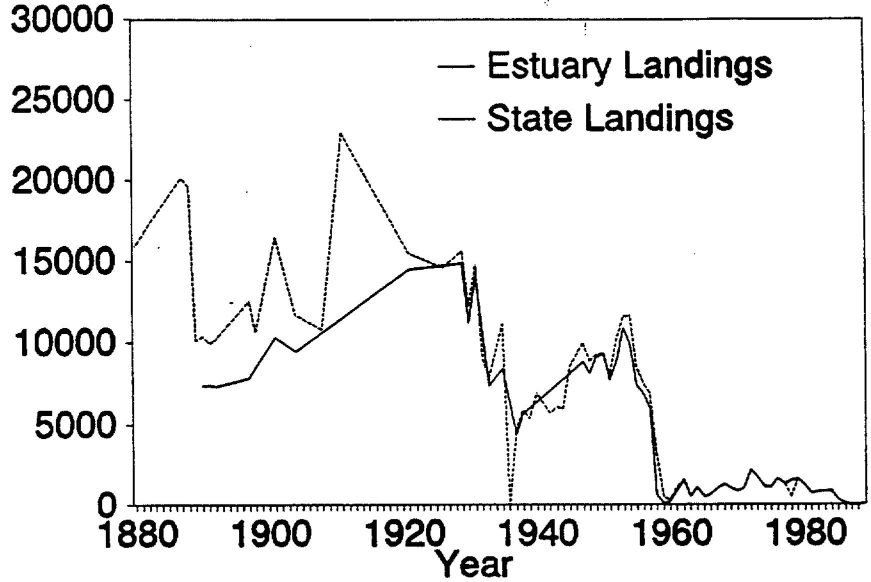


Figure 26

Blue Crab

Thousands of Pounds Landed

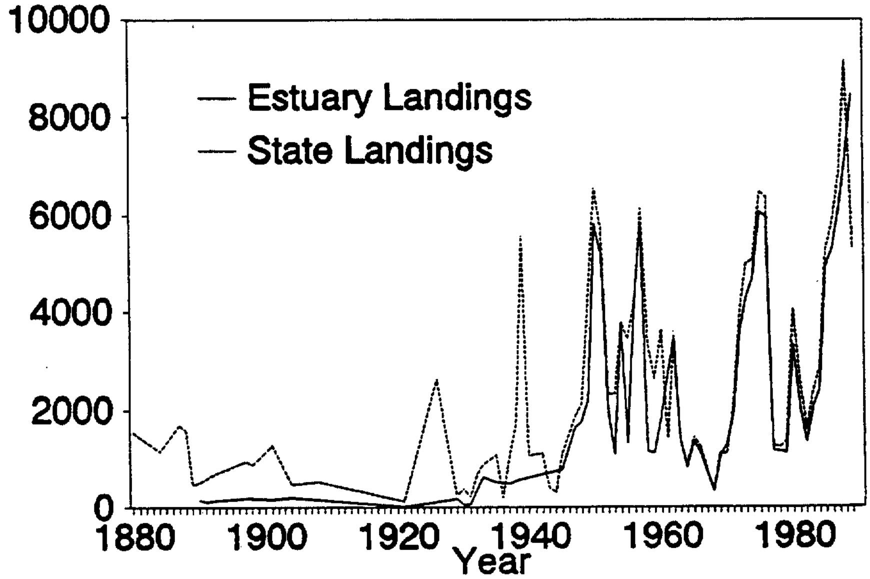


Figure 27

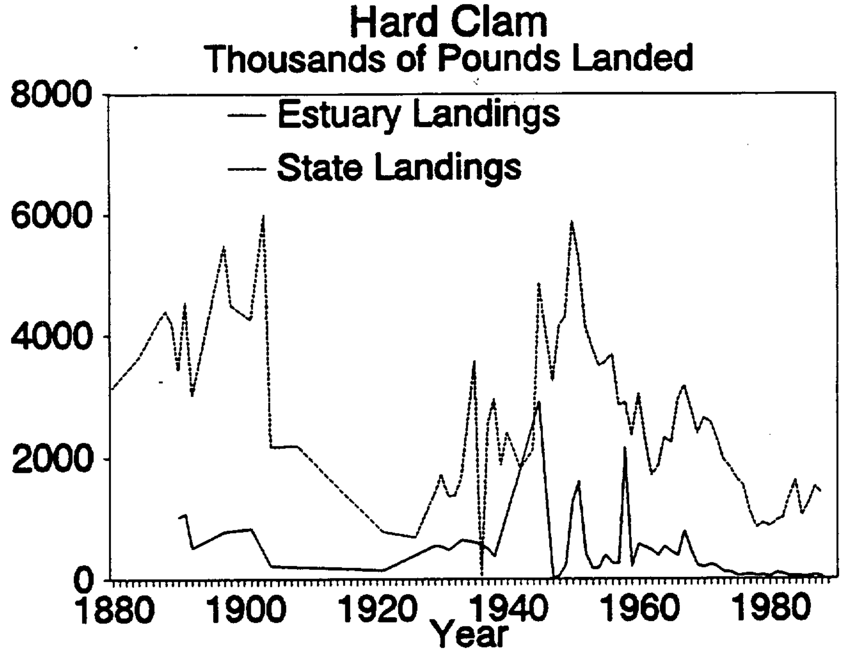
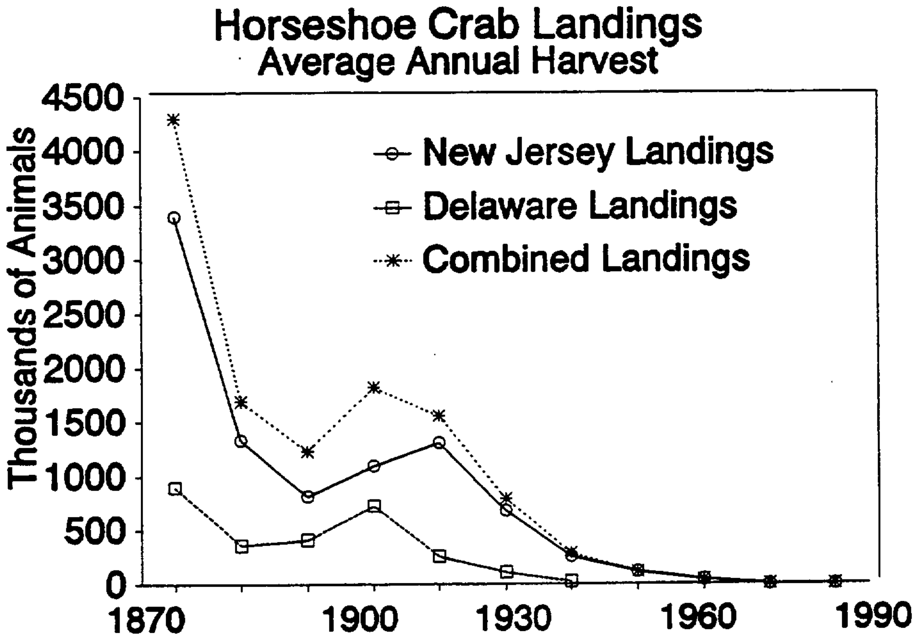
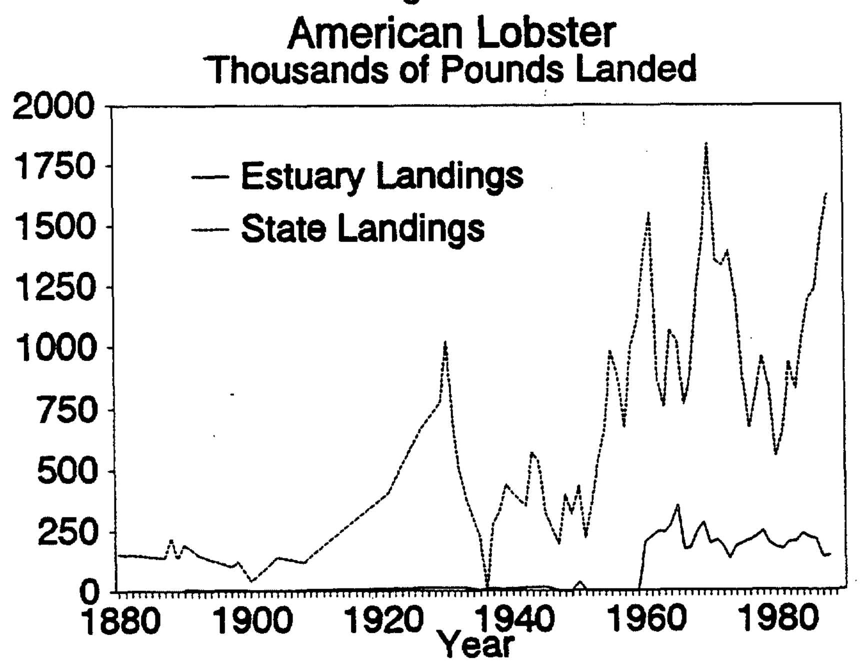


Figure 28



Source: Shuster and Botton 1985

Figure 29


American Lobster
Thousands of Pounds Landed
2000
1750
1500
1250
1000
750
500
250
0
1880
1900
1920
1940
1960
1980
Year
— Estuary Landings
— State Landings

Status and trends for important fish resources in the Delaware estuary were assessed using commercial and recreational landings statistics and fishery-independent survey data. For species of commercial importance, trends in abundance were examined using historical data available from the late 1800's through 1989. Commercial data were presented as: 1) Delaware estuary landings -- includes summations of Delaware, Pennsylvania, and New Jersey counties bordering the estuary, and 2) State landings -- summation of total state landings. During early years, data were reported intermittently, and Delaware estuary data were available less frequently than total state landings. Harvest data specific to the Delaware estuary were available for the years 1948 to 1977, due to the addition of water body codes in The National Marine Fisheries Service (NMFS) commercial landings dataset. However, trend analyses were conducted using county estimated harvest to maintain comparability with earlier data. This may result in over-estimation of landings for species that are harvested outside the estuary but landed within a county adjacent to the Delaware estuary.

One of two possible patterns were apparent from comparison of state and estuary landings:

- Delaware estuary landings are approximately equal to state landings. This would occur if the species is collected primarily in the Delaware estuary, or if fish from offshore are landed in Delaware estuary ports.
- State landings are much greater than Delaware estuary landings. This pattern would occur if the majority of the catch were landed in coastal waters, or in the Hudson River area.

Fishery-independent data were available from numerous sources. Long-term surveys have been conducted in each of the salinity regions, providing valuable fisheries information. In the Delaware Bay area, Delaware conducts an annual juvenile finfish trawl survey, and data were available from 1980 to the present. Other studies conducted by the state of Delaware from 1966 to 1970 and 1979 to 1984 used standardized surveys and larger trawl nets. In the transitional region, studies by PSE&G were conducted from the late 1960's through early 1980's. New Jersey has conducted juvenile finfish surveys (juvenile = age 0+, indicating fish less than one year old) in the transitional and freshwater regions since 1980. However, only striped bass data were available for examination. Numerous other surveys provided additional data.

Important species in the Delaware estuary were distributed throughout the salinity ranges. Most species were found throughout the estuary at some time of the year. However greatest abundance was generally limited to specific regions, depending on life history requirements (Figure 30). Species such as American shad, blueback herring, alewife, white perch, striped bass, and sturgeon are anadromous species and, during summer months, are most often associated with the freshwater regions of the estuary. Species such as weakfish, bluefish, scup, and summer flounder are typically considered marine species, although they may stray into the transitional region. Species such as bay anchovy, spot, and Atlantic menhaden are found throughout the estuary during summer months, although abundance is generally greater in areas of higher salinity.

The format used to present the status and trends for key biological fish species is: 1) introduction, 2) general life history information, 3) fisheries dependent commercial and recreational data, and 4) fisheries independent data. Individual fish species are presented in approximate order of their dominance in the estuary from the tidal fresh riverine portion to the mouth of the bay.

Sturgeon

Atlantic sturgeon, *Acipenser oxyrhynchus*, and shortnose sturgeon, *Acipenser brevirostrum*, are anadromous species. The shortnose sturgeon is considered a federally endangered species (USFWS 1990); Atlantic sturgeon is considered a species of special concern (Williams et al. 1989). A limited number of studies have attempted to examine Atlantic and shortnose sturgeon populations in the Delaware estuary.

The Delaware estuary once supported the largest commercial sturgeon fishery along the east coast of the United States (Ryder 1890, Cobb 1900). The principle fishing grounds in New Jersey were between Cape May (rkm 0) and Fishing Creek, NJ (rkm 76), and at Penns Grove in Salem (rkm 116). The principal fishing locations in Delaware were between the Mispillion River (rkm 19) and Delaware City (rkm 97), and in Pennsylvania between Marcus Hook and Chester (Cobb 1890). The peak harvesting period was 1880 to 1890 and was dominated by landings recorded in the states of New Jersey, Delaware and Virginia. During the 1978 to 1982 period, these states ranked only fifth, tenth, and sixth, respectively, with reported landings less than 1% of their former levels (Smith 1985). The Delaware estuary sturgeon fishery began around 1853. Average catch began to diminish by 1890 (Cobb 1900, Figures 31 and 32). Much of the initial decline in the sturgeon population was attributed to shad gill netters, who commonly killed sturgeon that became entangled in their nets (Cobb 1900); overfishing was also a factor (Smith 1985). By the turn of the century, all U.S. sturgeon fisheries had suffered substantial decreases in landings, and most of the major fisheries exhibited an almost total collapse. Sturgeon are still landed commercially in the Delaware estuary, although at a fraction of their historical levels (Figure 33).

Atlantic sturgeon

The Atlantic sturgeon inhabits large estuaries and Atlantic coastal waters from Labrador to eastern Florida (Vladykov and Greeley 1963). Available fishery-independent data indicate that the Atlantic sturgeon annually use different salinity regions within the Delaware estuary.

Atlantic sturgeon distribution within the Delaware estuary is dependent upon season. Seasonal distribution patterns were compiled from capture records. There were 130 reported captures of Atlantic sturgeon in the Delaware estuary between November, 1958 and July, 1980 (Brundage and Meadows 1982a). They were collected in the Delaware Bay region (rkm 0 to 55) during most months, although catch was greatest from March through May (14 to 23 fish/month) and lowest from July through August (1 fish/month). Abundance increased slightly during September through November (2 to 3 fish/month).

Atlantic sturgeon were most abundant in the lower tidal river (rkm 56 to 127) and upper tidal river (rkm 127 to 222) from June through September. This coincides with the periods of least abundance in the Delaware Bay and suggests a migration from the bay waters during the warmer months. Abundance in the upper and lower tidal portion of the Delaware declines in September, and the subsequent increase in the Delaware bay region suggests a return to overwintering areas. These abundance patterns may be biased by the greater fishing effort expended during spring relative to other seasons, although most commercial gill netters interviewed confirmed these findings (Brundage and Meadows 1982a).

Recent studies have suggested that distribution patterns within the Delaware estuary may be dependent on age of the fish. Eighty-nine juvenile Atlantic sturgeon were collected in the upper tidal region of the Delaware estuary (rkm 201 to 212) during 1981 to 1984 (Lazzari et al. 1986). This study suggested that at least a portion of the juvenile Atlantic sturgeon population use the upper tidal region to a much greater extent than in other river systems. Many juveniles appear to use the upper tidal region on an annual basis (although abundance declined during winter months), and it is suggested that this area (Roebling to Trenton, NJ; rkm 200 to 217) is an important nursery area for juvenile Atlantic sturgeon.

Because of the limited number of studies specifically directed at the Atlantic sturgeon, it is difficult to assess actual status of this species in the Delaware estuary. However, with a reduction in the commercial fishery, with recent improvements in water quality, and with the large number of juveniles recently collected in the tidal freshwater region, it is likely that the abundance of this species is increasing.

Shortnose sturgeon

Shortnose sturgeon inhabit large estuaries and nearshore waters along the Atlantic coast of North America from New Brunswick, Canada to the St. Johns River, Florida (Brundage and Meadows 1982b). In the Delaware estuary, shortnose sturgeon historically occurred from the lower bay (Fowler 1911) to at least as far upstream as New Hope, PA (rkm 238)(Cobb 1900). Based on historical and recent records, the range of the shortnose sturgeon has not changed significantly, and the species appears to use the entire mainstem estuarine complex (Masnik and Wilson 1980).

Brundage and Meadows (1982b) summarized recorded captures of shortnose sturgeon. During 1811 to 1913 some 1,949 captures were reported, mostly as by-catch of the shad gill net fishery. No documented captures were reported during 1913 to 1954. Thirty seven were reported during 1954 to 1979, mostly incidental to fishery and ecological studies. Most of these fish were taken in the upper tidal freshwater portion of the estuary (rkm 200 to 214), although ten were caught in a gill nets during March and April near Little Creek, Delaware (rkm 45).

Recent studies have collected numerous shortnose sturgeon in the tidal freshwater region of the Delaware estuary. A total of 1,371 shortnose sturgeon were collected between Philadelphia and Trenton (rkm 164 to 214) during 1981 to 1984. The Florence-Trenton region of the Delaware estuary (rkm 199 to 212) produced the majority of fish, and most sturgeon were collected in the river channel (Hastings et al. 1987). In the freshwater tidal region, shortnose sturgeon were collected throughout the year, although lower catches occurred from about December through April. Some shortnose sturgeon apparently overwinter in this area as evidenced by a few winter sets that yielded unusually large catches. From these collections, Hastings et al. (1987) calculated preliminary population estimates of 6,000 to 14,000 adult shortnose sturgeon in the Trenton-Florence region. Lower densities of shortnose sturgeon in the lower tidal freshwater region were attributed to water quality, which became progressively more polluted closer to Philadelphia. Fish surveys conducted in the transitional region (rkm 64 to 96) during the period 1968 to 1979 corroborate these findings (Masnik and Wilson 1980).

Further south in the estuary, the area near Artificial Island appears to be used only as a migratory route between down bay overwintering areas and upriver spawning and foraging areas. Catch per unit effort is much less than that reported in the freshwater region (Table 13). Masnik and Wilson (1980) estimated shortnose sturgeon density using data from other river estuaries and extrapolating to the Delaware estuary. Population estimates were 30,000 juveniles and 500,000 adults. This value appears quite large compared with the upriver estimates suggested by Hastings et al. (1987).

Shortnose sturgeon use certain regions of the estuary depending upon season and age of the fish. Only a few studies have been aimed directly at assessing sturgeon distribution and abundance. However, those directed at sturgeons have suggested that abundance may be improving from historical lows caused by overfishing and pollution.

Alewives and Blueback Herring

The alewife, *Alosa pseudoharengus* is an anadromous species that ranges from Newfoundland (Winters et al. 1973) to South Carolina (Berry 1964). The alewife uses coastal riverine systems, including the Delaware estuary and its tributaries, as spawning and nursery habitat. In the Delaware it is a seasonal, planktivorous member of a complex estuarine community (PSE&G 1984d; Richkus and DiNardo 1984).

The blueback herring, *Alosa aestivalis*, is an anadromous species that ranges from Nova Scotia south to the St. Johns River, Florida (Hildebrand and Schroeder, 1928). Blueback herring occur in the Delaware estuary to as far upstream as rkm 333.5 (Didun, 1978). The seasonal and spatial distribution of the blueback herring is similar to that of the alewife (PSE&G 1984d). Mihursky (1962) noted that above the fall line in Trenton, (rkm 214), both species were more confined to the mainstem river than in tributaries.

Spawning of both species overlaps both temporally and spatially. Blueback herring spawning occurs in tidal and nontidal freshwater, mostly in upstream areas or tributary creeks, during late April through early June. Alewives spawn in upstream freshwater areas of tributary creeks, and possibly in shallow areas of the Delaware River during April and May. (Wang and Kernehan 1979). They spawn in tidal tributaries in the transitional and Delaware Bay region, as well as in tidal freshwater tributaries (Smith 1971; Martin 1974; Miller 1982; Miller et al. 1975).

During development through early juvenile stages, a slow but steady downstream displacement within these freshwater nursery areas occurs. During September through November, the fall emigration of young alewife occurs (PSE&G 1984d).

The alewife and blueback herring (collectively referred to as river herring) are important ecologically and economically to the Delaware estuary. Ecologically, these species are important links between zooplankton and top piscivores, such as striped bass. Commercially, both species are used as sources of fish meal, fish oil, and protein (Fay et al. 1983b). The recreational fishery for alewives and blueback herring is significant during the spring spawning runs, although most of the catch serves as bait for other sportfish (National Marine Fisheries Service 1980).

The commercial catch of alewives (including blueback herring) has been documented since about 1880 (Figure 34). Large catches occurred in the late 1800s and early 1900s. Catch declined rapidly after this, except for large catches during 1930 and 1931. This brief increase in landings may have been caused by the depression, which created temporary markets for inexpensive fish (McHugh 1981). Rapid decline in landings during the early 1900's coincides with the declines noted for most anadromous species at this time, including American shad, striped bass, sturgeon and white perch. Part of this decline in catch rates has been attributed to overfishing; however, effort for these fisheries was also declining (McHugh 1981). Estuarine water quality probably contributed most to river herring declines. Water quality, especially in the Wilmington, DE to Philadelphia, PA area of the river, became progressively worse around the turn of the century (Albert 1988). This, and the construction of dams that reduced available habitat in many tributaries, contributed to reduced anadromous species populations (Sykes and Lehman 1957).

River herrings comprise a large proportion of fish collected in surveys of the upper, tidal Delaware River (Tables 14 to 16). During the summer months, these areas function as nursery areas for river herrings. Historical trends for river herring in this region of the estuary are available for the 1980s from the New Jersey beach seine survey data (P. Himchak, pers. comm.). An analysis of these data, however, were not included in the scope of this project. Recent collections in the tidal freshwater region suggest that bluebacks comprise a much larger proportion of the fish community in this region than alewives (Tables 16 to 18).

In the transitional and Delaware Bay area, river herring are most common during spring (March to May) and fall months (October-December), during spawning and emigration from the estuary (PSE&G 1984d; Seagraves and Cole 1989). Therefore, long-term and historical trends were not available in these regions.

American Shad

The American shad, *Alosa sapidissima*, is an anadromous species that occurs along the Atlantic Coast from the Gulf of St. Lawrence in Canada to the St. Johns River, FL. They are most abundant from North Carolina to Connecticut (Walburg and Nichols 1967; Richkus and DiNardo 1984). In the Delaware estuary, adult shad annually migrate from offshore to upstream spawning grounds. They enter the lower Delaware Bay during early March and move into the spawning grounds during April and May (Miller et al. 1982). Historically, shad spawned throughout the freshwater portion of the Delaware estuary. The highest density of fish occured between Dingmans Ferry, PA (rkm 381) and Hancock, NY (rkm 531) (Chittenden 1969). The Lehigh and Schuylkill rivers once held large shad runs, until dams prevented their access (Gay 1892; Meehan 1896). Spawning may have occurred as far downstream as Marcus Hook, PA (rkm 128), and in tidal tributaries throughout the estuary (Walburg and Nichols 1967). Chittenden (1969) suggested that a shift away from tidal freshwater spawning grounds towards nontidal regions was a result of poor water quality in the Philadelphia area. Very little spawning occurred downstream of the Delaware Water Gap through the mid-1970's. (Miller et al. 1982; Maurice et al, 1987).

Improvements in dissolved oxygen levels in the Delaware river near Philadelphia have benefitted the American shad population. Populations have increased and spawning areas are expanding (Miller and Lupine 1987; Albert 1988; Lupine 1989). Spawning has been observed between Trenton and the Delaware Water Gap (Maurice et al. 1987) and in the tidal freshwater region south of Trenton (Weisberg et al. 1987).

Juvenile shad remain in the nursery areas until September or October then begin a downstream migration (Sykes and Lehman 1957; Miller et al. 1975; Miller et al. 1982) initiated by decreasing water temperature and growth of individuals (Chittenden 1969, 1972; Miller et al. 1973).

The American shad is one of the Delaware estuary's most significant fishery resources. Historically the commercial catch of American shad in the Delaware estuary was unequalled by any other Atlantic riverine system (Stevenson 1899). Catch was estimated at 10.5 million pounds in 1836 (Sykes and Lehman 1957). At the turn of the century, average annual catch in the Delaware estuary was 12 to 14 million pounds (Figure 35). Drastic declines in shad abundance were observed in the early 1900's. The principal factors contributing to this decline were degraded water quality near Philadelphia (resulting in a 'dead zone' of water containing very little dissolved oxygen), construction of dams and other waterway obstructions, and overfishing (Ellis et al. 1947; Sykes and Lehman 1957; Walburg and Nichols 1967; Chittenden 1974, 1976). Throughout this century, shad population fluctuations have been strongly associated with anthropogenic factors such as sewage loading, dissolved oxygen, and bacterial oxygen demand (Summers and Rose 1987).

Recent evaluation of commercial statistics maintained by the state of Delaware indicates an increase in catch per unit effort between 1985 and 1988 (Miller 1988). Currently, the annual spawning runs support a moderate commercial fishery in the lower Delaware Bay, a small commercial fishery in the non-tidal portion of the River at Lambertville, NJ, and a large recreational fishery in the mainstem of the Delaware River (Miller and Lupine 1987). The recreational fishery for American shad is a multi-million dollar industry (Miller et al. 1982). Most of the recreational harvest occurrs upstream, in the non-tidal freshwater region of the estuary (Miller and Lupine 1987); very little occurs in the lower estuary (Miller 1982).

The most extensive study of shad was conducted by the Delaware Basin Fish and Wildlife Management Cooperative (DBFWMC) between 1968 and 1978. Results of the Anadromous Fishery Project were documented in annual reports (Miller et al. 1972; Miller et al. 1975). Portions of this program have been continued. The state of New Jersey currently conducts annual Delaware River shad population estimates and juvenile surveys (Lupine 1989).

Recent trends in adult shad population estimates conducted in the non-tidal region of the Delaware estuary suggest that the population is increasing (Table 19). Status of juvenile American shad was examined in the tidal freshwater and transitional regions during September and October, 1990 (Table 20). Abundance was greatest in the freshwater region, and none were collected in the transitional region between rkm 94 and 117.

Generally, shad are seasonal migrants in the transitional and Delaware Bay regions. Trawls restricted to the Artificial Island vicinity (rkm 64 to 97) during 1970 and 1980 reflected seasonal occurrence. Few juveniles occur from June through October. Peaks typically occur from November to December and March to May (PSE&G 1982). Impingement data collected between 1977 and 1980 suggests that shad density was increasing (PSE&G 1984a). Shad are also seasonal migrants in the Delaware Bay region. They are rarely collected in trawl or seine surveys.

Striped Bass

The striped bass, *Morone saxatilis*, is an anadromous species that ranges on the Atlantic coast from the St. Lawrence River, Canada to the St. Johns River, FL (Raney 1952) and historically has been one of the most important recreational and commercial fishes along the Atlantic coast. The mid-Atlantic coast is particularly important for striped bass, because most of the major Atlantic coast spawning grounds and an extensive recreational fishery occur within the region (Fay et al. 1983a).

The Delaware estuary was historically an important spawning and nursery area for striped bass (Abbott 1878; Bean 1892; Meehan 1896; Brice 1898). Adults were known to ascend the Delaware to its headwaters (Meehan 1896). During the late

1800s, declines in adult striped bass abundance were reported in the non-tidal freshwater regions above Trenton and to a lesser degree in the tidal portion (Abbott 1878). More recent studies have confirmed that decline. Chittenden (1971) captured no striped bass in the non-tidal waters of the Delaware River in an extensive sampling program during spring through fall of 1963 to 1965. As for other anadromous species, declining water quality around the turn of the century was associated with declines in stocks and landings in the lower Delaware River.

Currently, spawning areas that contribute to the striped bass production in the Delaware estuary include the Chesapeake and Delaware Canal (Kernehan et al. 1981) and the Delaware River (Murawski 1969; Chittenden 1971; Weisberg et al. 1987; P. Himchak, pers. comm.). Smith (1971) found no evidence of spawning in tidal tributaries near Artificial Island, although juveniles were collected.

Commercial landings of striped bass in the Delaware estuary have been highly variable (Figure 32). Koo (1970) reports that landings of striped bass along the Atlantic coast dropped severely by 1929. The most severe decline occurred in the Mid-Atlantic region. The biggest factor was a drastic decline in landings in New Jersey, Delaware, and Pennsylvania. The fishery apparently rebounded until the 1970s, although major fluctuations in annual catch occurred. Since the early 1970s, a noticeable decline in landings has occurred. Declines in abundance of striped bass were noted at this time in other estuaries as well. Steady declines in the abundance of striped bass, particularly Chesapeake Bay stocks, began in the early 1970s, as evidenced by drastic declines in commercial harvests and other indicators of striped bass abundance and spawning success (Versar 1990). Recent restrictions in commercial harvest of striped bass have probably contributed to the continual decline in landings during the late 1980s (Figure 36).

The New Jersey Division of Fish and Wildlife, Department of Marine Fisheries has conducted a juvenile striped bass survey since 1980 in the Delaware river between Penn Beach (rkm 106) and Duck Island (rkm 208). Results of this survey suggest an increase in successful spawning during the 1980s (Figure 37).

In the transitional region, numerous surveys conducted near Artificial Island during the 1970s provide the most insight on striped bass abundance and distribution. Juvenile striped bass were taken infrequently near Artificial Island. Overwintering striped bass were taken between rkm 80 and 117 during January, 1980. Maximum density at this time was 0.009/100 m^3. During late March to mid-April these age 0+ fish moved upstream from overwintering to foraging areas; densities declined to 0.007/100 m^3 during March (PSE&G 1980). Some 1+ and 2+ aged striped bass are collected during the summer in the transitional area. Trends observed in trawl data collected during 1970 and 1980 suggested that a decline in abundance and a change in seasonal occurrence happened after 1973. From 1970 to 1973, striped bass were taken in most months and were most abundant from June to September. Catch per unit effort was greatest in 1970 and 1971, reflecting the dominant 1970 year class. From 1974 to 1980 populations appeared to decline sharply, and striped bass were taken mostly in late fall and spring. This corresponds with the decline in abundance of striped bass that occurred throughout the mid-Atlantic region.

Striped bass are collected infrequently in the shore zone and deep areas of the Delaware Bay region (Shuster 1959; De Sylva et al. 1962). They were collected in 0.1% of the trawls during annual surveys conducted from 1966 to 1970 (Daiber and Smith 1977). Catch per trawl ranged from less than 0.3 per nautical mile in 1980 to none from 1982 to 1984 (Smith 1987). Juvenile striped bass were collected infrequently in juvenile fish trawl surveys conducted by the state of Delaware in the 1980s.

Summer Flounder

The summer flounder, *Paralichthys dentatus*, is a common estuarine and marine species that ranges from Nova Scotia to southeastern Florida, although it is most abundant from Cape Cod, Massachusetts to Cape Hatteras, North Carolina (Hildebrand and Schroeder, 1928). Summer flounder inhabit coastal and estuarine waters during warmer months, and most move offshore to the continental shelf (20-100 fathoms) during the fall and winter (Bigelow and Schroeder 1953). Spawning occurs during fall and winter, and larvae migrate towards inshore coastal and estuarine nursery areas (Smith 1973).

Summer flounder have become more important as a commercial and recreational fishery. Summer flounder were caught in commercial quantities by a small fleet of trawlers that fished within Delaware Bay from the early 1940s until the mid-1960s. This trawl fishery ceased in the bay in 1966, when commercial catch was limited to incidental catch by gill netters (Lesser and Ritchie 1979). Summer flounder were not abundant in the Delaware Bay during the late 1960s and early 1970s. Incidental commercial landings began to increase in 1975 (Figure 38; Table 21). The proportion of summer flounder in the recreational catch began to increase at this time also (Table 22). Summer flounder recreational catch declined dramatically during 1989, and comprised only four percent of total catch. During previous years (1979-1988), summer flounder averaged 27% of total catch (Table 23).

Smith and Daiber (1977) found summer flounder to be ubiquitous in the Delaware Bay (rkm 0 to 61). They were collected in water temperatures ranging from 1.6°C to 26.8°C, salinities from 10.6 ppt to 31.8 ppt, and from the shore to 25 m. Ninety-five percent were collected during the months of May through September. A few juvenile fish were taken in every winter month, indicating that some juveniles move to deeper parts of the estuary during winter rather than offshore.

Summer flounder are collected infrequently in the transitional region. In numerous studies in the vicinity of Artificial Island very few summer flounder (<.02/trawl) were collected from 1970 to 1972 (Schuler 1971; Rohde and Schuler 1974a; 1974b). The few that were collected between 1970 and 1976 were generally collected in the months of April to November (PSE&G 1980). Very few summer flounder were collected in this region with seines or trawls during September and October, 1990

(Weisberg, pers. comm.). No summer flounder were collected in the tidal freshwater region in numerous studies (Miller et al. 1975; PA Fish Commission, unpublished data; Weisberg, pers. comm.).

Fisheries trends for summer flounder appeared to increase slightly, except for 1989 data. Daiber and Smith (1971) found they averaged 0.49% of the catch from 1966 to 1970. By 1979 to 1982, they averaged 2.3% of the catch (Smith 1981). Smith (1987) reported that the increase in abundance in the bay at this time was caused by strong year classes produced in the late 1970s and early 1980s. Juvenile trawl survey data shows variable annual catch per unit effort for summer flounder in the lower Delaware Bay region (Figure 39).

Bluefish

The bluefish, *Pomatomis saltatrix*, is an oceanic species that ranges along the Atlantic coast from Cape Cod to southern Florida. This species is a coastal migrant, spending the winters off southern Florida and migrating north along the coast during the spring (Bigelow and Schroeder 1953).

In the Delaware estuary, the bluefish is a seasonal migrant that is abundant in the higher salinity regions of the Delaware Bay during summer months. Historically, bluefish were less important in Delaware Bay commercial fisheries than they have been in recent years (Grimes 1983). Recent increases in commercial catch of bluefish since the early 1970s (Figure 40) also have been reflected in increasing recreational catch (Tables 22 and 23). During the late 1960s to late 1978, bluefish constituted two percent to 13% of the recreational fishery; in 1979 to 1989 they constituted nine percent to 23%, and generally ranked in the top three species annually. Available information suggests that bluefish have been increasing in abundance since the mid-1970s. Commercial landings have increased markedly, and recreational catch has remained very strong.

Bluefish are infrequently collected in transitional and freshwater tidal regions (Schuler 1971; Smith 1971; Rohde and Schuler 1974a, 1974b; Miller et al. 1975; Weisberg, pers. comm.). Abundance increases with increasing salinity.

Bluefish are most common in deep water and along shorelines in the Delaware Bay region. Juveniles were abundant in the shore zone from the mouth of the Delaware Bay to Salem Beach (De Sylva et al. 1962). Bluefish comprised 0.03% of the fish collected in trawl surveys conducted from 1966 to 1970 (Daiber and Smith 1971). Bluefish abundance was low during the late 1960s (<0.1 fish/tow) but was relatively stable through the mid-1980s (0.1 to 0.4 fish/tow) (Smith 1987). In 1989, bluefish were most abundant from June through September, averaging 0.58 fish/tow (Seagraves and Cole 1989). Juvenile bluefish abundance was monitored from 1980 to 1990 by the state of Delaware (Figure 41). Although this species comprised a large portion of commercial and recreational catch during these years, relative abundance estimates based on trawl survey data have remained low. The bluefish is a fast-swimming species, and trawl avoidance may play a role in these low estimates.

Weakfish

The weakfish, *Cynoscion regalis*, ranges from the east coast of Florida to Massachusetts Bay and strays as far north as the bay of Fundy (Bigelow and Schroeder 1953). Weakfish are the most important species in the Delaware estuary in terms of economic value (McHugh, 1981, Grimes 1983). They are also top predators in this complex ecosystem.

Adults enter the Delaware Bay in late March and April. During spawning (late May-August), weakfish are widely distributed throughout the bay. Juveniles use almost the entire bay and transition regions as nursery areas (PSE&G 1984a). Spawning occurs in the lower Delaware Bay (Woodland Beach to the Atlantic ocean) during mid- May through early August, where salinities are generally greater than 15 ppt (Wang and Kernahan 1979). Very few adults were collected in the lower Delaware River and upper Delaware Bay at salinities less than 15 ppt. Adults were abundant below Artificial Island and especially in the lower bay (rkm 040) (Thomas 1971). Weakfish spawning cycles in the Delaware estuary appear to have two peaks occurring during June and July (Harmic 1958; Epifanio pers. comm.).

Weakfish are common components of the commercial and recreational fisheries in the Delaware estuary and contribute significantly to the economy of the region (Tables 21 to 23). Weakfish commercial landings peaked during the late 1970s and have declined since then (Figure 42). A corresponding decline in proportion of catch in theecreational fishery occurred during this time. These fluctuations in weakfish abundance could be natural cycles or could be caused by anthropogenic effects, such as overfishing.

Weakfish were not collected in the tidal freshwater region in numerous surveys (Anselmini 1974; Hastings 1983; Miller et al. 1975; Weisberg, pers. comm.; PA Fish Comm. unpublished data 1984-1986).

Weakfish are very common in the transitional region. All life stages were taken near Artificial Island (Thomas 1971). During September and October 1990 they were taken at numerous locations in the transitional region between rkm 94 and 128, but were most common between rkm 94 and 105 (Weisberg, pers. comm.) Taylor et al. (1973) reported that weakfish were commonly collected in the Delaware portion of the C & D Canal and adjacent waters (rkm 88 to 102), ranking second in abundance and biomass only to white perch. Long-term surveys near Artificial Island document the use of this area as a nursery for juvenile weakfish. Annual abundance fluctuates but typically peaks during June and July (PSE&G 1980). From 1970 to 1980 (rkm 64 to 97) year class strength fluctuated considerably. Strong year classes were evident in 1970, 1975, and 1978. The peak in 1978 was 413.8 weakfish per 10 minute tow (PSE&G 1984a).

Near Artificial Island, juvenile weakfish were very common and appeared by the month of June (Thomas 1971). In a study of tributaries of the Delaware estuary near Artificial Island, Smith (1971) found that weakfish were the fifth most abundant species collected in trawls. These fish were found in salinities ranging from 0 to 8 ppt.

During June through October, weakfish were found primarily in deeper channels within the tributaries. Thomas (1971) speculated that upriver movement of juveniles might be restricted by pollution near Philadelphia and the low dissolved oxygen and low salinity in that region. Temperature appeared to be the chief factor responsible for initiating fall movement out of estuaries into deeper waters (Mercer 1983; Thomas 1971; Smith 1971). Juveniles begin their down bay movement during August and are virtually absent in estuaries by late October and November (Wang and Kernehan 1979).

As expected, weakfish abundance is greatest in the high salinity Delaware Bay region. Peak densities ranged from about 5.5 to 16.5 per 100 m^3 between rkm 0 to 80 during 1979 and 1980. The center of age 0+ density shifted to the lower bay (rkm 0 to 32) during September in most years, as the fish congregated near the mouth of the bay prior to the autumnal migration (PSE&G 1984a). Through time, weakfish have comprised a large proportion of catch in annual trawl surveys. They averaged 31% of the catch from 1966 to 1970 (Daiber and Smith 1971). Smith (1987) documented a decline in abundance beginning in the early 1970s. He found that, with the exception of 1982, weakfish numbers were relatively stable but low from 1979 to 1984. Juvenile weakfish was typically the second or third most common species taken in annual trawl surveys, after bay anchovy and hogchoker. Juvenile weakfish abundance appears to have remained relatively stable during the survey period (Figure 43). Mean catch per trawl in 1989 approximated the grand mean of the ten year time series since 1980 (Seagraves and Cole 1989).

Spot

Spot, *Leiostomous xanthurus*, is distributed from Massachusetts Bay, south to the bay of Campeche, Mexico. Areas of greatest abundance and centers of the commercial fishery are in the Chesapeake Bay area and in the Carolinas (Dawson 1958). The spot is a marine and brackish water species. PSE&G (1984a) summarized general spawning and seasonal distribution patterns for spot in the Delaware estuary. Spawning and early development occurs offshore in the shelf waters. The juvenile stage is estuarine-dependent, and age 0+ fish use the numerous estuaries along its range, including the Delaware estuary, as nursery areas. Some yearling and older spot also summer in these systems. In the Delaware Bay and River, spot occurrence is seasonal and is dominated by age 0+ fish, which exist as demersal, carnivorous members of the complex estuarine community. Age 0+ spot arrive as early juveniles, first appearing in the estuary during May and concentrating through June in the upper bay and lower River, including the Artificial Island area (rkm 80). During July, abundance in the bay and River below rkm 97 decreases, as much of the population apparently moves up into regional marshland tributaries and farther upriver. Distribution of spot age 1+ and older is generally restricted to the Delaware Bay proper (rkm 0 to 64) (PSE&G 1980). During the fall, fish begin to move back to the bay, and those that pass through the Artificial Island area typically do so during October-December, to congregate in the bay prior to emigration from the estuary. By January, nearly all have moved offshore, reportedly to overwintering areas in the Carolinas.

Generally, spot does not support a directed commercial fishery, but instead is included as bycatch or as incidental species. Spot commercial landings in Delaware Bay are relatively small (Figure 44). Large differences in state and estuary landings suggest that spot are also caught in large numbers offshore.

Recent surveys in the tidal freshwater region suggest that, although spot does use this region, it is not as abundant as in the higher salinity regions (Table 24). In seine and gill net surveys in the tidal freshwater region, spot was collected very infrequently (PA Fish Comm. Unpubl. data, Hastings 1983), and it was rarely collected at intake screens, constituting less than 0.07% of the fish impinged in the region between rkm 136 to 204 (Miller et al. 1975).

In the transitional zone, age 0+ spot typically occurred during April through December, although most common from May to November. Peak abundance occurred during June and July, after which spot continued to move upstream and into tributaries, and in October and November, when spot returned to the bay prior to emigrating from the estuary (PSE&G 1984a). Migrations through this area appear to be influenced by salinity and water temperature (PSE&G 1980). Maximum densities observed in the transitional area during 1979 were 0.79/100 m^3 in December, and in 1980 were 0.22/100m^3 in November. In the transitional region a large proportion of fish collected at water intake screens is spot. It was the most common species collected at Deepwater station and was 41.2% of impinged fish (Meldrim et al. 1977). At Edgemoor station (rkm 116), spot ranked third in abundance and was 12.5% of the catch (Molzahn 1975). Spot was the second most abundant species impinged at intake screens located at rkm 99 and 116, and constituted 23% of the catch (Miller et al. 1975).

Large fluctuations in spot abundance have been documented in the lower Delaware estuary. In the Delaware Bay region, spot averaged 2.56% of the catch between 1966 and 1970 (Daiber and Smith 1971). Abundance was variable from 1979 to 1981; spot were 3.8%, 10.4%, and 15.3% of the trawl catch, respectively. From 1966 to 1984, annual spot abundance varied greatly (Smith 1984). Annual catch per unit effort estimates for juvenile spot are highly variable (Figure 45). These large fluctuations in annual abundance of spot have been identified previously (Joseph 1972, Thomas 1971). Joseph (1972) attributed some of these fluctuations to year class abundance, since the catch in most years is composed of a single year class. He reports that these nonperiodic fluctuations are most likely environmental differences that prevail on the spawning grounds. These fluctuations in year class strength are probably responsible for the highly variable annual abundance estimates for spot in the Delaware estuary.

Scup

Very little biological information exists for the scup, *Stenotomus chrysops*, in the Delaware estuary region. This species is an important commercial component of this region (Table 22; Figure 46). During the 1970s through the 1990s scup constituted a large proportion of commercial catch in the Delaware estuary region (19%, 22%, 14% of the biomass during 1970, 1980, 1989, respectively), second only to weakfish.

Scup are most common in the Delaware Bay region. Scup was common in research trawl catches in the Delaware Bay. It was 11.8% of the catch between 1966 and 1971 (Daiber and Smith 1971), but has declined greatly in abundance during the late 1970s and 1980s to less than 0.05% of the catch (Smith 1987). Similarly, scup was collected infrequently during the recent juvenile trawl surveys (Seagraves 1981, 1982; Cole et al. 1984, 1985, 1986, 1987; Seagraves and Cole 1989). Given its apparent lack of abundance in recent Delaware Bay trawl surveys, it is reasonable to expect that the most scup are caught outside the bay.

Atlantic menhaden

The Atlantic menhaden, *Brevoortia tyrannus*, inhabits temperate coastal waters from Nova Scotia south to Jupiter Inlet, FL (Dahlberg 1970). This species is seasonally abundant in the mid-Atlantic region, and concentrations of age 0+ fish occur in inshore estuarine waters along the entire Atlantic seaboard (Rogers and Van Den Avyle 1989). This species provides an important ecological link between plankton and piscivores.

Menhaden is an important commercial fishery throughout the mid-Atlantic region. Menhaden is classified as a non-food fish in the United States, and nearly all the commercial catch is processed into fish meal, fish oil, and condensed solubles (Lesser and Ritchie 1979). The menhaden fishing industry in Delaware began in the late 1800s, when the major Atlantic menhaden population center shifted from the Gulf of Maine to the mid-Atlantic region. In Delaware, one of the first menhaden processing plants was built in 1917 in Lewes, later (1938) it became the largest menhaden processing plant in the U.S. (Horn 1957). Around 1946, a second processing plant began to operate in Lewes, and by 1953 this town had the highest seafood landings in the U.S. In 1962 Lewes landings began a precipitous decline, causing the plants to close in 1963 and 1966. During the years since 1966, menhaden has been caught continuously, although in lower commercial quantities, by boats originating from out of state. Since the fish are landed at out of state ports, Delaware receives no credit for the millions of pounds of menhaden caught annually in its waters (Lesser and Ritchie 1979) (Figure 47). The Atlantic menhaden is one of the most common species in the Delaware estuary annually due primarily to the abundance of age 0+ fish (PSE&G 1980).

In the freshwater region, menhaden abundance estimates were highly variable because of its schooling behavior and patchy distribution (Table 25). From 1984 to 1986, no menhaden was collected in the tidal freshwater region between rkm 174 and 214 (PA Fish Comm. unpublished data). Menhaden was not collected at freshwater intake screens at rkm 136 to 204 during 1973 (Miller et al. 1975), and was not reported from Burlington or Mercer generating station impingement samples (Anselmini 1974; Ichthyological Associated, 1979b). It is reasonable to expect that, for fish with a non-random distribution, the larger the area sampled, the greater the chance of encountering a school of this species.

Abundance of menhaden increases in the transitional region of the Delaware estuary. Age 0+ menhaden first appeared near Artificial Island as larvae during early spring and remained in the area through late fall, before migrating down-bay and offshore (PSE&G 1980). Local distribution of menhaden was patchy through much of the year, except late spring and early summer. Large numbers of young were taken in both deep and shallow areas of the river. By late summer and through fall few were taken nearshore, and those taken offshore were patchy in distribution (PSE&G 1980). Menhaden is also reported to use tidal tributaries in this region (Smith 1971). De Sylva et al. (1962) reported that the Delaware estuary is an important nursery area for juvenile menhaden. It was the third most common species collected in the nearshore area and constituted 10.3% of the catch. Recent studies near Keystone Cogeneration plant reported that menhaden was 88.5% of the fish and biomass collected during June through August 1990 (Biosystems Inc. 1990). It also was a large proportion of impinged fish at Deepwater and Edgemoor generating stations (Ichthyological Associates 1977; Meldrim et al. 1977) and was a frequent component of seine collections between rkm 94 and 128 (Table F4).

Atlantic menhaden is a pelagic species and, in deep water, is not sampled efficiently with a bottom trawl. For these reasons, trend analysis using trawl data from the lower bay region would be inappropriate. In the shore zone, Shuster (1959) reported that menhaden was fairly common along the bay shore. It was fifth in abundance and constituted three percent of fish collected along the bay shore (De Sylva et al 1962).

Atlantic coast menhaden stocks were drastically reduced during the 1960s, forcing the closure of processing plants, including those in Delaware. Several factors have been implicated in the decline of the Atlantic coast menhaden stocks including overfishing, deteriorating environmental conditions, and fluctuations in year class strength (Price et al 1983; Rodgers and Van Den Avyle 1989).

White perch

White perch, *Morone americana*, is a semi-anadromous species common in estuarine waters from Nova Scotia to South Carolina (Woolcott 1962). White perch is one of the most abundant resident fishes in the Delaware estuary. It is distributed throughout the estuary and occurs from rkm 0 to approximately 330 (Ashton et al. 1975). White perch is relatively uncommon in the mainstem river system below about rkm 35 (PSE&G 1984a). It is, however, very common in most of the tidal tributaries in the mid and lower bay (Smith 1971; Wang and Kernahan 1979; Martin 1974). White perch tends to overwinter in the Delaware Bay region, and deeper portions of the estuary and to migrate upriver towards fresher water during spring and summer.

White perch is an important commercial and recreational species in the Delaware estuary. Commercial landings of white perch have declined since the late 1800s, with a brief resurgence in the early 1930s (Figure 48). In the Delaware estuary, most white perch is caught down-bay during winter. Delaware landings of white perch have declined sharply in recent decades, probably as a result of a combination of factors, including reduced demand, reduced fishing effort, and perhaps low dissolved oxygen levels in the Camden/Philadelphia area (McHugh 1981; PSE&G 1984a). White perch also supports an important recreational fishery throughout the estuary.

White perch is abundant in tidal creeks and in the upper freshwater region of the estuary during the summer and fall months (PSE&G 1984a). In the tidal freshwater region, white perch is a large proportion of the ichthyofauna (Table 16). It was typically one of the top five species collected using a variety of methods including gill nets, seines, trawls and impingement (Table 26).

White perch is also commonly collected in the transitional region. It often constituted a large proportion of fish collected this in area. Smith (1971) documented white perch abundance in the tidal tributaries within this region. It was the most common species collected within the tributaries. Extensive studies near Artificial Island (rkm 64 to 97) conducted between 1970 and 1980, suggested a decline in abundance of white perch (PSE&G 1984a). The investigators reasoned that, although numerous other factors such as a change in distribution could cause or contribute to the decrease in catch per unit effort, the data suggested some other mechanism was producing the decline.

Extensive trawl surveys document the occurrence and relative abundance of white perch in the Delaware Bay region (Daiber and Smith 1971; Seagraves 1981, 1982; Smith 1987; Cole et al. 1983, 1984, 1985, 1986, 1987, 1988; Seagraves and Cole 1989) (Table 26). However, these surveys are conducted mainly during the months of April through October, when white perch abundance is lowest. This results in extreme annual variation in catch per unit effort (Figure 49). Smith (1987) noted that annual changes in white perch relative abundance were highly variable from 1966 to 1980. He suggested that these fluctuations may be due to annual variations in temperature influencing the timing for white perch return to the lower bay. For these reasons, it would be inappropriate to examine trends in abundance with this trawl data.

Bay Anchovy

The bay anchovy, *Anchoa mitchilli*, is one of the most abundant species of the estuaries from the mid-Atlantic region through the Gulf of Mexico (Wang and Kernehan 1979). Bay anchovy is probably the most abundant fish of the Delaware estuary. It inhabits both inshore and offshore waters throughout the salinity gradient (De Sylva et al. 1962; Wang and Kernehan 1979). The bay anchovy is a small, schooling species that occurs throughout Delaware Bay, is seasonally abundant in the lower Delaware River to between Wilmington (rkm 120) and Philadelphia (rkm 150), and has been recorded as far upstream as rkm 212, near Trenton, NJ (PSE&G 1984a). Bay anchovy also has been collected in many of the tidal tributaries within the estuary (Smith 1971; Martin 1974; Academy of Natural Sciences of Philadelphia 1974). After overwintering in deep down-bay channels or nearshore ocean water, bay anchovy generally migrate into shoal areas within the Delaware estuary during spring.

Spawning is protracted, occurring from May through September. As progeny develop, they move into low salinity nursery areas, where they remain until fall. In the fall, juveniles and adults reverse the spring migration, returning to overwintering areas (PSE&G 1984a).

The bay anchovy is an important component in the complex Delaware estuary ecosystem. It is a forage fish for many important commercial and recreational species. There presently is no commercial fishery in the Delaware estuary directed at the anchovy.

Bay anchovy is distributed throughout the Delaware estuary. Numerous surveys have documented its abundance and distribution (Table 27). It is most common in the transitional and Delaware Bay region. In the freshwater region, it is collected less frequently, but often in large numbers. PSE&G (1984a) conducted an extensive fisheries survey in the transitional and lower bay areas, documenting bay anchovy abundance and distribution. In a baywide study (rkm 0 to 177), bay anchovy juveniles (0+) typically were taken between July and October from 1979 to 1982 (PSE&G 1984a). Highest total mean density in surface collections occurred in August, and ranged from 7.0/100 m^3 in 1979 to 33.3/100 m^3 in 1982. Bay anchovy 0+ were distributed throughout the total study area during periods of occurrence; however, they were typically less abundant in deeper, offshore waters of the middle to lower bay (ca. rkm 0 to 48) than in the remainder of the study area (PSE&G 1984a). Bay anchovy adults (1 + or older) were taken in all months sampled from 1979 to 1982; they were most abundant in the study area between May and early August. As with the 0+ fish, bay anchovy 1 + and older were distributed throughout the study area (rkm 0 to 117) during periods of occurrence. However, densities varied regionally, typically being lower near the mouth of the bay (rkm 0 to 16) and higher in the middle to upper bay and lower River. In the bay they were generally more abundant in the nearshore areas than offshore. Catch per unit effort data suggest that the bay anchovy population in the Delaware estuary experiences considerable annual variation in either absolute or localized abundance or in recruitment from nearby coastal waters (Seagraves 1980, 1981; PSE&G 1984a; Cole et al. 1982, 1983, 1984, 1985, 1986, 1987; Seagraves and Cole 1989).

Summary for Fish Community Assessment

Status and trends of fish populations in the Delaware estuary are of major interest to the general public and of major concern to fishery managers responsible for maintaining or improving these resources. Numerous factors have been cited as contributing to fishery fluctuations in the Delaware estuary, these include the geographic location of the estuary climatic conditions, and anthropogenic effects. The Delaware estuary is located in the Mid-Atlantic region, and in general, is in an area that intersects the ranges of warm and cold temperate species. This location contributes to annual variability in species diversity and abundance. Climatic conditions, including variables such as temperature, amount of precipitation, direction and strength of tides and currents, and river flow rates, also influence fish populations in the estuary. A third factor influencing fishery populations is anthropogenic impacts, including overfishing, water pollution, and construction of dams and other physical barriers. Anthropogenic factors historically have had significant impacts on Delaware estuary fish populations, especially anadromous species.

General spatial and temporal distributional patterns were identified for key biological species. In general, during spring and summer months, anadromous species migrate from offshore or down-bay overwintering areas to upriver spawning and foraging sites (Figure 30). Juvenile anadromous fish tend to remain in these nursery areas until fall and winter, when the majority travel downstream to overwinter in deeper water of Delaware Bay or offshore. Species characteristic of more saline waters typically use the Delaware Bay and transitional region of the estuary. Some species, such as bay anchovy, spot, Atlantic menhaden, and white perch have a broad spatial distribution throughout the estuary during the summer months (Figure 30). During fall months, the majority of the key species move down-bay or to deeper waters. During winter, the majority leave the Delaware Bay for offshore waters, and many migrate south along the Atlantic coast. Juveniles of each species may not migrate as extensively as adults.

In recent years, it appears that populations of many of the anadromous species have improved. Juvenile striped bass indices and adult American shad population estimates have shown marked increases during the past decade. Possible factors cited as contributing to increases in abundance include improvements in water quality (allowing fish to access and utilize traditional spawning and foraging areas), and restrictions placed on harvest of species such as striped bass.

Weakfish, summer flounder, and bluefish have contributed significantly to commercial and recreational harvest in the Delaware estuary. Recent declines in harvest of summer flounder and weakfish are cause for concern. Again, it must be emphasized that because of the migratory nature of many of these key fish species, their abundance may be influenced by impacts occurring throughout a broad geographic range and are not necessarily indicative of problems specific to the Delaware estuary.

Table 13
Shortnose Sturgeon Catch and Effort Trawl Data from the Delaware River

STUDY	GEAR	RKM	EFFORT-#TRAWLS OR HAULS	CATCH	CATCH/ HAUL OR TRAWL
DRBAFP* Freshwater Region	4.9m TRAWL	163-198	261	1	0.0160
Ichthyological Associates, Newbold Island Freshwater Region	4.9m TRAWL	ca. 200	2,162	6	0.0028
Ichthyological Associates, Artifical Island Transitional Region	4.9m TRAWL	64-96	10,096	1	<0.0001

* Delaware River Basin Anadromous Fishery Project.

Table from Masnik and Wilson (1980)

Table 14 Blueback Herring Summary Information		
Author	**Location**	**Results**
Anselmini(1974)	RKM 209	23% Trawl catch, 25% Seine catch, 9% Impinged Fish
Miller et al. (1975)	RKM 136-204	18% Impinged fish, #3 in abundance
Ichthyological Associates (1979b)	RKM 190	Impingement rate of 2.635 PER 10^5 M^3
Hastings (1983)	RKM 163-214	0.18% Gill net catch
Weisburg (pers. comm.)	RKM 128-208	7%-100' Seine, 17%-200' Seine, 1.5%-30' Trawl
Taylor et al. (1973)	RKM 88-102	#12 in Abundance
Miller et al. (1975)	RKM 99-116	0.5% Impinged fish
Meldrim et al. (1977)	RKM 114-123	2% Impinged fish
PSE&G (1980)	RKM CA. 64-99	Ranked #5 in Trawl Survey, #8 in seine survey (1970-1976)
Weisberg (pers. comm.)	RKM 94-128	0%-100'Seine, 0.3%-200' Seine <0.1%-30'Trawl
Daiber and Smith (1971)	RKM 0-72	Averaged 0.01% of catch during 1966-1970.
Seagraves and Cole (1989)	RKM 10-127	Less than 0.1%

Table 15
Alewife Summary Information

Author	Location	Results
Anselmini (1974)	RKM 209	35% Trawl Catch, 0.8% Seine 19% Impinged
Miller et al.(1975)	RKM 136-204	5% Impinged Fish, # 5 In Abundance
Ichthyological Associates (1979b)	RKM 190	Impingement rate of 0.608 per 10^5 M^3
Hastings(1983)	RKM 163-214	Ranked #11 in gill nets, 0.1% Catch
Weisberg (pers. comm.)	RKM 128-208	0.8%-100' Seine, 0.9%-200' Seine, 0.6%-30' Trawl
Taylor et al.(1973)	RKM 88-102	#5 in abundance, #4 in biomass
Miller et al.(1975)	RKM 99-116	0.4% Impinged fish
Meldrim et al. (1977)	RKM 114-123	3-6% Impinged fish
PSE&G (1980)	CA. RKM 64-99	Ranked #9 in trawl survey,#4 in seine 1970-1976
Weisberg (pers. comm)	RKM 94-128	0.2%-100'Seine, 0.03%-30'Trawl
Daiber and Smith (1971)	RKM 0-72	Averaged 0.1% of catch (1966-1970)
Smith (1987)	RKM 0-72	Averaged 1.4% of catch (1979-1981)
Seagraves and Cole (1989)	RKM 10-127	Averaged 0.1% of catch

Table 16
Species Composition in Freshwater and Tidal Fresh Regions -- Top 6 Species Collected September & October 1990

Gear	Transitional rkm 94-128 Species	%	Freshwater rkm 129-208 Species	%
100' Seine	White perch	28	White perch	35
	Spot	23	Spottail shiner	23
	Atlantic Menhaden	21	Silvery minnow	12
	Silvery minnow	11	Blueback herring	7
	Striped bass	7	American shad	5
	Gizzard shad	4	Striped bass	5
200' Seine	Atlantic Menhaden	58	Bay anchovy	19
	Bay anchovy	22	Blueback herring	17
	Atlantic Silverside	7	White perch	16
	Gizzard shad	5	Atlantic Menhaden	14
	White perch	3	American shad	12
	Spot	2	Striped bass	8
30' Trawl	Hogchoker	47	White perch	43
	Bay anchovy	38	Bay anchovy	28
	White perch	6	Hogchoker	8
	Striped bass	2	Spot	5
	Channel catfish	2	Silvery minnow	4
	Weakfish	2	Striped bass	3

Source: Weisberg, pers. comm.
Data collected September and October, 1990.

Table 17
Blueback Herring: Catch per haul (± SE)

RKM	100' Seine	200' Seine	30' Trawl
175-208	8.0±3.8	-	2.0±3.8
143-153	2.4±1.3	49.0±24.5	0.2±0.2
129-142	0.7±0.2	35.7±14.1	0.2±0.1
117-128	0.0	3.0±1.0	0.1±0.1
106-117	0.0	0.0	0.0
94-105	0.0	-	0.0
129-208 Freshwater	3.4±1.4	37.8±12.3	0.9±0.4
94-128 Transitional	0.0	1.5±0.8	<0.1

Data collected September and October, 1990

Source: Weisberg (pers. comm.)

Table 18 Alewife: Catch per haul (± SE)			
RKM	100' Seine	200' Seine	30' Trawl
175-208	1.0 ± 1.0	-	0.8 ± 0.5
143-153	0.0	5.0 ± 4.0	0.0
129-142	0.7 ± 0.4	1.5 ± 1.0	0.2 ± 0.1
117-128	0.1 ± 0.0	0.0	0.1 ± 0.1
106-117	0.0	0.0	0.0
94-105	0.0	0.0	0.1 ± 0.1
129-208 Freshwater	0.4 ± 0.3	2.0 ± 1.0	0.4 ± 0.2
94-128 Transitional	< 0.1	0.0	< 0.1

Data collected September and October, 1990

Source: Weisberg (pers. comm.)

Table 19
Delaware River American Shad Populations
Estimates from 1975 - 1989

Year	Population Estimate[1]
1975*	118,700 ± 093,773
1976*	178,760 ± 096,150
1977*	106,202 ± 065,058
1978*	233,060 ± 171,126
1979	111,839 ± 032,191
1980	181,880 ± 055,058
1981	546,215 ± 133,590
1982	509,102 ± 176,680
1983	249,578 ± 087,342
1984	-
1985	-
1986	595,407 ± 231,060
1987	-
1988	-
1989	831,595 ± 235,608

* Conducted by the Delaware River Basin Fish and Wildlife Management Cooperative Fishery Project.

[1] Reported variance assumed to be standard deviation.

Source: Lupine (1989)

Table 20 American Shad: Catch per haul (± SE)			
RKM	100' Seine	200' Seine	30' Trawl
175-208	4.0±0.9	-	0.4±0.3
143-153	5.8±2.0	40.2±20.0	0.0
129-142	1.0±0.4	13.6±03.4	0.3±0.1
117-128	0.2±0.1	00.7±00.7	0.1±0.1
106-117	0.0	0.0	0.0
94-105	0.0	-	0.0
129-208 Freshwater	2.4±0.4	17.9±04.4	0.3±0.1
94-128 Transitional	0.1±0.0	00.3±00.3	0.05±0.05

Data collected September and October, 1990

Source: Weisberg (pers. comm.)

Table 21
Delaware Estuary Commercial Fisheries Landings
Percent contribution of top 5 species collected.

Species	1901	1921	1945	1960	1970	1980	1989
Shad	66						
Alewife	10						
Weakfish	8	12	2		20	31	10
Menhaden	3	62	91	96			
Butterfish	3			<1	8		
Scup		7	2	1	19	22	14
Croaker		7					
Bluefish		3					
Striped Bass					12		
American Eel					20		
White Perch					9		
Mackerel			1			8	39
Summer Flounder			1	1	15	17	14
Silver Hake				<1			
Whiting					6	7	
Black Sea Bass							5
Cumulative Total	90	91	97	99	86	85	82

* Source: NMFS fisheries landings data. Estimated from county data. Data reported by waterbody for 1947 to 1977 suggest scup, black sea bass, and mackerel are probably over-represented in 1980 and 1989 tables.

Table 22
Marine Recreational Fishing in Delaware. Summary of results from recreational surveys conducted in 1968, 1973, 1976, and 1978. Percentages rounded to nearest whole number.

1968:	%	1973:	%
Weakfish	35	Weakfish	56
Winter flounder	16	Summer flounder	36
Black sea bass	14	Black sea bass	4
Bluefish	2	Bluefish	3
Summer flounder	<1	Atlantic croaker	<1
TOTAL	67%	TOTAL	99
1976:	**%**	**1978:**	**%**
Weakfish	40	Weakfish	29
Atlantic croaker	20	Summer flounder	23
Summer flounder	11	Atlantic croaker	14
Bluefish	8	Bluefish	13
Sharks	6	Black sea bass	3
TOTAL	85	TOTAL	82

Source: Miller (1978)

Table 23
Marine Recreational Fisheries Statistics
Percent contribution of top 5 species collected.

Species	1979	1980	1983	1985	1986	1987	1988	1989
Weakfish	12	9	11		6	10	7	
Bluefish	22	18	14	11	9	22	11	22
Summer Flounder	28	19	28	29	18	30	37	
Black sea bass			11	9	34			16
Atlantic mackerel	7			6		6		6
Winter flounder	8			19			6	
Silver hake		26						
Tautog								7
Serobins		8	10		12	9	9	9
Cumulative %	77	80	74	74	79	77	70	60

Source: National Marine Fisheries Service, Marine Recreational Fishery Statistics Survey, Atlantic and Gulf Coasts, 1979-1989.

Table 24
Spot: Catch per haul (± SE)

RKM	100' Seine	200' Seine	30' Trawl
175-208	0.0	-	0.0
143-153	0.0	00.2±0.2	1.3±0.9
129-142	1.2±0.4	04.6±1.7	5.7±1.5
117-128	3.8±1.2	12.7±9.8	2.3±0.9
106-117	4.4±3.0	07.7±6.2	4.4±3.9
94-105	8.5±5.9	-	1.3±0.4
129-208 Freshwater	0.7±0.3	03.9±1.4	3.2±0.9
94-128	5.8±2.6	10.2±5.3	2.0±0.6

Data collected September and October, 1990

Source: Weisberg (pers. comm.)

Table 25
Menhaden: Catch per haul (± SE)

RKM	100' Seine	200' Seine	30' Trawl
175-208	0.0	-	0.0
143-153	0.0	158.6±158.6	0.0
129-142	0.1±0.1	2.0±2.0	0.1±<0.1
117-128	3.3±1.6	392.3±257.6	0.2±0.1
106-117	2.8±1.2	195.3±146.6	0.0
94-105	8.2±4.8	-	0.2±0.1
129-208 Freshwater	0.1±0.1	27.3±25.6	<0.1
94-128 Transitional	5.3±2.2	293.8±139.6	0.1±0.1

Data collected September and October, 1990

Source: Weisberg (pers. comm.)

Table 26
White Perch Summary Information:Delaware Estuary

Author	Location	Results
Anselmini (1974)	RKM 209	20% Trawl Catch, 2.5% Seine 55% Impinged. White perch and river herring = 75% of total catch.
Miller et al.(1975)	RKM 136-204	28% Impinged Fish, # 2 In Abundance
Ichthyological Associates (1979b)	RKM 190	Impingement rate of 9.27 per 10^5 M^3
Delaware River Basin Commission (1988)	RKM 136-210	Number one fish collected in gill nets
Hastings (1983)	RKM 163-214	Ranked #1 in gill nets, 58% of catch
Weisberg (pers. comm.)	RKM 128-208	35%-100' Seine catch, 16%-200' Seine, 43%-30' Trawl
Taylor et al.(1973)	RKM 88-102	#1 in abundance, #1 in biomass
Miller et al.(1975)	RKM 99-116	20% Impinged fish, #3 in abundance
Meldrim et al. (1977)	RKM 114-123	19% Impinged fish, #2 in abundance
PSE&G (1980)	CA. RKM 64-99	Annually ranked #3 trawl survey,#9 in seine 1970-1976
Ichthyological Associates (1977)	RKM 109	9% Impinged fish, collected year round
Smith (1971)	RKM 77-88	Most abundant fish collected in tidal tributaries. 64% trawl catch, 19% seine
Weisberg (pers. comm)	RKM 94-128	28%-100'Seine catch, 3%-200'Seine 6%-30'Trawl catch
Daiber and Smith (1971)	RKM 0-72	Averaged 1% of catch (1966-1970)
Smith (1987)	RKM 0-72	Averaged 4% of catch (1979-1981), very variable annual catch
Seagraves and Cole (1989)	RKM 10-127	Averaged 1.6% of catch

Table 27
Bay Anchovy Summary Information

Author	Location	Results
Anselmini (1974)	RKM 209	None reported
Miller et al. (1975)	RKM 136-204	0.02% Impinged Fish
Weisberg (pers. comm.)	RKM 128-208	0.06%-100' Seine catch, 19%-200' Seine, 28%-30' Trawl
Taylor et al. (1973)	RKM 88-102	#6 in abundance, #1 in biomass
Ichthyological Associates (1977)	RKM 190	Impingement rate of .01 per 10^5 M^3
Miller et al. (1975)	RKM 99-116	33% Impinged fish, #1 in abundance
Meldrim et al. (1977)	RKM 114-123	44% Impinged fish, #1 in abundance
PSE&G (1980)	CA. RKM 64-99	Annually ranked #1 trawl survey (>50% total fish),#2 in seine (1970-1976)
Ichthyological Associates (1977)	RKM 109	10% Impinged fish, collected April-October
De Sylva et al. (1962)	RKM 82-117	51% Beach seine catch
Smith (1971)	RKM 77-88	2nd most abundant fish collected in tidal tributaries. 64% trawl catch, 19% seine
Weisberg (pers. comm)	RKM 94-128	0.8%-100'Seine catch, 22%-200'Seine (#2 fish), 39%-30'Trawl (#2 fish)
De Sylva et al. (1962)	RKM 0-82	16% Seine catch
Daiber and Smith (1971)	RKM 0-72	Didn't include in survey (1966-1970)
Smith (1987)	RKM 0-72	Didn't include in survey (1979-1981)
Seagraves and Cole (1989)	RKM 10-127	#1 fish, 67% annual catch

Figure 30
Fish Species Distribution

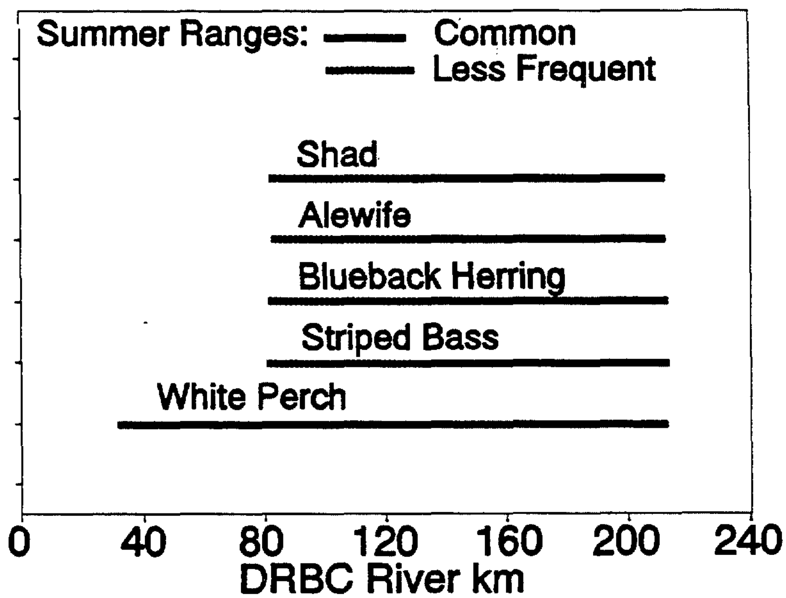


Figure 30 (continued)
Fish Species Distribution

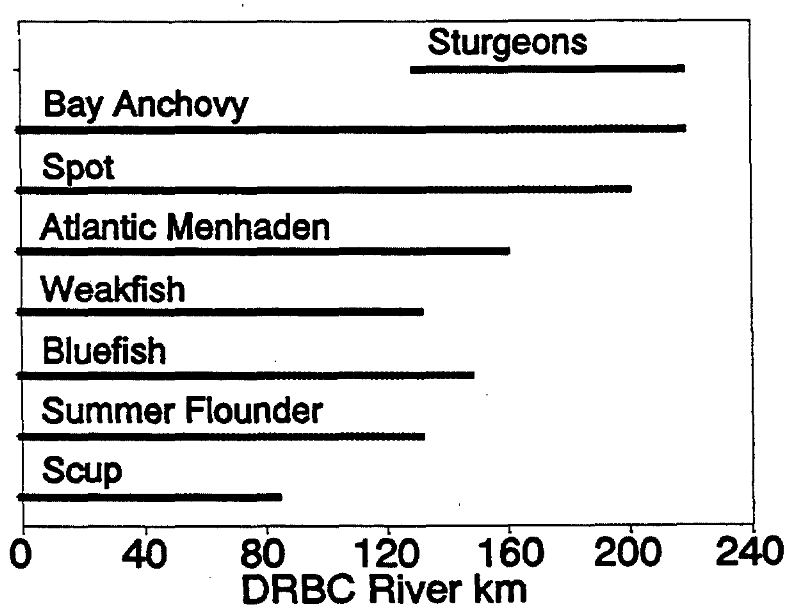


Figure 31

Sturgeon

Thousands of Pounds Landed

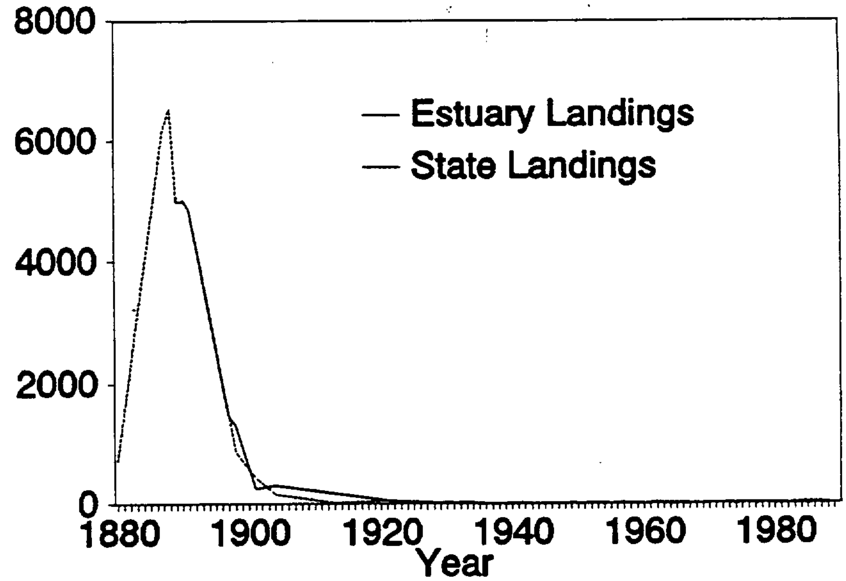


Figure 32

Sturgeon

Catch Per Unit Effort

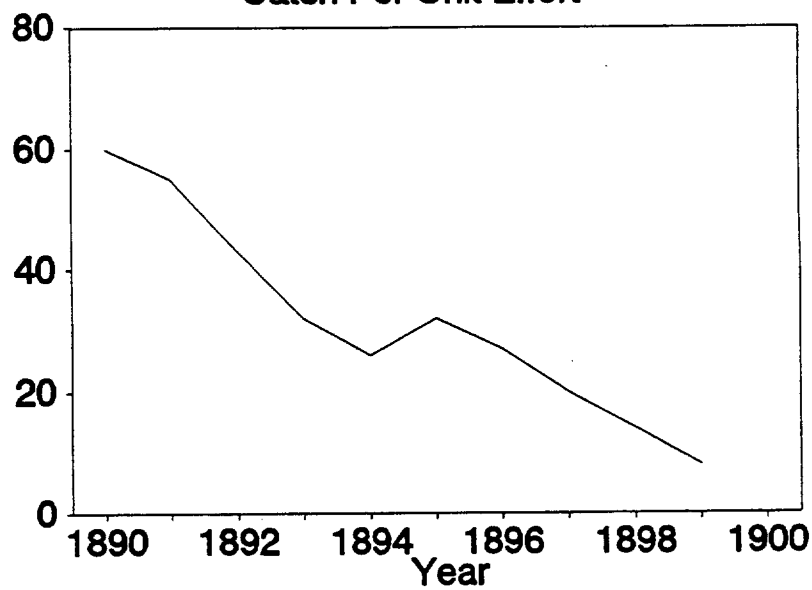


Figure 33

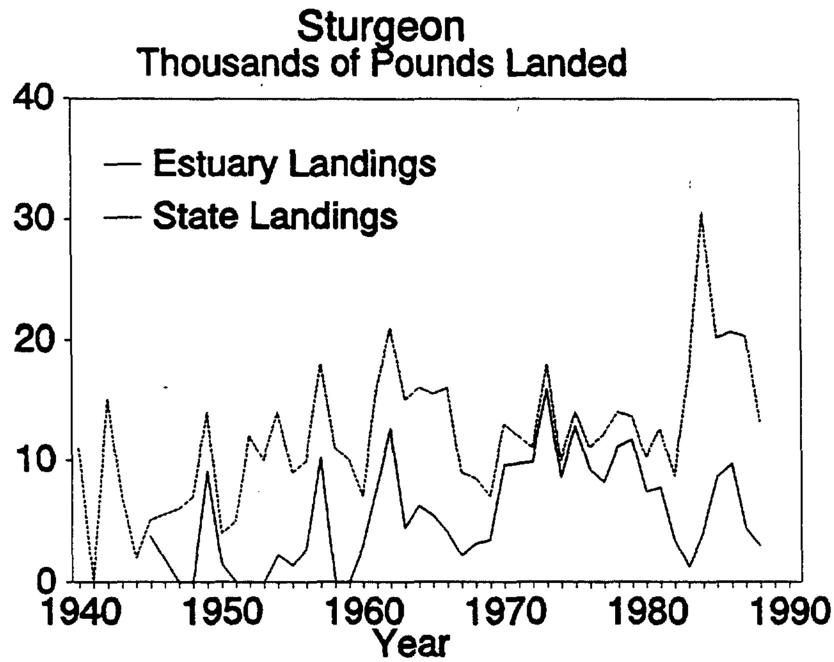


Figure 34

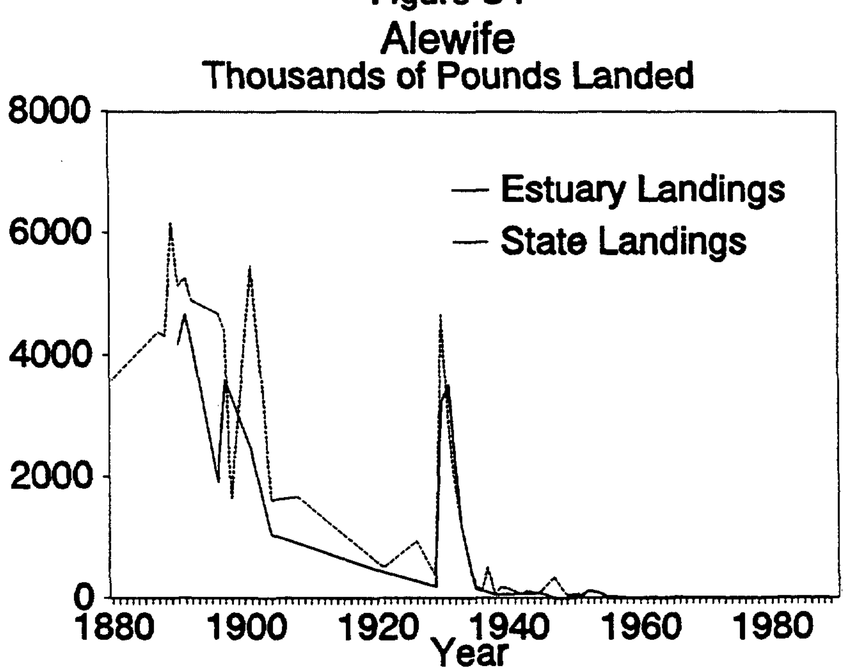


Figure 35
Shad
Thousands of Pounds Landed

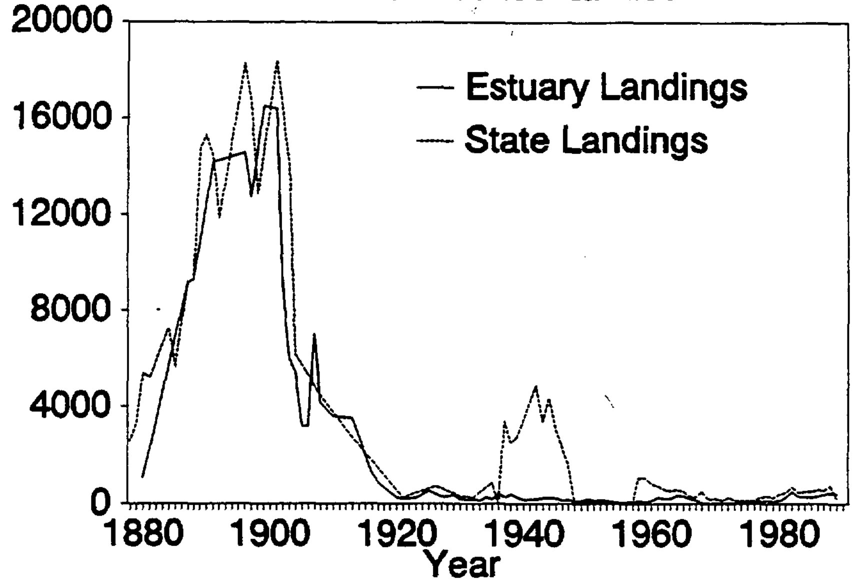
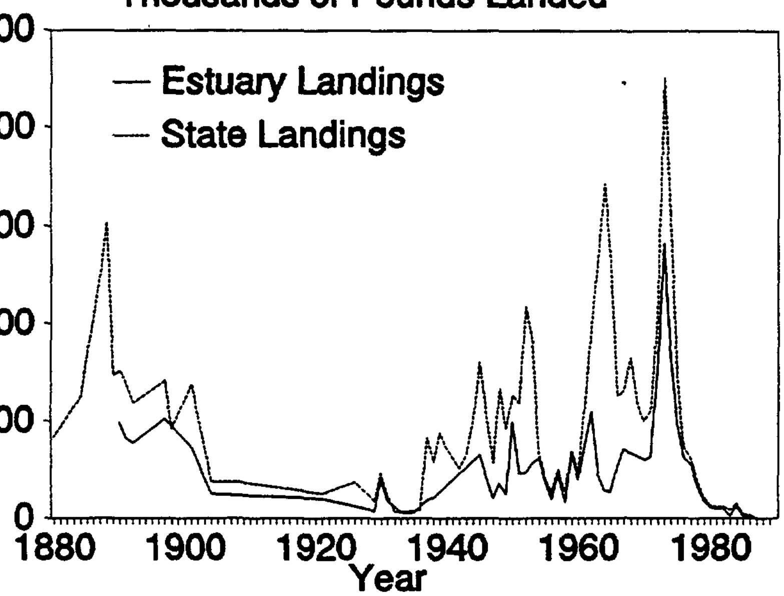


Figure 36
Striped Bass
Thousands of Pounds Landed



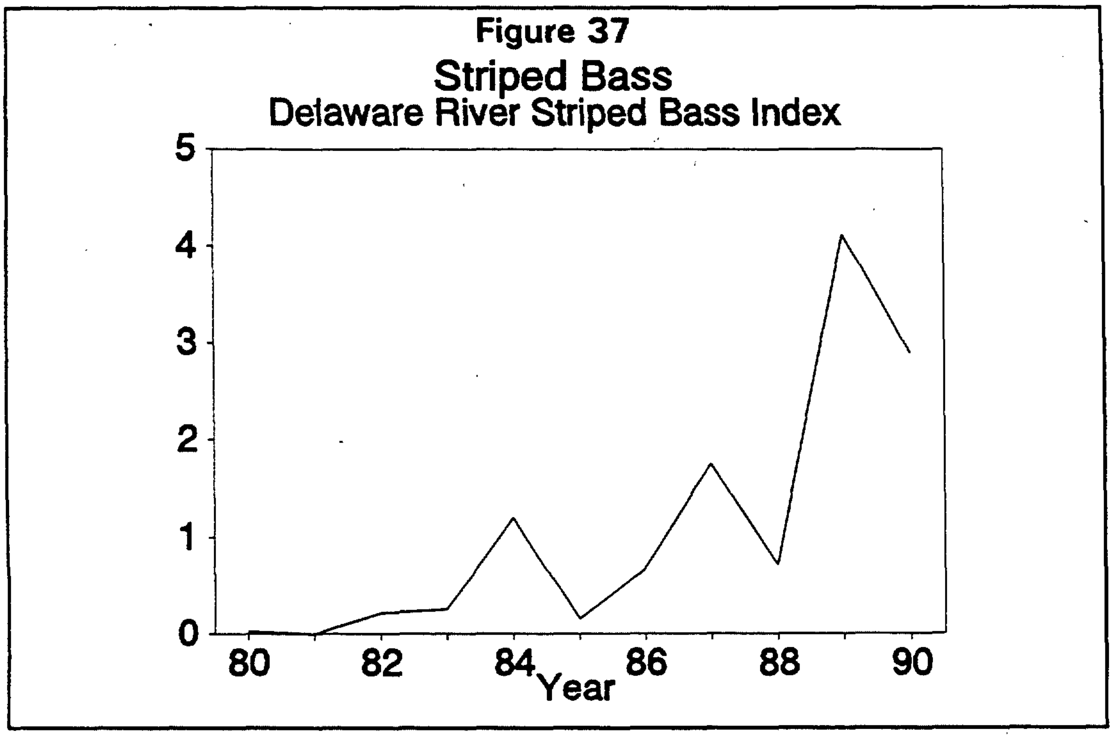


Figure 37
Striped Bass
Delaware River Striped Bass Index
5
4
3
2
1
0
80
82
84
86
88
90
Year

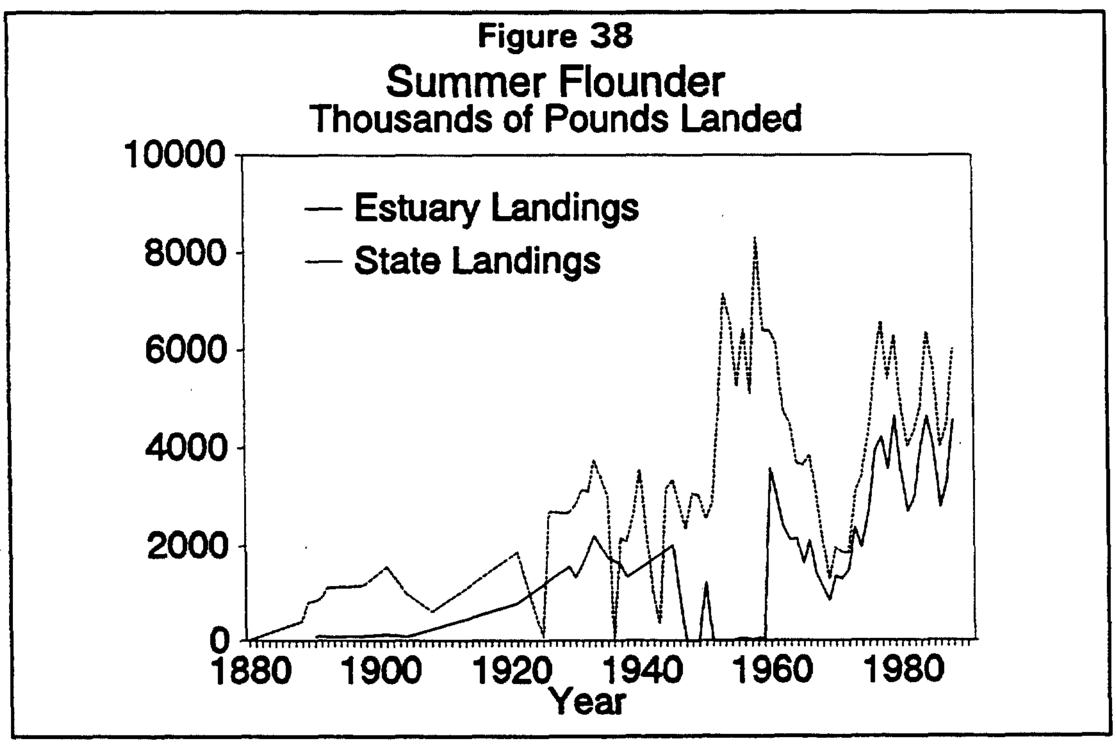
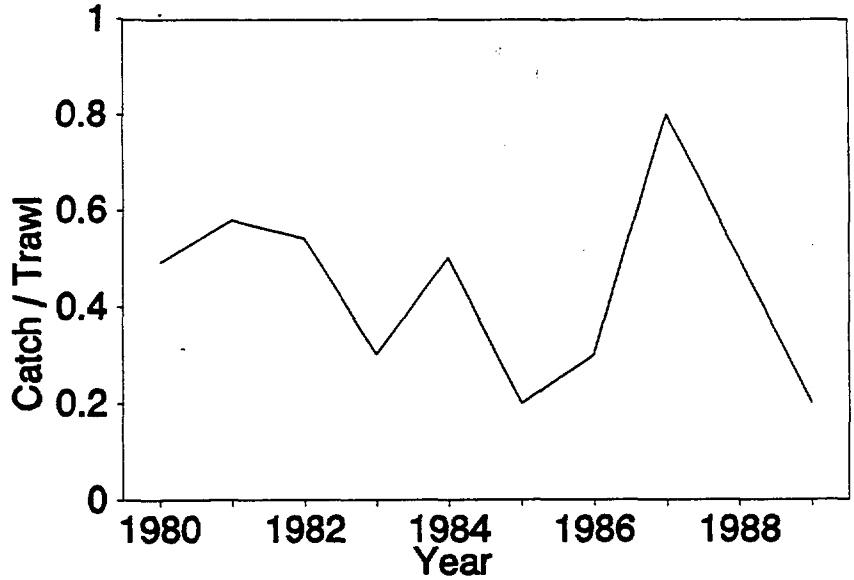


Figure 38
Summer Flounder
Thousands of Pounds Landed
10000
8000
6000
4000
2000
0
— Estuary Landings
— State Landings
1880
1900
1920
1940
1960
1980
Year

Figure 39
Summer Flounder



Source: Delaware DNREC

Figure 40
Bluefish
Thousands of Pounds Landed

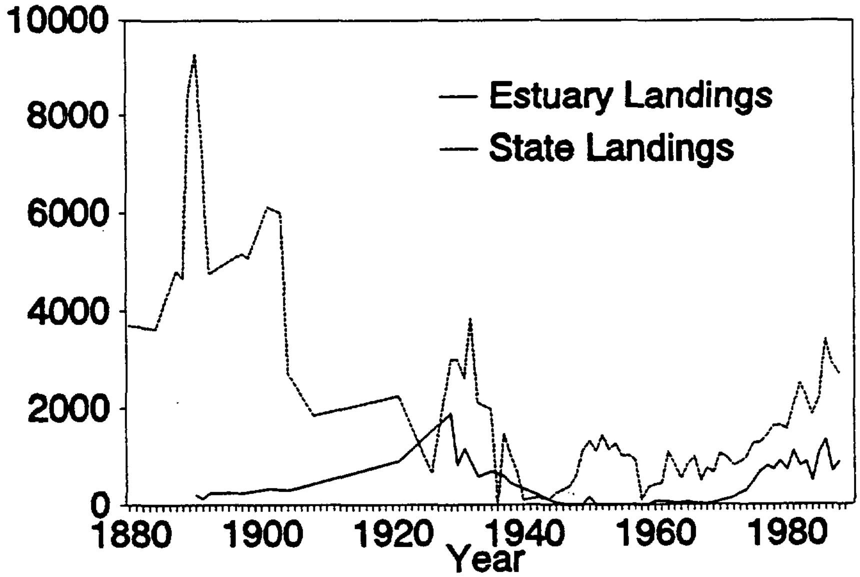
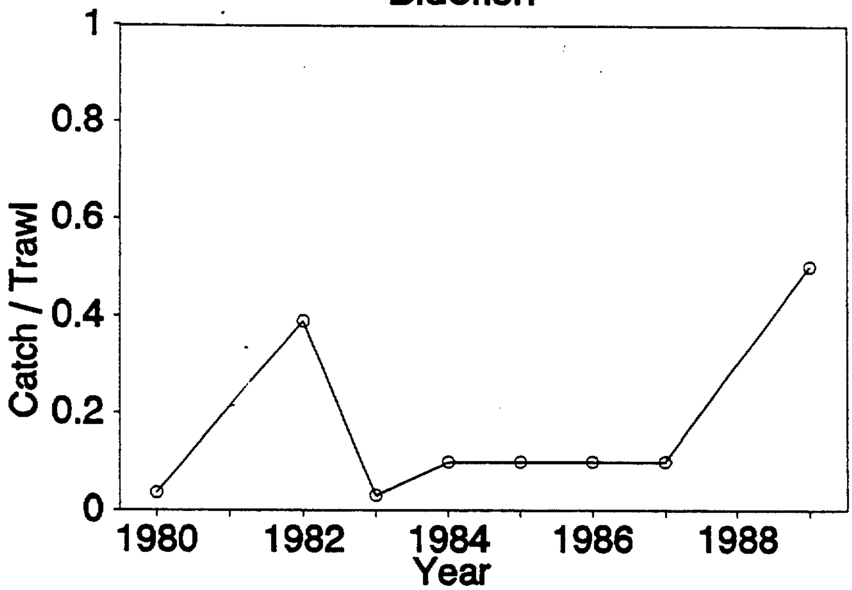


Figure 41

Bluefish



Source: Delaware DNREC

Figure 42

Weakfish

Thousands of Pounds Landed

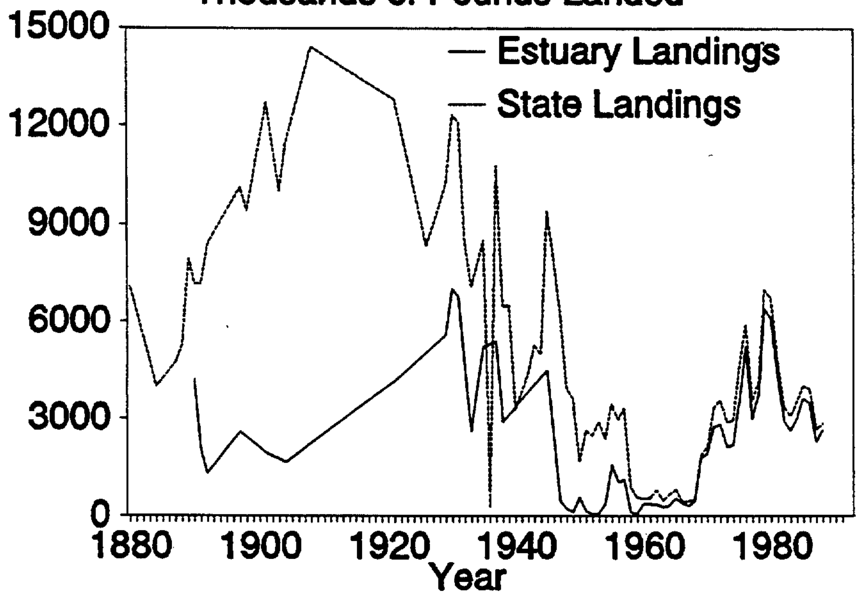
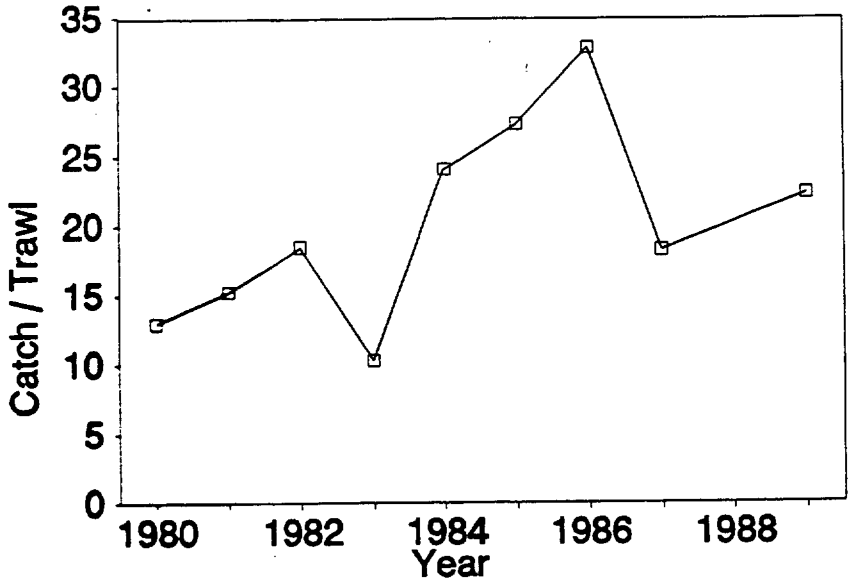


Figure 43

Weakfish

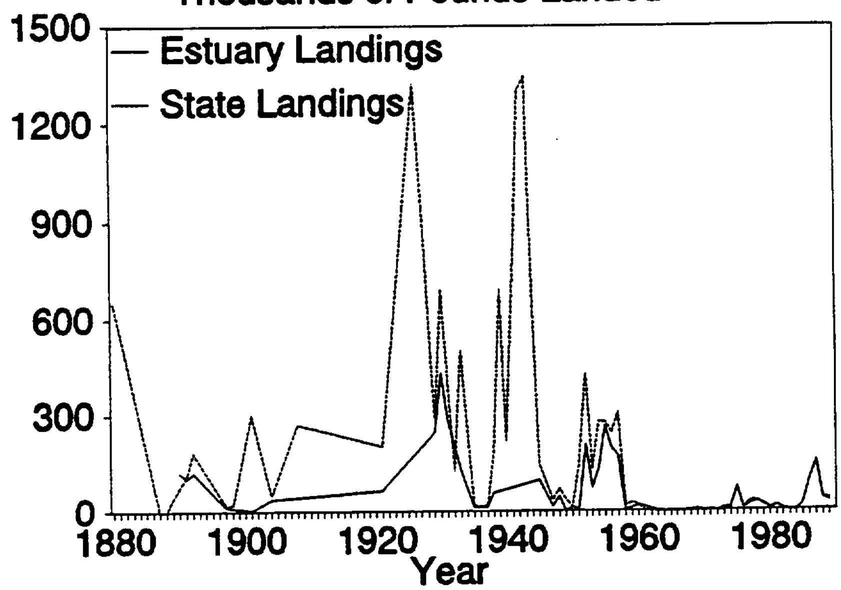


Source: Delaware DNREC

Figure 44

Spot

Thousands of Pounds Landed



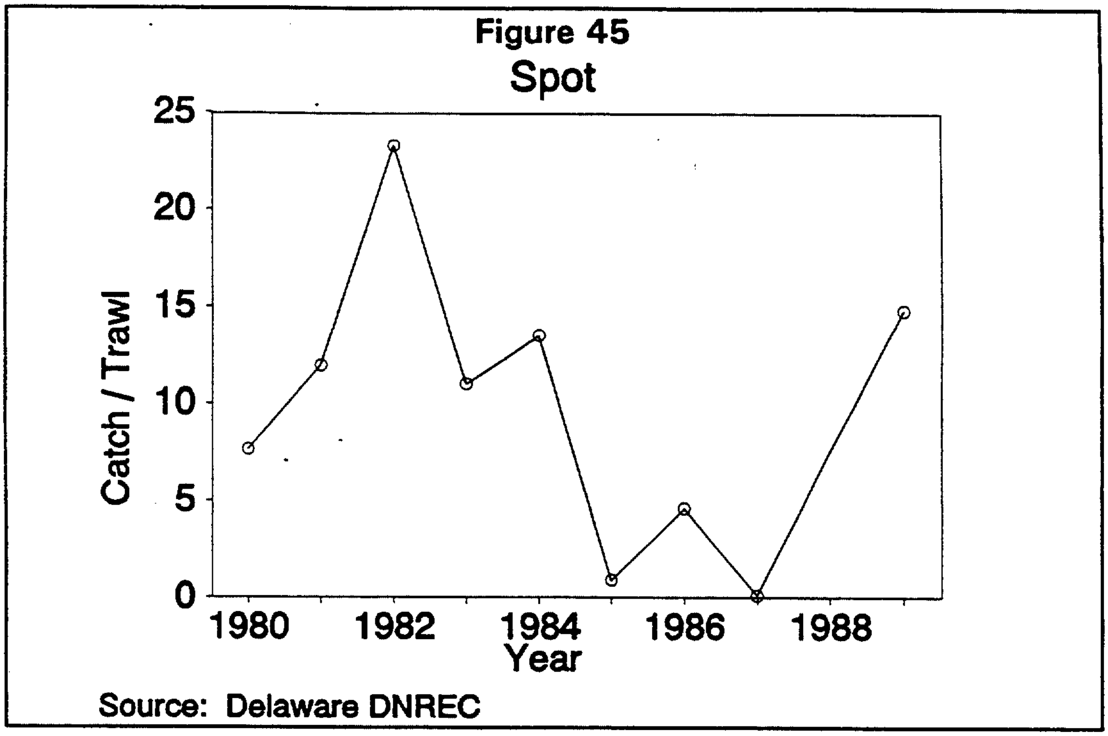


Figure 45
Spot
25
20
15
10
5
0
Catch / Trawl
1980
1982
1984
1986
1988
Year
Source: Delaware DNREC

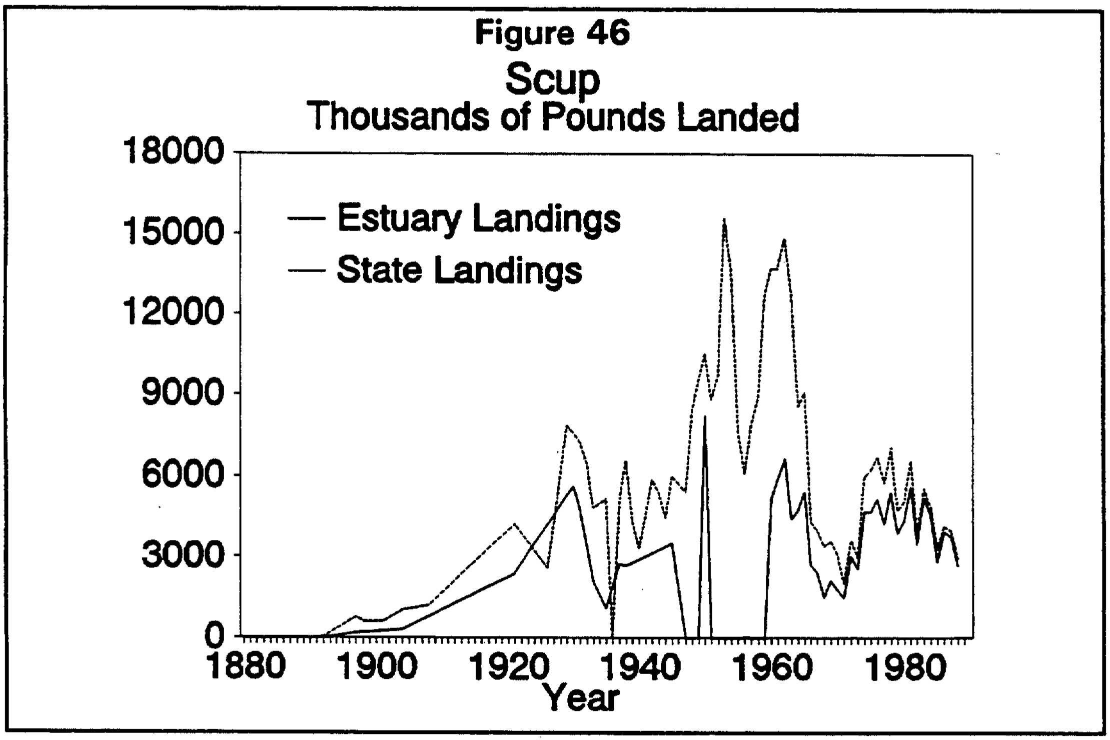


Figure 46
Scup
Thousands of Pounds Landed
18000
15000
12000
9000
6000
3000
0
Estuary Landings
State Landings
1880
1900
1920
1940
1960
1980
Year

Figure 47

Menhaden

Thousands of Pounds Landed

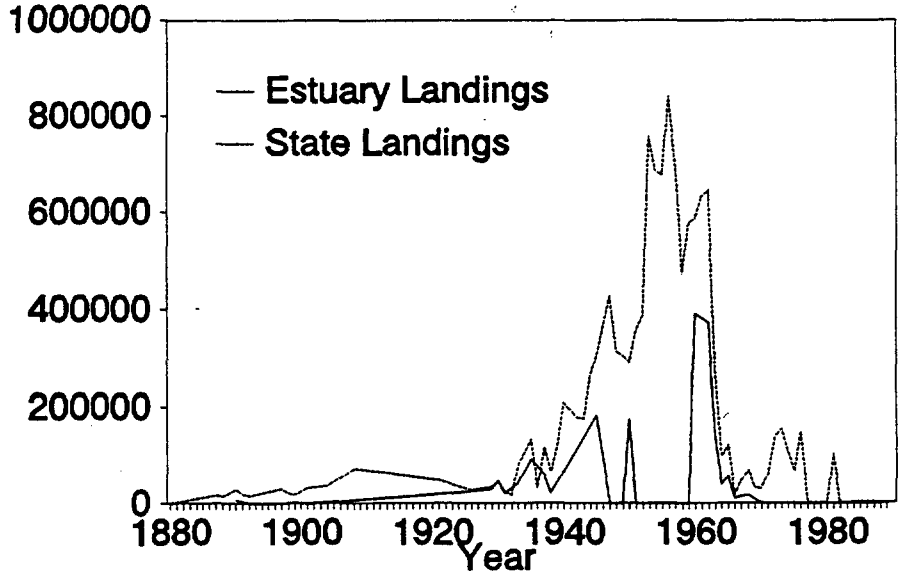


Figure 48

White Perch

Thousands of Pounds Landed

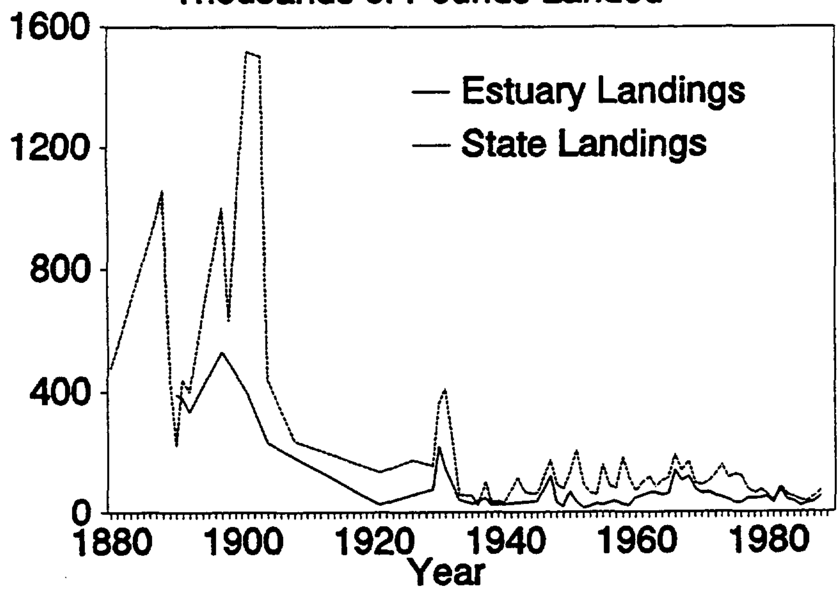
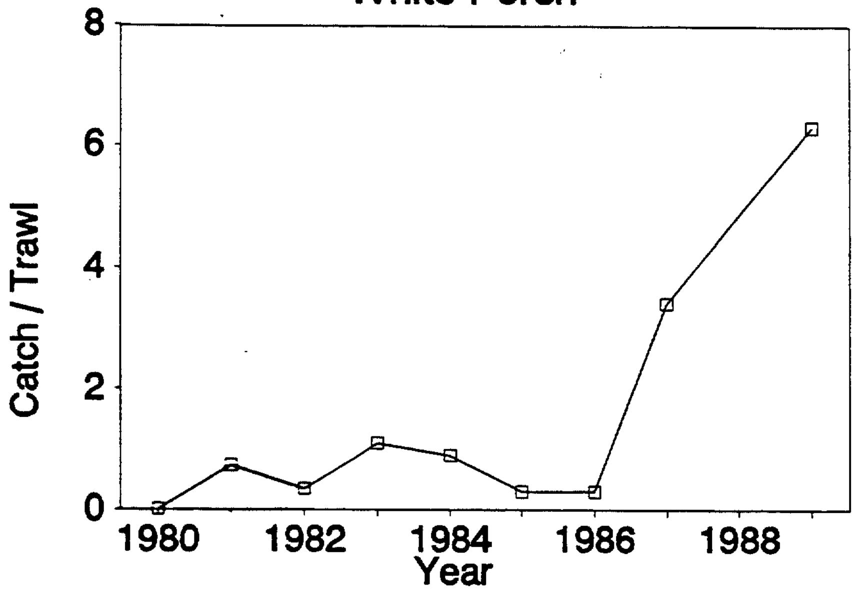


Figure 49

White Perch



Source: Delaware DNREC

Birds

Status and trends information for birds is presented for individual species in the following groups: raptors, shorebirds, wading birds, waterbirds, and gulls and terns. In this way, species having generally similar habitat and life history characteristics can be examined together. General trends for key bird species are summarized in Table 28. With the exception of shorebirds, most of the species are distributed throughout the Delaware estuary for feeding or nesting purposes. Therefore, it was inappropriate to examine differences in abundance by salinity region. Seasonal trends for key bird species are summarized in Table 29.

Raptors

Raptor populations in the Delaware estuary have been heavily impacted by hunting, habitat destruction, and pesticides (Stone 1939; Mellon 1990). Over the last forty years local breeding populations of the peregrine falcon, bald eagle, osprey, sharp shinned hawk, Coopers hawk, red-shouldered hawk, and northern harrier all declined. As apex predators, these birds readily bioaccumulate many contaminants, especially early generation pesticides. Evidence indicates that the decline of the first five were directly linked to DDT, and although the cause of the decline of the last two is less certain, their sudden decline with increasing pesticide use and the concurrent easing of hunting and habitat destruction pressures suggest that anthropogenic factors may be responsible (Mellon 1990). Residual components of DDT and other pesticides continue to influence raptor reproduction (Clark 1990; Griffen and Steidl 1990; Steidl et al. 1990)).

Two of the raptors in the Delaware estuary -- the bald eagle and peregrine falcon -- are federally listed as endangered species and, are considered to be in danger of extinction throughout all or a significant portion of their range. In addition to these species, the states surrounding the Delaware estuary have designated additional species in need of protection (Table 30).

Raptor populations have been monitored using a variety of methods. Raptors maintain large territories, are secretive, and often occur in remote or inaccessible areas. It is, therefore, more cost effective and logistically feasible to monitor raptor populations at areas where they concentrate during migrations (Dunne and Sutton 1986). Cape May County, New Jersey, is one area where raptors traditionally occur during migrations, and this area has been monitored since 1935 (Dunne and Sutton 1986, Figures 50 and 51) (Data in Dunne and Sutton (1986) were standardized to an eight hour day to correct for differences in annual effort).

Audubon Christmas count data were used as an index of general population levels from 1961 to 1989. Because winter counts may be influenced by a variety of factors, it is inappropriate to use these data for rigorous trend analysis. Winter observations were sporadic for birds such as ospreys, that do not overwinter in the Delaware area.

General patterns can be described for those that do overwinter, including bald eagle (Figure 52), and peregrine falcon (Figure 53). During the early 1960s, wintering populations in the estuary appeared to decline. They remained fairly low and stable through the 1970s, and then increased through the 1980s. Similar trends were observed at Cape May Point (Dunne and Sutton 1986). Between 1976 and 1985 there was a five-fold increase in numbers of peregrine falcon, and a doubling in bald eagle, northern harrier, and osprey counts. Population declines in the 1960s are generally attributed to pesticide poisoning. The strong regulation of pesticides is thought to have contributed to increases in abundance during the 1980s. Audubon data for northern harrier were not obtained.

USFWS-breeding bird survey data has been standardized to number of birds per route because, number and location of routes run in the Delaware estuary varied annually. Limitations in the number and location of routes completed each year, as well as non-random distribution patterns of bird species, contribute to the variability observed in these data. No data were available for peregrine falcon or bald eagle. Examination of northern harrier and osprey trends show the high variability characteristic of species that are very low in abundance (Figures 54 and 55); however, counts for both species appear to be increasing in recent years.

Pennsylvania (1984 to 1988), Delaware (1983 to 1987) and New Jersey (1981 to 1985) have each conducted standardized breeding bird surveys. The purpose of these studies was to identify the distribution of species that breed within the states. All four species breed throughout the Delaware estuary. Ospreys were the most numerous of the raptors. Most osprey nesting sites were in the southern Bay area (Tables 31 and 32). Northern harriers apparently nest primarily in the New Jersey portion of the estuary (Dunne 1984 1986). Osprey and peregrine falcon both historically nested in Bucks County, PA (rkm 140 to 203) but have not nested there since 1937 and the 1950s, respectively. Their loss from this freshwater portion of the estuary has been attributed to increased human activity, loss of habitat, and pesticide poisoning (Almshouse Neshaminy Manor Center 1990).

In addition to general studies, separate investigations have been conducted to identify the abundance and distribution of specific species. Each of the states in the Delaware estuary have established non-game programs that monitor raptor populations. Detailed information on bald eagle nesting (number of sites and productivity) has been monitored in New Jersey since 1959 (Niles 1989; Niles and Clark 1990; Figure 56) and in Delaware since 1978 (Alexander 1978, 1980, 1981, Gelvin-Innvaer pers. comm.). The bald eagle suffered serious population declines in New Jersey. Twenty-two pairs were known to nest prior to 1960, and by 1970 the population had dwindled to just one nest. The accumulation of chlorinated hydrocarbons, particularly DDT, was the main factor in the decline (Wiemeyer et al. 1984 cited from Niles 1989). From 1976 to 1982 this single pair failed to rear young. In 1982 the state of NJ began to transfer captive-bred chicks into nests to augment natural production (Niles, 1989). Five pairs of eagles nested in New Jersey in 1990, four laying eggs and three fledgling youny (Niles and Clark 1990). This was the first time since 1959 that New Jersey had more than one productive eagle nest. These nests were located in Salem, Cumberland and Cape May counties, all of which border the Delaware estuary. Monitoring programs in the state of Delaware suggest that nesting success may be increasing; however, due to the overall low population size, these numbers should be viewed with caution. Concerns remain: production at secure sites (eg. Bombay Hook NWR) is not always guaranteed; some pairs are highly intolerant of human disturbance; the majority of nest sites used since 1985 are located on private land; and the state is continually faced with increasing development pressures (Gelvin-Innvaer, pers. comm.).

Despite low number of nests and reproductive pairs, overwintering populations of bald eagle were higher in 1988 than ever before in the ten year monitoring program (Niles 1989). During 1988, observers counted more bald eagles in the Delaware estuary than along the Atlantic coast, and abundance in the upper Delaware River had increased relative to other years (Niles 1988). The Maurice River (rkm 30.5) is a core area for wintering bald eagles and supports the highest eagle use on the coastal plain of New Jersey (Sutton 1988).

Peregrine falcons are another species that experienced drastic population declines, mainly due to DDT. The eastern population plunged from an estimated 350 active breeding sites in the 1930s and 1940s (Hickey 1942) to no active breeding birds in 1964 (Berger et al. 1969; cited from Clark, 1990). Recovery efforts began in 1975, when organochlorine pesticides were discontinued. To re-establish the peregrine population in New Jersey, peregrines raised in captivity were released into the wild. In the Delaware estuary, some nest sites are now located along the Delaware River Bridges, (Clark 1990), and one site is located in New Castle County, Delaware. Breeding probably occurs in two other regions adjacent to the Delaware Bay in Delaware (West et al. In Press; Table 31).

The northern harrier was a common species historically along portions of the Delaware estuary, but today, it is a rare breeder (Stone 1937, Dunne 1984, Mellon 1990). The principal causal factor is believed to be the indiscriminate use of DDT for mosquito control. Another factor that may have contributed to the decline is increased development and recreational use of coastal wetlands (Dunne 1984). Recent studies have been conducted to investigate the status of the northern harriers breeding in the Delaware estuaries (Dunne 1984, 1986). Numerous nests have been found adjacent to the Delaware Bay from Reeds Beach (rkm 24) to Mad Horse Creek, NJ (rkm 72). Environmental conditions apparently have a considerable impact on nesting success of this species. Flooding caused by high tides may destroy nests (Dunne 1986).

Currently ospreys are endangered in Pennsylvania, and threatened in New Jersey, and each state monitors the status of ospreys. Clark (1990) noted that despite good production of ospreys along the Atlantic coast, production in Salem County on the Delaware Bay has been consistently low. However, the number of occupied nests in the remainder of the Delaware estuary has been increasing steadily (Table 32).

Reproductive problems associated with environmental contaminants are of increasing concern for osprey and other raptor species that are reestablishing nesting sites in the

Delaware estuary. Recent studies have suggested that reproduction of raptor species, such as osprey and peregrine falcons, continues to be impacted by contaminants such as DDE and PCBs. Osprey eggs collected from 1981 to 1984 showed mean DDE levels of 9.2 ppm, and average eggshell thickness 13.6% thinner than pre-DDT eggs (Gilroy and Barclay 1988, cf Clark 1990). Eggs collected in New Jersey from 1985 to 1988 revealed average DDE levels of 14.6 ppm, and shells 16.4% thinner than pre-DDT (Peregrine Fund, cited from Clark 1990). Eggshell thinning greater than 17% of pre-DDT values has been associated with declining and extirpated populations (Peakall and Kiff 1975). Concentrations of DDEs and PCBs in osprey prey species have been identified at levels known to cause reproductive impairment in raptors (USFWS 1990).

This apparent buildup of environmental contaminants in raptor species is cause for concern. Because of their limited populations, increases in DDE and PCB concentrations could have a significant impact on future reproduction and behavioral patterns (Clark 1990; Steidl et al. In Press; Niles 1990; Griffin and Steidl 1990). In addition, reproduction of ospreys and peregrine falcons may also be impacted by predators; such as great-horned owls (Clark 1990; Steidl et al. In Press).

Shorebirds

Shorebird populations in the Delaware estuary have been impacted historically by hunting and coastal development. Hunting pressure resulted in shorebird declines in the Delaware Valley until about 1920. At this time, the number of shorebirds was considerably lower than today (Mellon 1990). Today, coastal development, loss of habitat, and associated pressures continue to influence shorebird populations.

The Delaware estuary is a major spring staging site for migratory shorebirds in eastern North America (Stein et al. 1983; Meyers 1987). A staging site is an area with an abundant food source, where species remain for a few days to restore energy reserves before continuing their migration. The main attraction to the Delaware estuary for many species appears to be the abundance of horseshoe crab eggs which provide a rich food source for many migratory species (Dunne et al. 1982; Meyers 1987; Roberts 1989). The arrival of migratory shorebirds and the spring spawning of horseshoe crabs appear to be coordinated (Botton 1984) since the migratory shorebirds are always more abundant during the spring northern migration than during late summer southern migration (Urner and Storer 1949). The more important shorebirds in the Delaware estuary include: semi-palmated sandpiper, ruddy turnstone, sanderling, red knot, black-bellied plover, dunlin and piping plover. With the exception of the piping plover, these species are common inhabitants of the Delaware estuary during migration (Table 33).

The piping plover is the only federal or state designated endangered shorebird species (USFWS 1990, Table 30) and the only key species that breeds in the Delaware estuary (Stein et al. 1983; Dunne et al. 1989; Table 29, 31). Its status is monitored closely by state non-game programs (Gelvin-Innvaer, pers. comm.), and breeding bird surveys have documented their distribution (Tables 31 and 34). Delaware breeding bird surveys conducted between 1983 and 1987 provided evidence that piping plovers nested primarily in the Cape Henlopen region and further south. Kane and Farrar (1976) found 93 piping plover pairs between Cape May Inlet, NJ and Holgate, but none in the Delaware Bay area. Their numbers appear to have increased from the historic lows earlier in the century caused by hunting pressures (L. Niles, pers. comm.).

Shorebird distributions during migrations are highly clumped, and these birds are generally not visible from roadside surveys such as the USFWS breeding bird survey. Because of these factors, studies such as the International Shorebird Survey (ISS) were developed. The purpose of the ISS has been to identify important stopovers and enhance knowledge of migration routes (Howe et al. 1989). From these surveys, it appears that sanderlings have experienced substantial and statistically significant population declines between 1972 and 1983 (Howe et al. 1989).

Audubon Christmas count data were available for sanderling, black-bellied plover, dunlin, and piping plover. Piping plovers, which do not overwinter in the estuary, were counted in only two winters (1961 and 1979). Although some of these species overwinter in the Delaware estuary, their primary overwintering grounds are in South America. Many individuals included in the Christmas count are transients on their way farther south. Therefore, these data cannot be used to examine trends rigorously and are instead used as a relative population index. Sanderling, dunlin, and black-bellied plover had variable population levels, although through time (1961 to 1988) overwintering populations in the Delaware estuary have appeared to be relatively constant (Figures 57 to 59). Using the Audubon data, overwintering sanderling levels in the Delaware estuary show no evidence of the drastic declines mentioned by Howe et al. (1989).

During the past decade, many studies have attempted to examine species composition, seasonal distribution, and spatial patterns within the Delaware estuary (Wander and Dunne 1981; Dunne et al. 1982; Burger 1986; Clark 1989a). The actual stopover time in the Delaware estuary is very limited. Shorebirds begin to arrive in early May, abundance peaks in late May, and declines sharply into early June (Wander and Dunne 1981; Dunne et al. 1982; Clark 1989a; Figure 60). The sheer numbers of shorebirds that use the Delaware estuary annually is remarkable. From 370,000 to 643,000 shorebirds, representing 20 species, were estimated to be present on the Delaware Bay shore of New Jersey from mid-May through mid-June, 1981 (Wander and Dunne 1981). These numbers emphasize the importance of the Delaware estuary as a migratory stopover.

Spatial distribution of migratory shorebirds was examined in detail by Dunne et al. (1982) and Clark (1987, 1988, 1989a). Clark found peak numbers of shorebirds occurred along the New Jersey beaches at East Moores Beach (rkm 29), North Thompsons (rkm 31), Goshen Creek (rkm 26), Reeds Beach (rkm 24), and Beadon Point (rkm 46). In Delaware, Pickering Beach (rkm 43), the Mispillion River (rkm 19), Kitts Hummock (rkm 40), and Little River (rkm 45) were areas of highest concentration. Dunne et al (1982) found that patterns of shorebirds differ between the four principal species and also between the Delaware and New Jersey sides of the Bay. The upper reaches of the Bay, north of Gandy's Beach on the NJ side (rkm 49) and Bombay Hook on the Delaware side, are virtually devoid of shorebirds. Also, red knot clearly favor the New Jersey side, concentrating at Reed's Beach and nearby Moore's/Thompson Beach and Fortesque (rkm 45). On the Delaware side, the Mispillion River and adjacent beaches hold most of the state's shorebirds. Ruddy turnstone in New Jersey concentrate at Reed's Beach, Dennis Creek, Moore's Beach/Thompson Beach and Fortescue. In Delaware, they were much less numerous at the Mispillion River. Sanderling were restricted almost exclusively to the NJ side and only on the southern portions between North Cape May and Thompsons Beach. In Delaware, only Cape Henlopen held sanderling. The Little and Mispillion Rivers contain the largest concentrations of semipalmated sandpipers, although they are more evenly distributed along the Delaware coast than the others species. Differences in feeding habits, and competition among species are possible reasons for species segregation (Wander and Dunne 1981; Dunne et al. 1982). Red knot and ruddy turnstone are very dependent on horseshoe crab eggs; sanderling and semipalmated sandpiper appear to be somewhat less dependent (Wander and Dunne 1981). General spatial distributions for the four principal migratory species are presented in Figure 61.

The Delaware estuary is critically important as a red knot staging area. The population of red knot using the estuary may constitute between one half and two-thirds of the total New World population (Wander and Dunne 1981). The most current data collected on shorebird abundance and distribution suggests decreasing numbers of red knots and sanderlings (Clark 1989a). Decreases in red knot abundance have averaged 20% per year since 1986. Sanderling numbers have dropped about 57%. This trend matches declines observed by Howe et al. (1989).

Wading Birds

Wading birds chosen as key biological species in the Delaware estuary include: great blue heron, green-backed heron, black-crowned night heron, great egret, and snowy egret. These birds are common migrants to the Delaware area, and all are common breeders. Most are present during the winter months, although they are less abundant than during the remainder of the year. Fluctuations in wading bird populations in the Delaware estuary can be related to hunting (late 19th century, early 20th), habitat losses, or pesticide poisoning. They have been proposed as biological indicators in estuarine ecosystems because: 1) they are the terminal link in many aquatic food chains and, as a result, may reflect changes originating in several different ecosystem components; 2) they are distributed over a wide geographic area and may indicate local changes in many areas; and 3) they nest in colonies that are easily monitored and can be sampled repeatedly (Custer and Osborn 1977).

While none of the key wading bird species are federally endangered, some are considered threatened or of special concern within individual states (Table 30). Some counties adjacent to the northern portion of the Delaware estuary once supported breeding populations of wading birds. The great blue heron and black-crowned night heron once nested in Bucks County, Pennsylvania but have not nested there in many years (Almshouse Neshaminy Manor Center, 1990).

General seasonal distribution and population trends for wading birds over the last 100 years has been examined (Tables 28 and 29). During the 1970s attempts were made to survey the coastal colonial waterbird colonies from Maine to Florida (Custer and Osborn 1977) and from Maine to Virginia intensively (Erwin 1979; Erwin and Korschgen 1979). As part of this survey, New Jersey's coastline was sampled by New Jersey Audubon's Wildlife Research Unit (Kane and Farrar 1976, 1977). The Delaware Bay shoreline was surveyed in 1976 only.

Results of these surveys provided abundance and distribution data on colonial waterbirds including: great blue heron, black-crowned night heron, green-backed heron, great and snowy egrets, laughing gull, and least tern. Most of the data in Delaware were summarized from studies on Pea Patch Island (Erwin, 1979). All of the key wading bird species were found to nest on Pea Patch Island (Erwin 1979; Erwin and Korshegen 1979). In addition, great blue herons had a large rookery in Delaware City, DE (rkm 96) and a smaller one in Milton, DE (rkm 3). In New Jersey, no heronries were found on the Delaware Bay shore during the 1976 survey (Kane and Farrar 1976). However, one great blue heronry has been identified recently near Stow Creek (L. Niles and K. Clark, pers. comm.). In the surveys of the 1970s, one heronry did exist at Cape May Inlet, and this contained four of the key species (black-crowned night heron-50 adults, great egret-1 adult, snowy egret-4 adults, and green-backed heron-4 adults). Adult counts probably represented less than half the total adult population for each rookery, assuming that at least one bird of each pair was feeding at the time of the count (Kane and Farrar 1976).

Weise (1979) provided a detailed description of the ecology, and nesting biology of herons, egrets, and ibis nesting on Pea Patch Island (rkm 98) and constituting the largest mixed species heronry in the Delaware estuary. This study was conducted during 1975 to 1978 and identified nine species and 6,000 to 7,000 pairs that used Pea Patch Island annually. He found that great blue herons and great egrets returned during mid-March and nested in hardwoods. Snowy egrets arrived in mid-April and dispersed over extensive areas of blueberry and elderberry shrubs. Black-crowned night herons returned in late March-April and nested in hardwoods and shrubs in 1975 and 1976, and in *Phragmites* in 1977 to 1978.

The USFWS has not conducted follow-up research to the 1970s surveys. However, state and private agencies have collected more current information (R. Erwin, pers. comm.). The state of Delaware collects information on wading birds nesting on Pea Patch Island (Delaware Division of Fish and Wildlife, cited from Jenkins et al. 1989). The state of New Jersey conducted recent wading bird surveys. However, these were restricted to the Atlantic Coast (K. Clark, pers. comm.; Jenkins et al. 1989).

Information is available to describe general seasonal patterns for each of the major wading birds. The great blue heron ranges from Alaska and Nova Scotia south to the West Indies and winters as far north as New England and southern Alaska (Daiber and Roman 1988). A gradual increase in the numbers of great blue herons is apparent in both the USFWS breeding bird survey data and the Audubon Christmas bird count data (Figures 62 and 63). Recent breeding bird surveys conducted by the individual states in the Delaware estuary suggest that the great blue heron uses a variety of areas for nest building (West et. al. In Press; Table 31).

The green-backed heron is a common inhabitant of the United States but its general range is more limited than the great blue heron. It is seldom found west of the Rocky Mountains, although it is found north into Canada, east of the mountains, and in most southern states (Daiber et al. 1976). This species is rare in the Delaware estuary during winter months, and this is reflected in the sporadic low counts obtained on Audubon Christmas surveys (Figure 64). Trends observed in the USFWS breeding bird survey similarly show similarly highly variable annual counts (Figure 65). Recent breeding bird surveys conducted by Delaware show green-backed herons breeding in 77% of the available blocks in the state and possible breeding occurring in many other blocks (Table 31). Quantitative studies found the green-backed heron distributed throughout Delaware, but they were more common closer to the estuary (West et al. In press). In Pennsylvania, green-backed herons were located in Bucks, Delaware, and Philadelphia counties; nests were observed observed in some areas (Brauning, In Press).

Black-crowned night herons are widely distributed across the continent (Daiber et al. 1976). They are an extremely gregarious species, and large rookeries containing hundreds of nests are not uncommon. Most of the northern night herons migrate south during the winter and the refuges of Delaware are often used by these birds during migrations (Daiber et al. 1976). Audubon Christmas count trends in the Delaware estuary appear to decrease slightly over time, although the data are variable (Fig. 66).

In Delaware, the only known breeding population of black-crowned night herons is on Pea Patch Island, although they feed throughout the coastal regions of Delaware (West et al. in press). In Pennsylvania, confirmed breeding of black-crowned night herons was observed in Delaware county, with probable breeding in Bucks County also (Tables 31 and 34).

Great and snowy egrets were once hunted to the point of extinction for their plumes (Daiber et al. 1976; Mellon, 1990). Both of these species are spring, summer and fall residents of the Delaware area; most move to more southerly areas during December to February (Daiber et al 1976). The number of great and snowy egrets observed in Audubon Christmas counts was low, and highly variable (Figures 67 and 68). Because these species generally overwinter farther south, these fluctuations may be influenced by weather patterns in the Delaware estuary. During 1970 to 1976, snowy egrets were observed during winter counts, while in the remainder of the years little or no individuals were encountered (Figure 68). The cause of this is not known. Number of birds per route examined during the USFWS breeding bird survey are very sporadic for these species (Figures 69 and 70). Because these species generally nest only on Pea Patch Island (West et al. In Press), and feeding generally occurs along the coastal regions of the estuary, these species may be susceptible to biases in the data resulting from different routes being run each year. In years where more coastal routes are run, the chances of encountering these species would greatly increase. In Pennsylvania, great egrets nested in Delaware and Philadelphia County, with possible breeding in Bucks County (Brauning et al. In Press). Snowy egrets were probable nesters in one block in Philadelphia County.

Waterfowl

Ducks and geese are an important component of the Delaware estuary system. Historically, many of these species were hunted for recreational and food purposes. Three species chosen as key biological species in the Delaware estuary are: black duck, wood duck, and canvasback. These species are not considered endangered or threatened by federal or state agencies (Table 30). Whitman and Cole (1988) discuss waterfowl population declines during the last century. They determined that as habitat quantity and quality have declined during the last century, important waterfowl populations in the Atlantic Flyway also suffered rapid losses. While many factors are responsible, habitat loss and degradation of migratory and wintering grounds are believed to be primary contributors. Since 1955, populations of black duck, mallard, canvasback, and others have all declined significantly. In the case of the black duck, the U.S. Fish and Wildlife Service has estimated the decrease to be as much as 60% over this time period. These flyway declines were reflected proportionately in the waterfowl population of the Delaware estuary.

General seasonal distribution of key waterfowl in the Delaware estuary (Table 29) suggests that all are common migrants through the area. The black duck and wood duck commonly breed in the Delaware estuary. These species are considered game species, and their abundance has been closely monitored. In NJ, aerial waterfowl surveys have been conducted along the coast for over forty years, mainly to determine population abundance and trends (Ferrigno 1990b). These surveys are conducted in cooperation with the Atlantic Flyway Council and the U.S. Fish and Wildlife Service. A similar study is conducted in the state of Delaware (T. Whitendale, pers. comm.). Since 1974, Delaware has kept detailed information on waterfowl. Also, abundance estimates of waterfowl species is monitored weekly or monthly at both Prime Hook and Bombay Hook National Wildlife Refuges (G. O'Shea, and F. Smith, pers. comm.). Much of this information is detailed in annual reports produced by these state and federal agencies.

Audubon Christmas counts depict relatively stable trends for waterfowl. Wood duck counts have remained fairly low over time (Figure 71). Canvasbacks, although generally more abundant, also show fluctuating counts (Figure 72). Black ducks are the most abundant of these key waterfowl species, and annual variations are less than for wood or canvasback ducks (Figure 73). Black ducks can be found in the Delaware estuary year round. During the months of December and January, it is possible to find numerous black ducks in areas like Bombay Hook Refuge (Daiber et al. 1976). Breeding bird surveys document numerous black and wood duck nests located throughout the estuary (Tables 31 and 34).

In New Jersey, the Cumberland County hardwood swamps, like Bear Swamp and the Maurice-Manumuskin River drainage, host a large number of spring waterfowl migrants. Some 20,000 waterfowl gather in late winter-early spring in these marshes (Dunne et al. 1989). Black duck and wood duck both breed in the Bear Swamp (Sutton and Sutton 1986).

Gulls and Terns

The laughing gull and least tern are common migrants in the Delaware estuary and actively breed in the estuary (Table 29). The least tern is considered endangered by the state of New Jersey (Table 30). Trends in populations of these species over the last century have been reviewed by Mellon (1990) (Table 28).

The least tern suffered drastic population declines during the mid to late 1800s due to the high demand for their feathers by the millinery trade. Stone (1937) gives descriptions of millinery hunters literally "knee deep" in piles of least and common terns. Evidence suggested that least tern eggs were becoming very scarce in 1884, and by 1921, Stone (1937) recorded drastically reduced numbers of least terns and piping plovers in the Cape May County area. Coastal development has an additional stress on terns. As early as the late 1800s development along barrier islands began to infringe on least tern habitat. Like many coastal, ground-nesting species, the least tern population suffered from habitat losses, increased predation, and increased human disturbance associated with increased human population (Burger 1989). Kane and Farrer (1977) reported that least terns will have difficulty maintaining present population levels without protection and management.

Coastal colonial waterbird surveys identified least tern populations in the Delaware estuary during 1976 to 1977 (Kane and Farrar 1976, 1977; Erwin 1979; Erwin and Korschgen 1979). On the Delaware Bay shore least tern colonies were located at Dividing Creek, NJ and at Cape May Point. One hundred-twenty adults and 71 active nests were counted at Dividing Creek in 1976. Two sites at Cape May held 48 adults. During 1977, the Delaware Bay shore site was not resurveyed, and one colony containing 85 adults was located in South Cape May on outer beaches and spoil sites. Least tern colonies are still found in these areas (L. Niles, pers. comm.). Least tern colonies were found at four locations in Delaware during 1977 (Erwin 1979, Erwin and Korschgen 1979). Two of these sites were located within the Delaware estuary at Broadkill Beach (rkm 2) (20 nesting pairs) and at Cape Henlopen State Park (rkm 0) (92 nesting pairs).

Least terns have a limited distribution within the Delaware estuary. They breed on beaches and spoil islands in the lower Delaware Bay area. They do not overwinter in the Delaware estuary. For these reasons it would be inappropriate to examine trends in their abundance using the Audubon Christmas counts or the U.S. Fish and Wildlife Service breeding bird survey. Most recent data available on their abundance is collected by Delaware and New Jersey non-game species programs and breeding bird surveys conducted during the 1980s.

Laughing gulls are common inhabitants of the Delaware estuary. Burger and Galli (1987) examined gull distribution in the Delaware Bay area (Figure 74). They found that laughing gulls constituted 88% of the five gull species observed. Seasonal abundance peaked during spring and summer months (Figure 75). On coastal Delaware Bay (Cape May, NJ to Delaware Memorial Bridge) (rkm 111) gulls and terns, and shorebirds constituted 40% and 60% of the species, respectively. Less than one percent were other species. Along inland Delaware Bay (ca. 1 km inland) these trends were reversed. During 1977, laughing gull nesting colonies were located on saltmarsh from Wildwood to Barnegut Inlet, with approximately 60% occurring near Stone Harbor, NJ (coastal region) (Kane and Farrer 1976, 1977). More recent surveys reported colonies along the entire New Jersey Atlantic coast, with approximately 40% in the Stone Harbor region (Jenkins et al. 1989). In Delaware, numerous nests were located near Big Reedy Island, south of Cape Henlopen. Recent breeding bird surveys in Delaware (1983-1987) confirmed the continued use of this area (West et al. In press). Laughing gulls were observed along the coastline of mid to southern Delaware during auantitative survey conducted throughout the state (West et al. In Press). Like the shorebirds, laughing gulls feed extensively on the eggs of horseshoe crabs.

Summary for Bird Community Assessment

Many avian species are dependent upon the Delaware estuary for breeding, overwintering, and staging areas. The estuary is situated along the Atlantic Flyway, an important flight corridor for many migratory species, and is one of the largest staging areas for migratory shorebirds in North America. The importance of the Delaware estuary to numerous bird species, including those chosen as key biological species, cannot be overstated.

Trend analysis revealed three principal factors contributing to fluctuations in avian populations in the Delaware estuary. These factors include hunting pressure, habitat alteration and degradation, and chemical contamination. Many of the species chosen as key biological species were hunted for food, sport, and millinery purposes, in some instances almost to the point of extinction. Restrictions placed on hunting during the early to mid-twentieth century allowed many species to recover. The second factor, habitat alteration and degradation, has been a continual problem in the Delaware estuary. The coastal location of the Estuary makes it a prime target for development. Habitat loss as a result of development and its associated anthropogenic effects has also had significant impact on species populations and has led to extirpation of breeding species in some areas. A third factor, contamination by organochlorine pesticides, especially DDT and metabolites such as DDE), continues to influence reproductive ability of some avian species, especially the raptors. Severe population declines have been directly linked to this pesticide. In addition, fluctuations in species abundance reflect broader population changes that have occurred over a large geographic range as a result of alterations to a species, remote breeding or overwintering habitats or other critical areas.

Spatial and temporal distribution patterns were examined for key bird species in the Delaware estuary. Temporal distribution patterns of key biological species in the Delaware estuary varied depending upon their specific life history requirements (Table 29). Spatial distribution patterns were more difficult to define. Birds are likely to be spatially distributed according to specific habitat preferences or food requirements; therefore, it would have been inappropriate to characterize their spatial distribution using the salinity boundaries defined for finfish and other communities.

General spatial patterns were summarized from research conducted by state (game and non-game) programs, and federal, private, and academic institutions. Aerial, ground, and boat surveys provided species diversity, abundance, and distribution information. Migratory shorebirds typically arrive in the Delaware estuary during mid to late-May. Shorebirds feed extensively on horseshoe crab eggs in the lower Delaware estuary before continuing their northward migration in early June. Colonial waterbirds are located throughout the Delaware estuary region. Many herons and egrets nest in single or multi-species colonies, the largest being Pea Patch Island, DE. These species feed throughout the coastal Delaware estuary region, and great blue and green-backed herons often use inland freshwater habitats. Least terns and laughing gulls are the other colonial nesters chosen as key biological species. Least terns prefer sandy, barrier beach locations for nesting. Many of their colonies are located in the southernmost areas of the Delaware estuary. Laughing gulls nest primarily in saltmarsh areas inland of the estuary but feed extensively along the Delaware Bay shoreline. Gulls located along the New Jersey portion of the Delaware estuary were principally located in the Delaware Bay region. Breeding status and distribution of bald eagles, peregrine falcons, and ospreys are closely monitored by state non-game programs in the Delaware estuary. Recent increases in nesting populations is encouraging; however, reproductive problems resulting from bioaccumulation of organochlorine pesticides and other chemical contaminants are still a major threat to recovery. Status of ducks and other waterfowl populations have been monitored by state gamebird programs and wildlife refuges as well as other organizations. Spatial distribution and abundance of black and canvasback ducks are monitored with annual aerial surveys in the Delaware estuary; however, species such as wood ducks require ground surveys because of their cryptic coloring. Intensive breeding bird surveys have been conducted recently by states bordering the Delaware estuary. These surveys document the location and status of breeding species located within a region (Figure 76). The results of these studies are currently in preparation for publication and should provide a thorough analysis of recent breeding status and distribution for many species located in the Delaware estuary.

Table 28
Trends for Key Bird Species Over the Last 100 Years

Species that were greatly reduced at the turn of the century and have rebounded in recent years.	
Breeding birds:	Great egret, Snowy egret, Wood duck
Non-breeding birds:	Red Knot
Species that were reduced at the turn of the century and have rebounded in recent years.	
Non-breeding birds:	Black-bellied plover, Semipalmated sandpiper, Dunlin
Species that were probably reduced at the turn of the century and have rebounded in recent years. However, the lack of good early records leaves question about their past status.	
Non-breeding birds:	Ruddy turnstone, Sanderling, Laughing gull
Species more common 100 years ago than today.	
Breeding Birds:	Bald eagle, Northern harrier, Peregrine falcon, Piping plover

Source: Mellon 1990.

Table 29
Seasonal Distribution of Key Bird Species in New Jersey

Species	Breeding	Migrant	Winter
Bald Eagle	R	U	U
Peregrine Falcon	R	U	R
Northern Harrier	R	C	C
Osprey	U	C	
Semipalmated Sandpiper		C	
Ruddy Turnstone		C	U
Red Knot		C	R
Sanderling		C	U
Dunlin		C	C
Black-Bellied Plover		C	C
Piping Plover	U	U	R
Great Blue Heron	U	C	U
Green-Backed Heron	C	C	R
Black-Crowned Night Heron	C	C	U
Great Egret	C	C	R
Snowy Egret	C	C	R
Black Duck	C	C	C
Canvasback Duck		C	C
Wood Duck	C	C	R
Laughing Gull	C	C	R
Least Tern	U	C	

C = Common, frequently encountered or numerous in appropriate habitat and season
U = Uncommon, regular but elusive, not always encountered in appropriate habitat and season
R = Rare, infrequently to rarely encountered, even in the appropriate habitat and season

Source: Dunne et al. 1989.

Table 30
Status of Key Bird Species in the Delaware Estuary

Species	Federal Status	Delaware	Penn.	New Jersey
Bald Eagle	E	E	E	E
Peregrine Falcon	E	E	E	E
Northern Harrier				E*
Osprey			E	T
Semipalmated Sandpiper				
Ruddy Turnstone				
Red Knot				
Sanderling				
Dunlin				
Black-Bellied Plover				
Piping Plover	E	E	E	E
Great Blue Heron			SC	T
Green-Backed Heron				
Black-Crowned Night Heron				
Great Egret			T	
Snowy Egret				
Black Duck				
Canvasback Duck				
Wood Duck				
Laughing Gull				
Least Tern				E

Source: USFWS (1990)
NJ. Div. Fish and Game (1987)
Almshouse Neshaminy Manor Center (1990)

E = Endangered
T = Threatened
SC = Special Concern
* = Only breeding populations endangered

Table 31
Delaware Breeding Bird Survey Results

Species	Number & percent total blocks	Conf.	Prob.	Poss.	Comments
Bald Eagle	10/4.5%	6	2	2	-
Perigrine Falcon	3/1.4%	1	2	0	All sites adjacent to Delaware Estuary
Northern Harrier	-	-	-	-	Breeding confirmed in 1 block in Kent County[1]
Osprey	40/18%	23	3	14	Sites primarily located in southern Delaware Bay area
Piping Plover	4/1.8%	3	0	1	All sites in Cape Henlopen area and south
Great Blue Heron	9/4.1%	9	0	0	Found throughout state, nests inland and coastal
Green-Backed Heron	171/77%	17	50	104	Nests throughout the state
Black-Crowned Night Heron	1/0.5%	1	0	0	Nests on Pea Patch Island Feeds throughout DE coast
Great Egret	1/0.5%	1	0	0	Nests on Pea Patch Island Observed 1° on coast
Snowy Egret	1/0.5%	1	0	0	Nests on Pea Patch Island Observed 1° on DE coast
Black Duck	78/35%	37	11	30	Nests mainly along coast in mid to lower DE
Wood Duck	136/61.3%	64	39	33	Nests throughout state in marine and freshwater
Laughing Gull	1/0.5%	1	0	0	Only one colony located, south of Cape Henlopen
Least Tern	-	-	-	-	No data obtained

Summary of Delaware Breeding Bird Atlas Data (West et al. In Press).
First number is the number of blocks within the county in which the species were sighted.
Second number is percent of blocks in which breeding was observed within the state .
Reports number of Possible, Probable and Confirmed breeding within blocks.

Table 32
Summary of Occupied Osprey Nests in New Jersey, 1982-1988

County	1982	1983	1984	1985	1986	1987	1988
Burlington	1	2	2	2	2	2	2
Cape May	49	44	53	56	63	61	64
Camden	0	0	0	0	0	0	0
Cumberland	3	3	2	3	3	5	7
Salem	13	13	14	11	9	11	11

Source: Clark (1989)

Table 33 Species composition of shorebirds observed along Delaware Bay			
General location	**Year**	**Species Composition**	**%**
New Jersey: Cape May Canal to Salem Nuclear Power Plant (rkm 0 to 88)	1981[1]	Semipalmated sandpiper Ruddy turnstone Red knot Sanderling Dunlin TOTAL	30 32 24 10 3 99
New Jersey: Cape May Canal to Salem Nuclear Power Plant. Delaware: Smyrna River South to Cape Henlopen (rkm 0 to 88)	1982[2]	Semipalmated sandpiper Ruddy turnstone Red knot Sanderling TOTAL	48 21 16 9 94
New Jersey: Cape May rkm 0	1979[3] 1980	Semipalmated sandpiper Red knot Sanderling Ruddy turnstone TOTAL	95
New Jersey: Norbury's Landing, Reed's Beach and Moore's Beach (rkm 18 to 29)	1982[4]	Semipalmated sandpiper Ruddy turnstone Sanderling Dowitchers (2spp.) Red knot Dunlin Greater yellowlegs TOTAL	95
New Jersey: Cape May Canal to Cohansey Point Delaware: Woodland Beach to Cape Henlopen (rkm 0 to 61)	1988[5]	Semipalmated sandpiper Ruddy turnstone Red knot Sanderling Dunlin and Dowitcher TOTAL	62 23 10 3 1 99

Sources:
1) Wander and Dunne (1981)
2) Dunne et al. (1982)
3) Botton (1984b)
4) Burger (1986)
5) Clark (1989)

Table 34
Pennsylvania Breeding Bird Survey Results*

Species	Bucks County	Philadelphia County	Delaware County
	#Blocks/Max Code	#Blocks/Max Code	#Blocks/Max Code
Bald Eagle	-	-	-
Peregrine Falcon	-	2/19	1/14
Northern Harrier	2/2	2/16	3/16
Osprey	1/2	-	-
Piping Plover	-	-	-
Great Blue Heron	47/2	-	1/2
Green-Backed Heron	53/19	4/19	13/19
Black-Crowned Night Heron	7/6	-	3/19
Great Egret	2/2	1/19	1/19
Snowy Egret	-	1/5	-
Black Duck	9/14	1/19	4/19
Wood Duck	35/18	-	8/19
Laughing Gull	1/2	-	-
Least Tern	-	-	-

Total number of blocks = 76 in Bucks County, 21 in Delaware and 15 in Philadelphia.

Entry = Number of blocks species were sighted in/Maximum Breeding Code within those blocks

Breeding codes were:
1) observed bird in county during appropriate season.
2) possible breeding
3-9) probable breeding
10-19) confirmed breeding

As number increases within the range, assurance of breeding increases.

Source: Brauning, In press.

Figure 50

Raptor Trends - Cape May Point

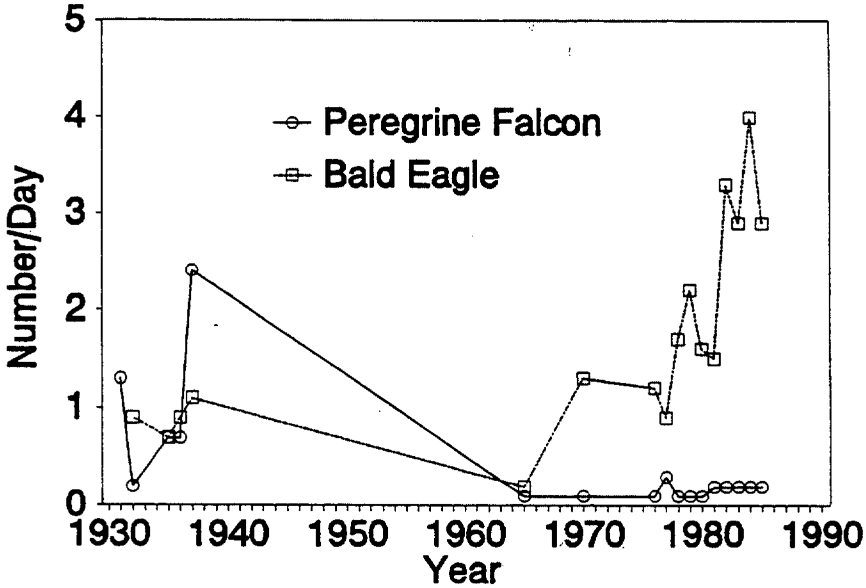


Figure 51

Raptor Trends - Cape May Point

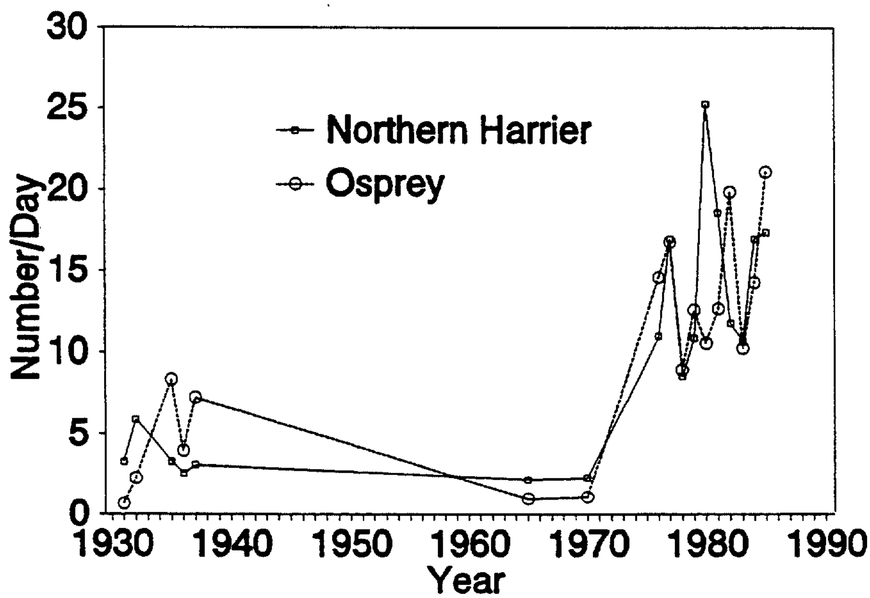


Figure 52

Bald Eagle
Audubon Christmas Bird Count

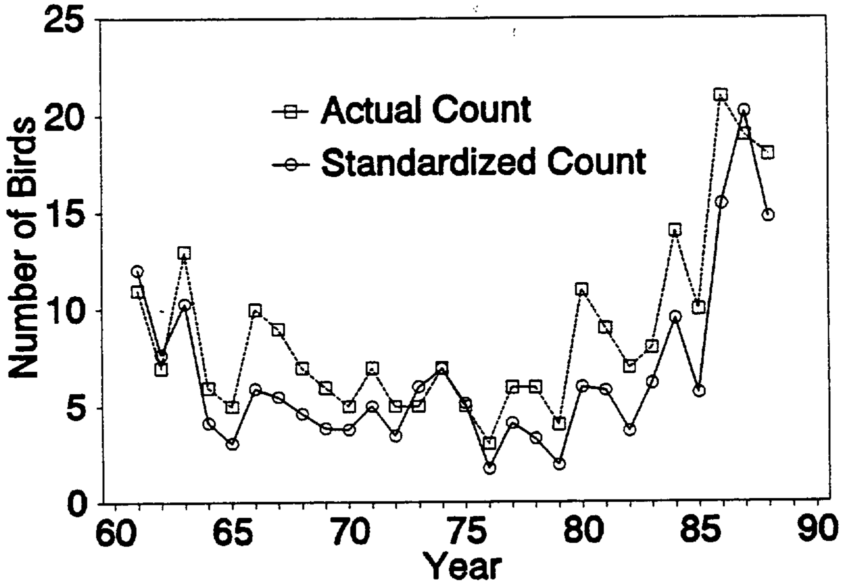
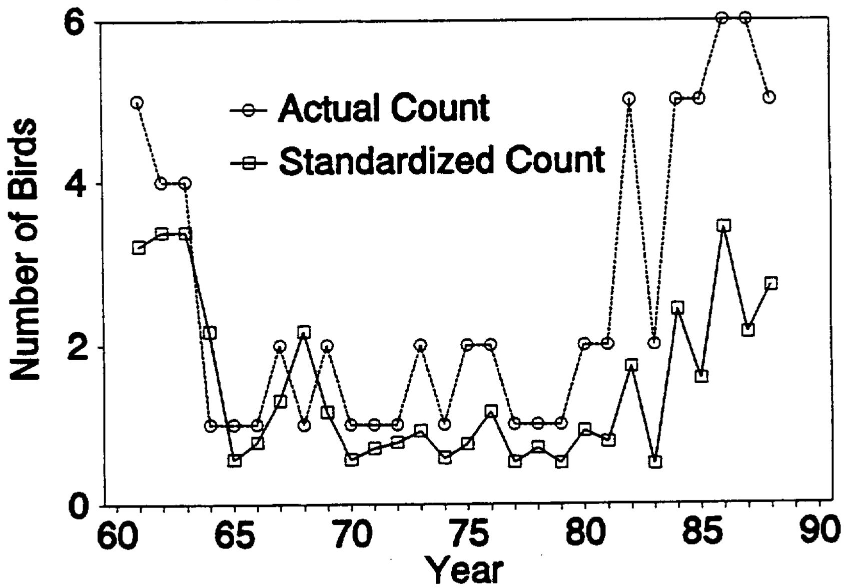


Figure 53

Peregrine Falcon
Audubon Christmas Bird Count



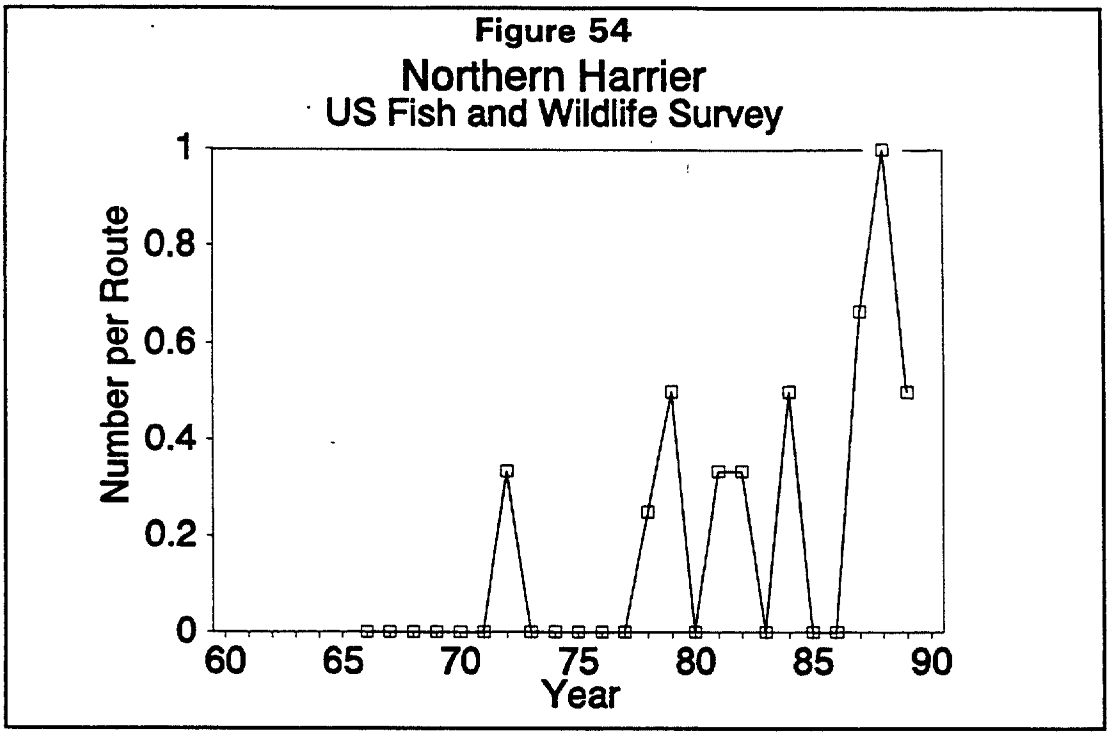


Figure 54
Northern Harrier
US Fish and Wildlife Survey
Number per Route
1
0.8
0.6
0.4
0.2
0
60
65
70
75
80
85
90
Year

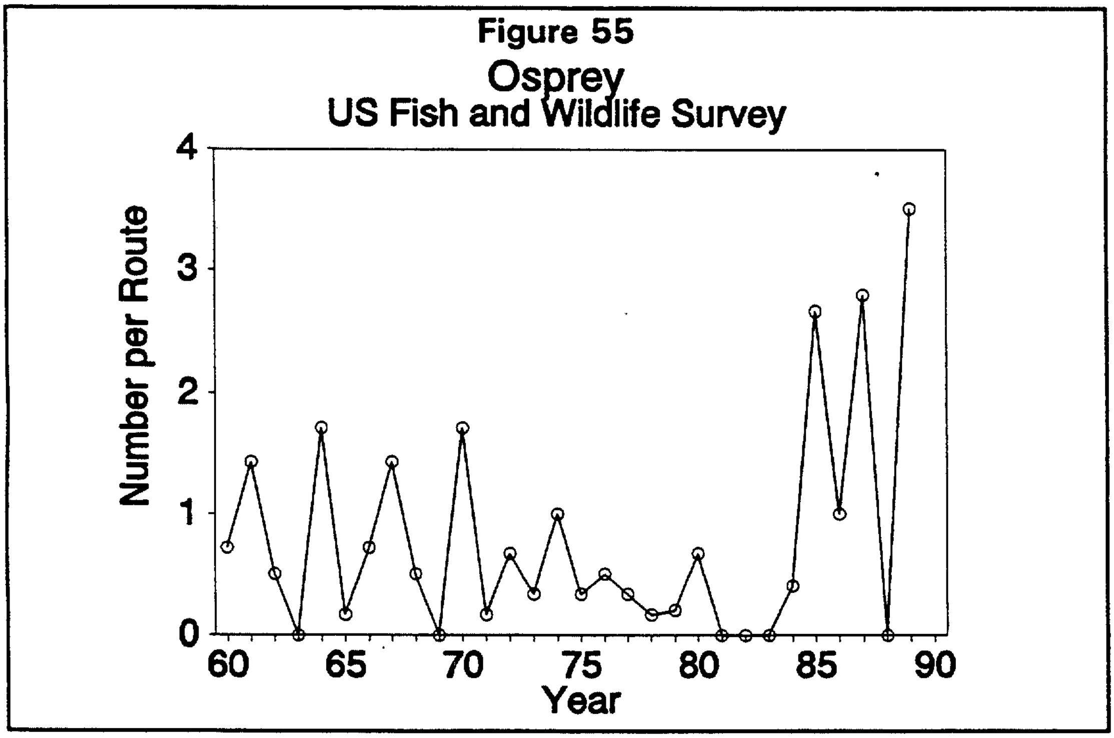


Figure 55
Osprey
US Fish and Wildlife Survey
Number per Route
4
3
2
1
0
60
65
70
75
80
85
90
Year

Figure 56

Bald Eagle and Chick Production

New Jersey Data from Niles (1988)

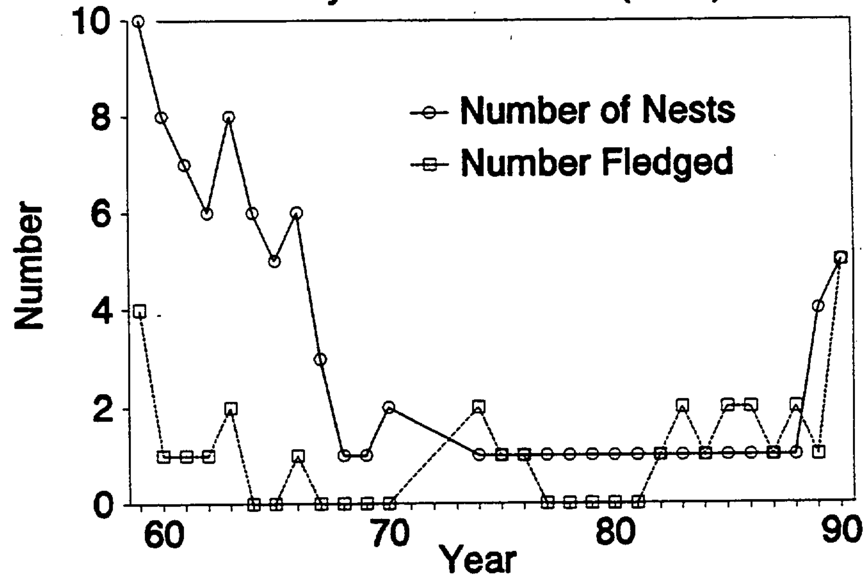


Figure 57

Sanderling

Audubon Christmas Bird Count

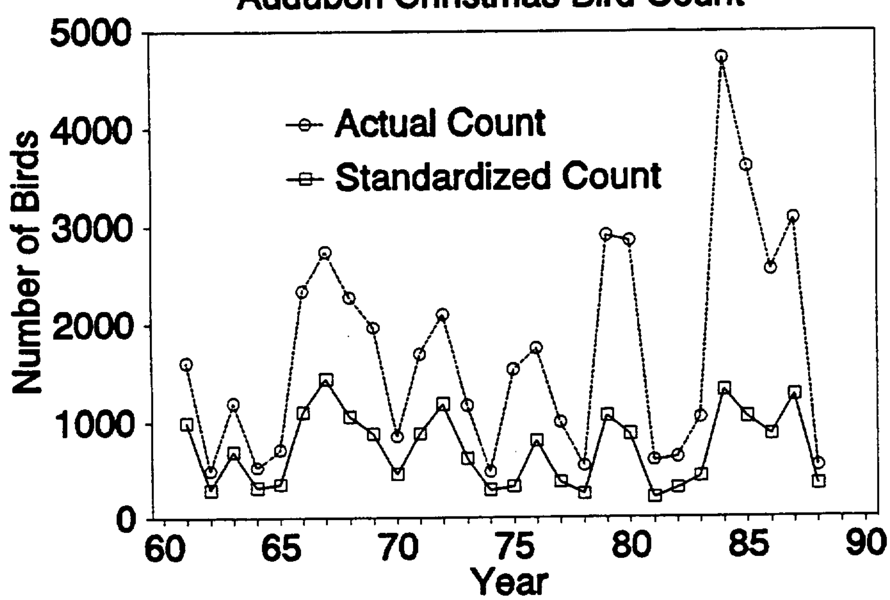


Figure 58

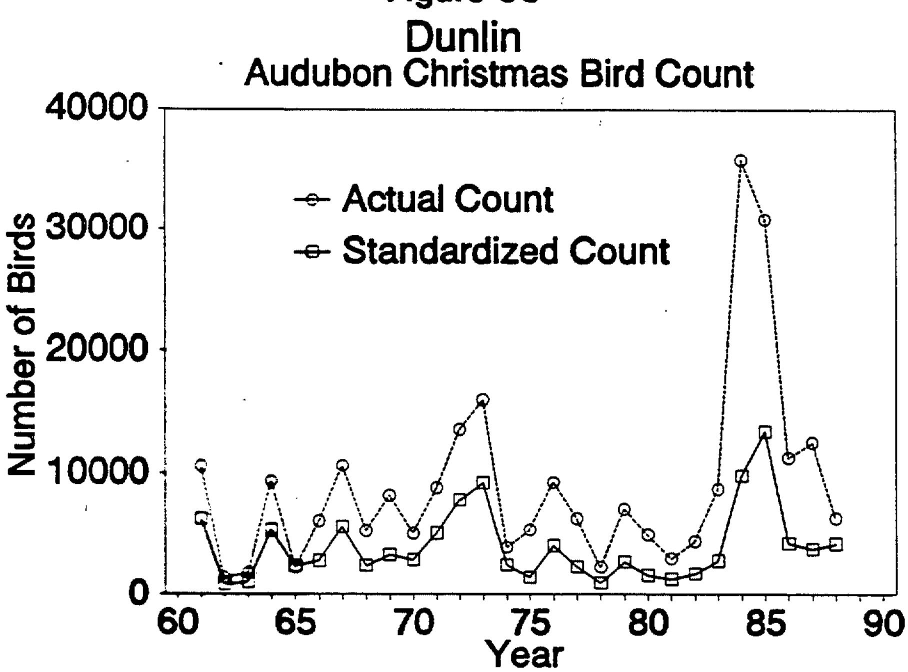


Figure 59

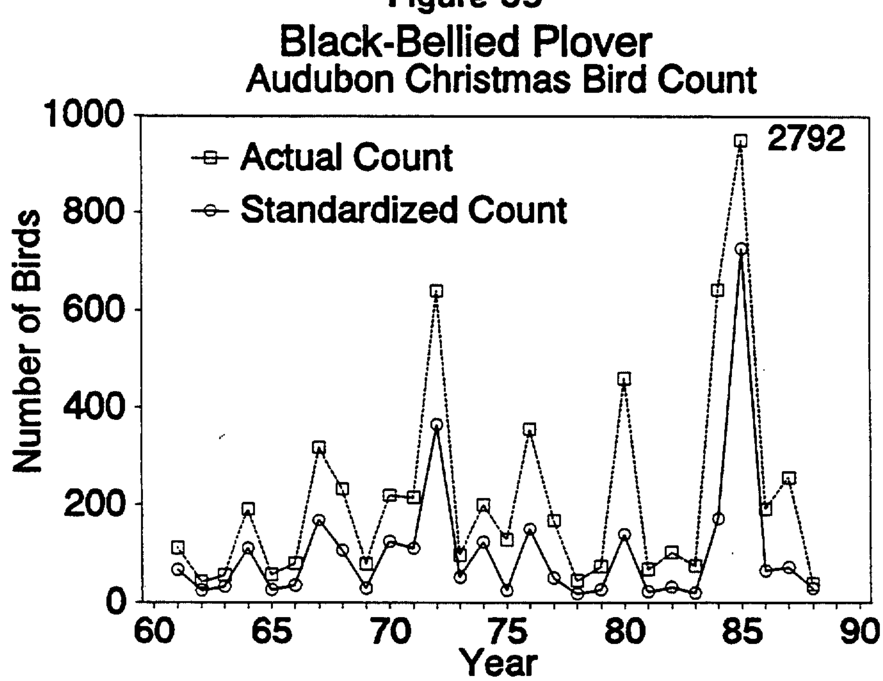
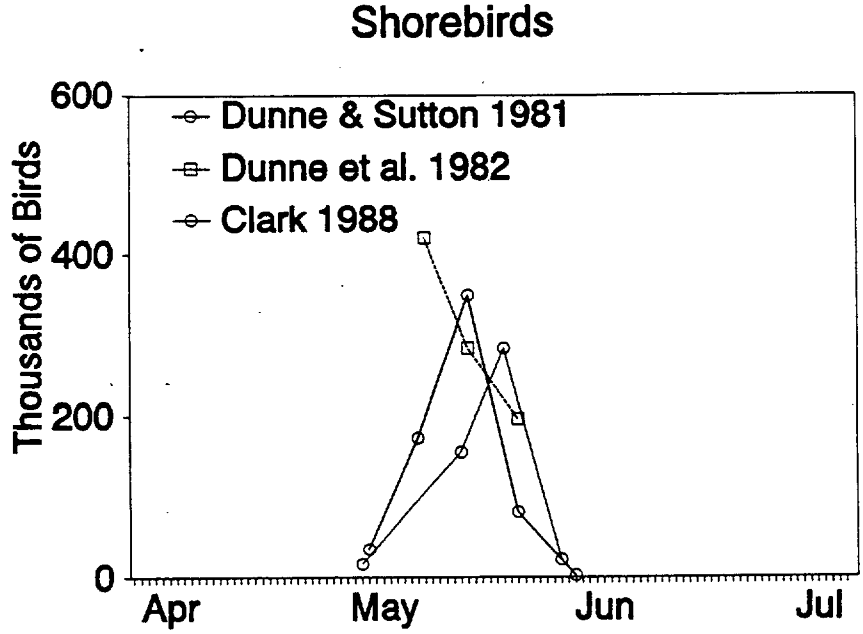
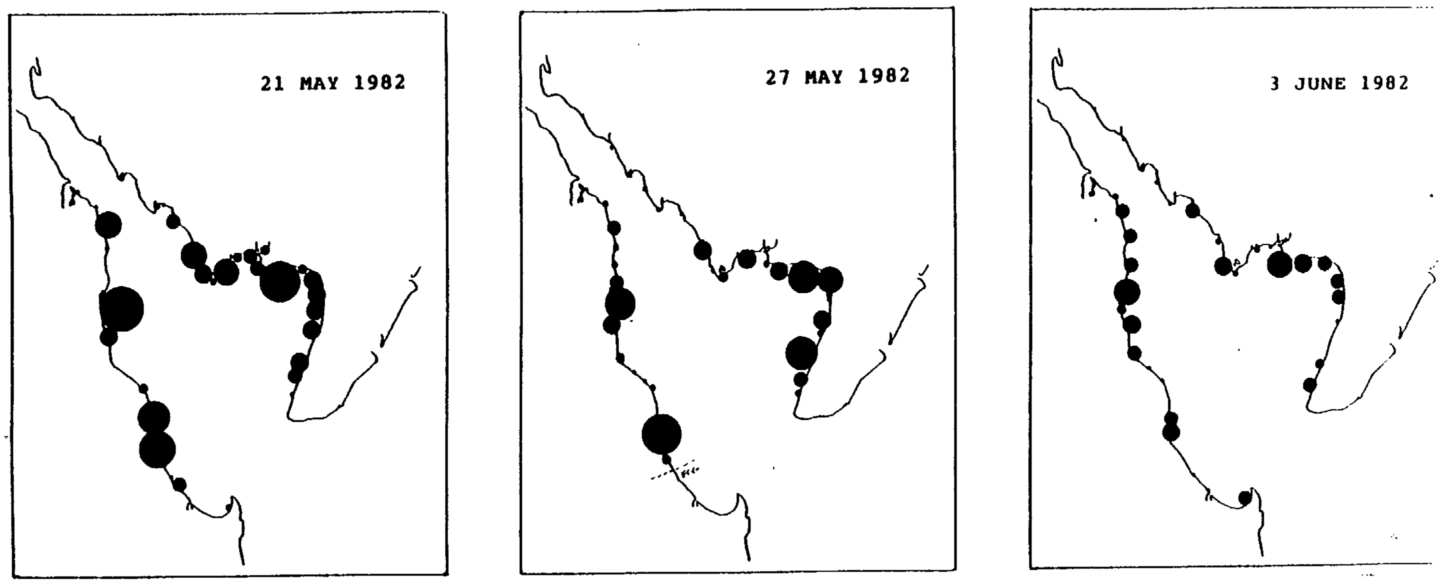


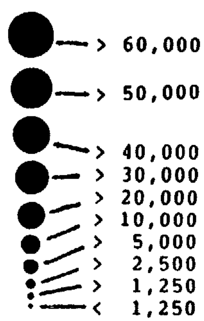
Figure 60



Shorebirds
600
400
200
0
Thousands of Birds
Dunne & Sutton 1981
Dunne et al. 1982
Clark 1988
Apr
May
Jun
Jul

Figure 61





Spatial distribution of the four principal migratory shorebird species in the Delaware Estuary. Includes summations of ruddy turnstone, red knot, semi-palmated sandpiper and sanderling aerial counts.

SOURCE: DUNNE ET AL. (1982)

Figure 62
Great Blue Heron
Audubon Christmas Bird Count

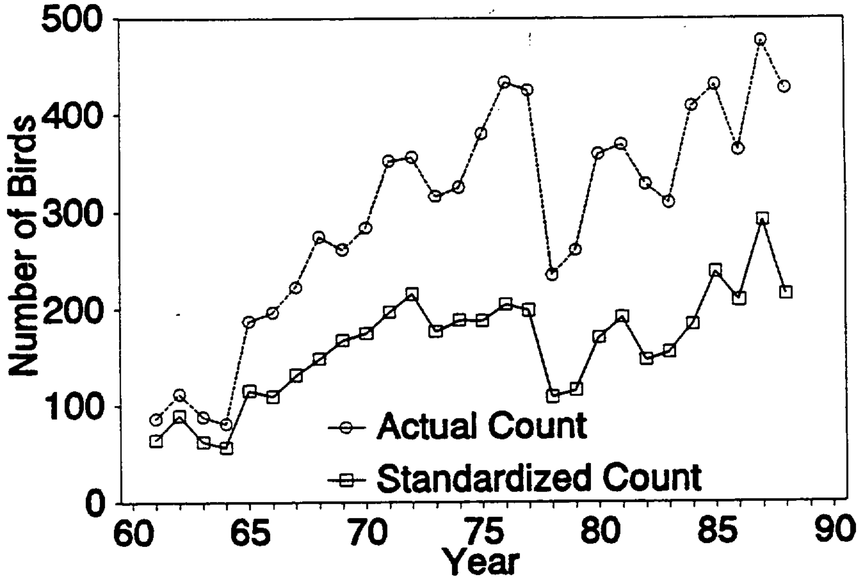
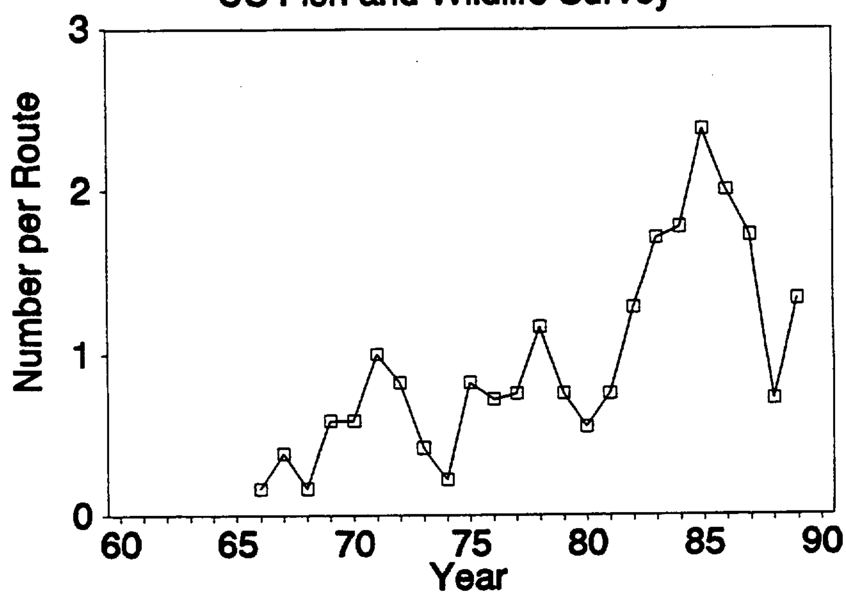


Figure 63
Great Blue Heron
US Fish and Wildlife Survey



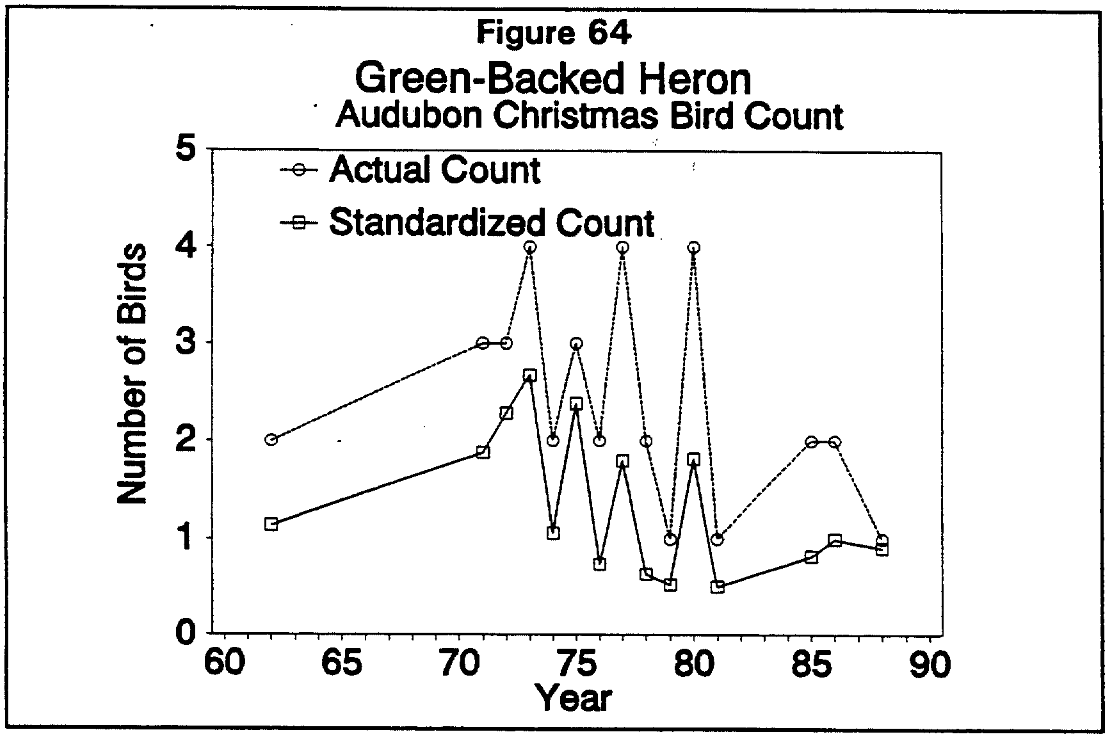


Figure 64
Green-Backed Heron
Audubon Christmas Bird Count
Actual Count
Standardized Count
Number of Birds
0
1
2
3
4
5
60
65
70
75
80
85
90
Year

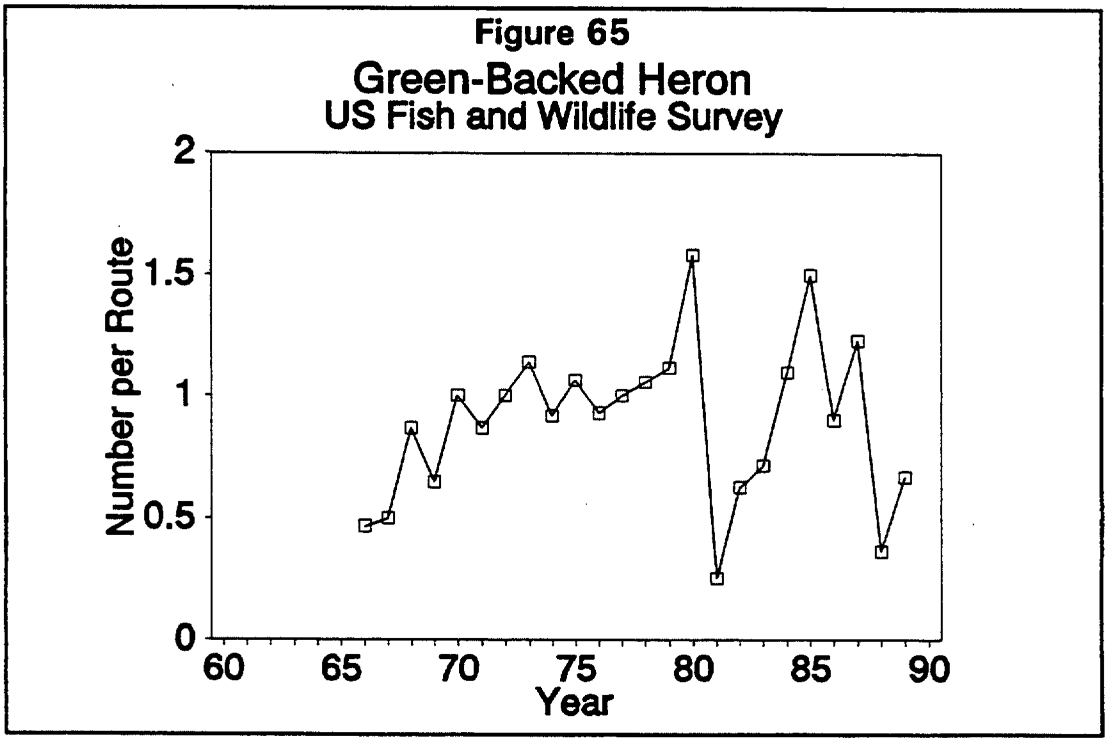


Figure 65
Green-Backed Heron
US Fish and Wildlife Survey
Number per Route
0
0.5
1
1.5
2
60
65
70
75
80
85
90
Year

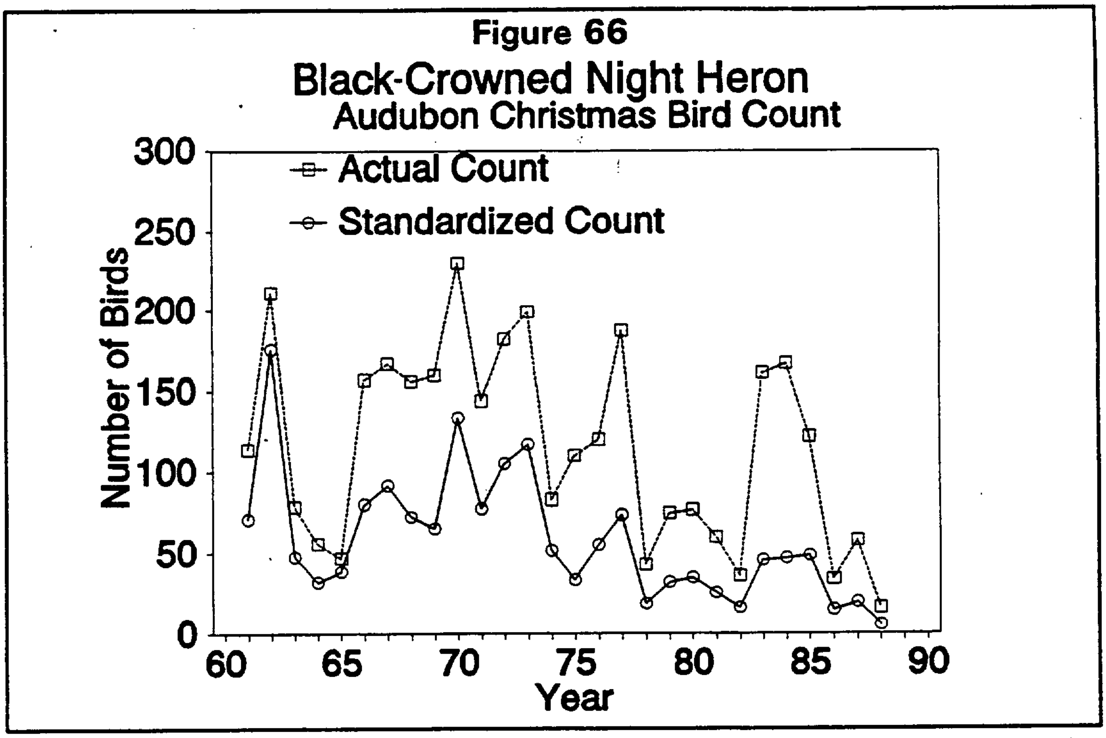


Figure 66
Black-Crowned Night Heron
Audubon Christmas Bird Count
Actual Count
Standardized Count
Number of Birds
300
250
200
150
100
50
0
60
65
70
75
80
85
90
Year

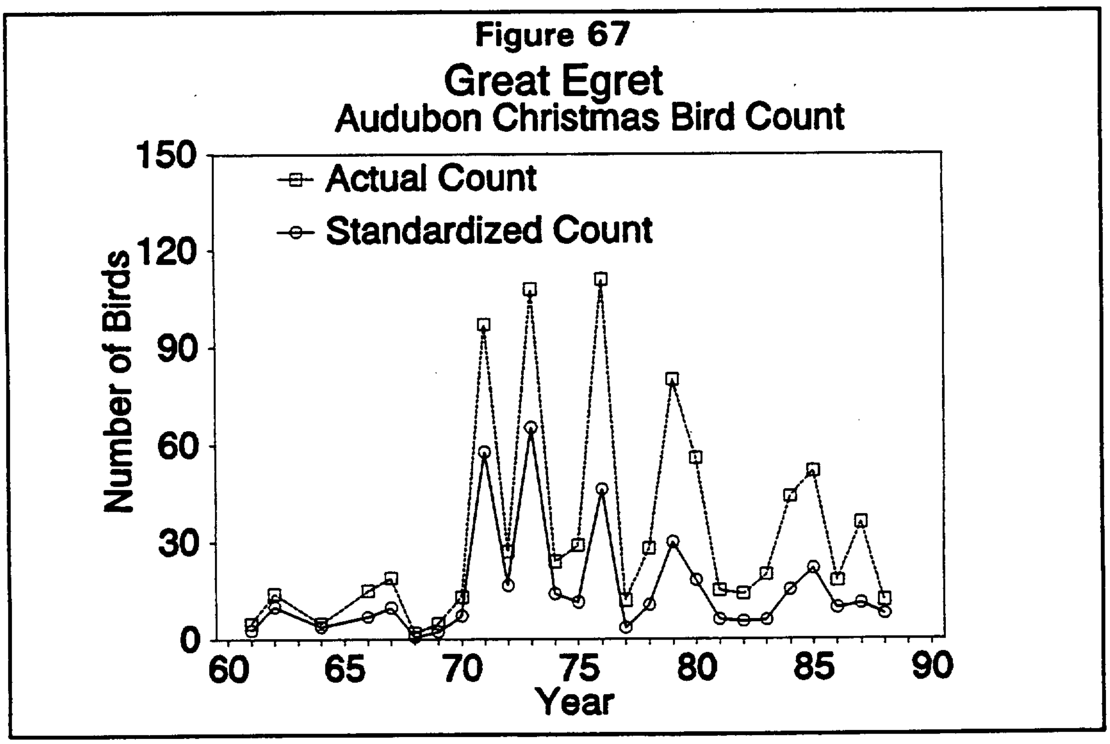


Figure 67
Great Egret
Audubon Christmas Bird Count
Actual Count
Standardized Count
Number of Birds
150
120
90
60
30
0
60
65
70
75
80
85
90
Year

Figure 68

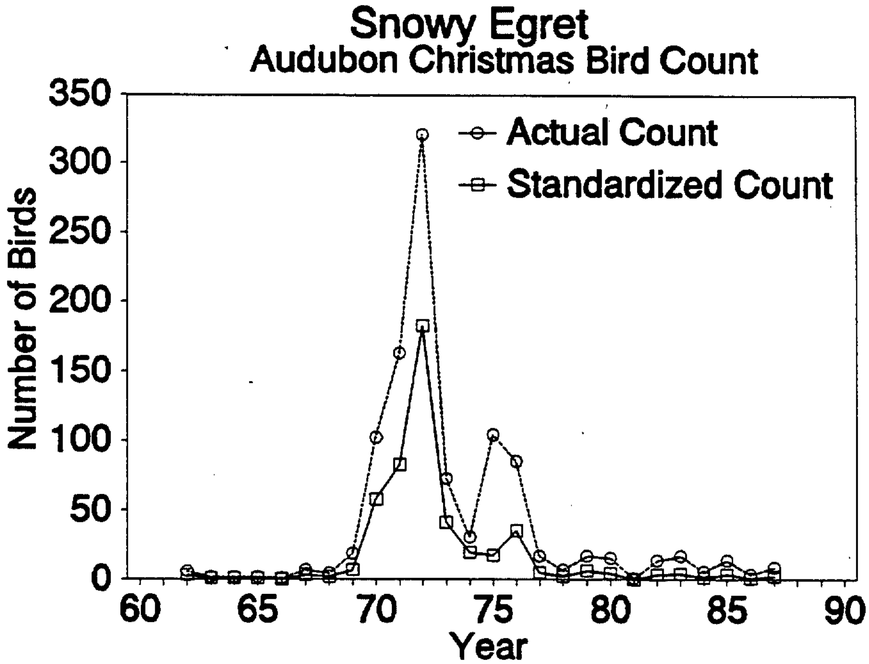


Figure 69

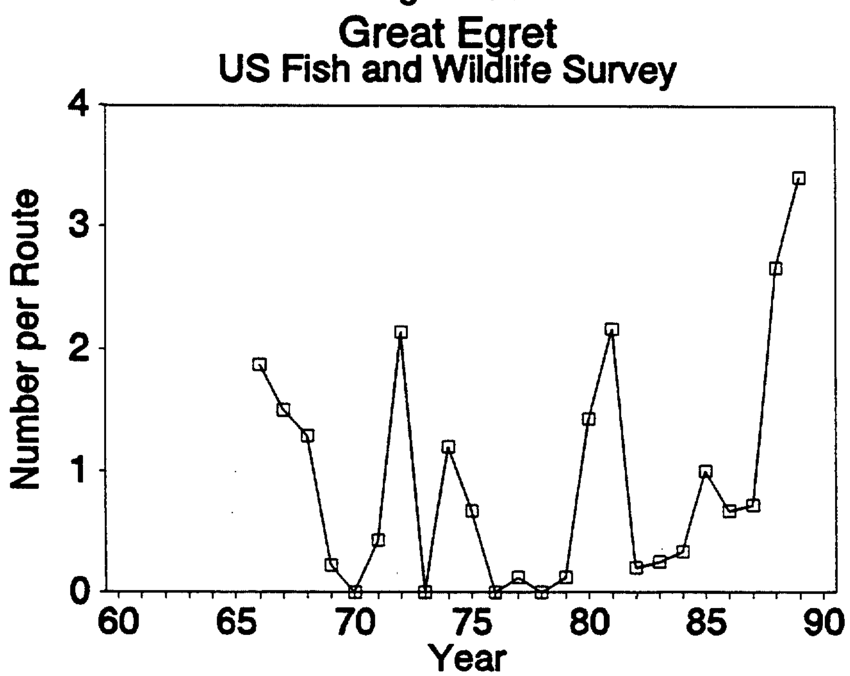


Figure 70

Snowy Egret
US Fish and Wildlife Survey

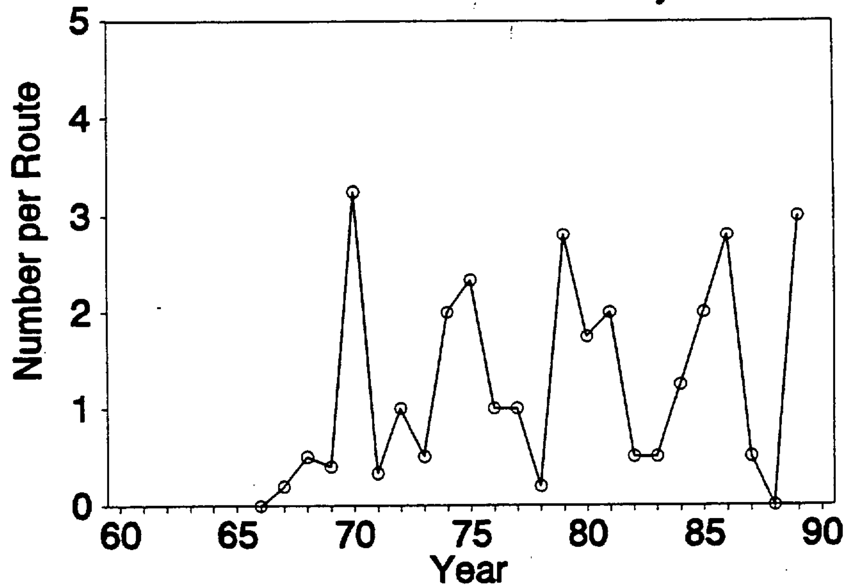


Figure 71

Wood Duck
Audubon Christmas Bird Count

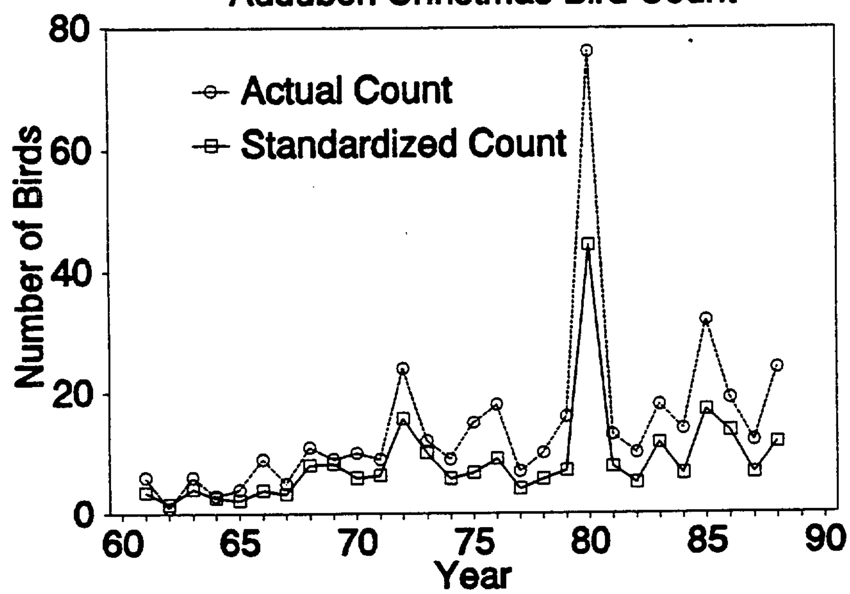


Figure 72

Canvasback Duck

Audubon Christmas Bird Count

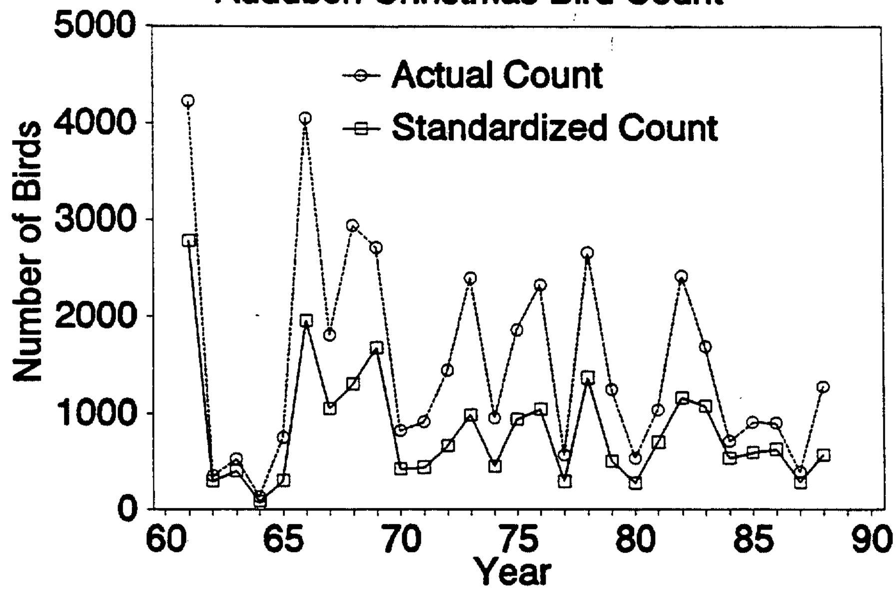


Figure 73

Black Duck

Audubon Christmas Bird Count

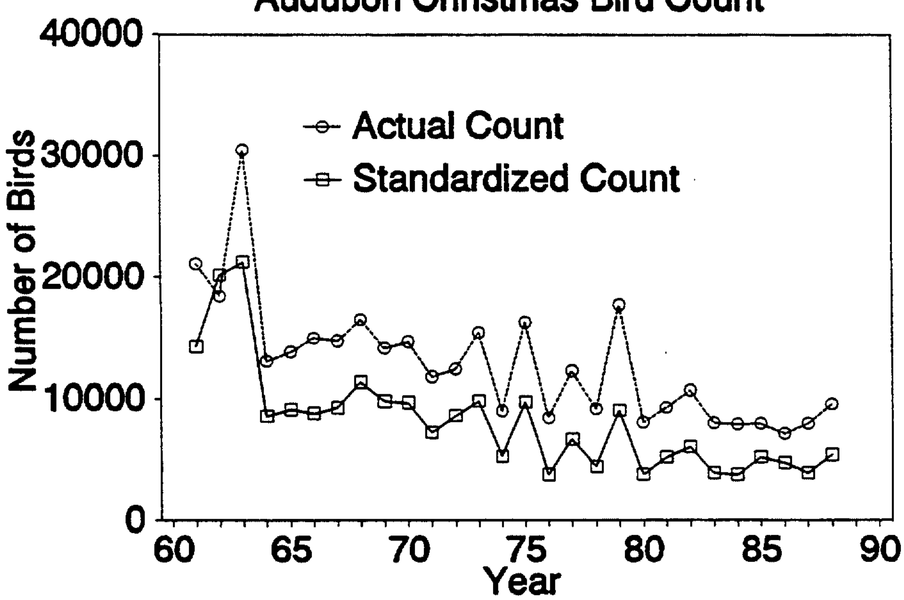
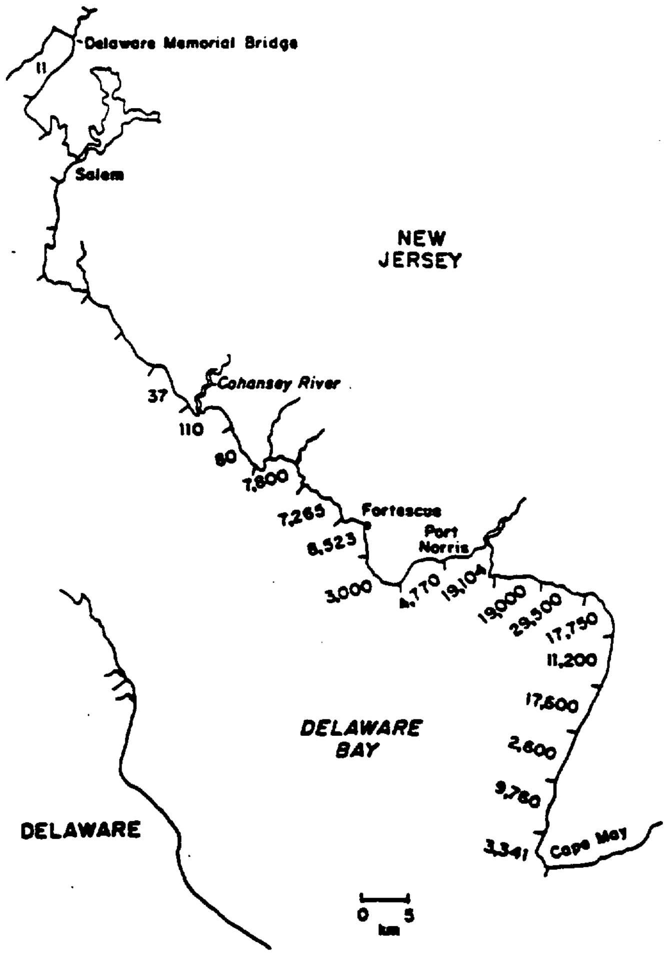


Figure 74

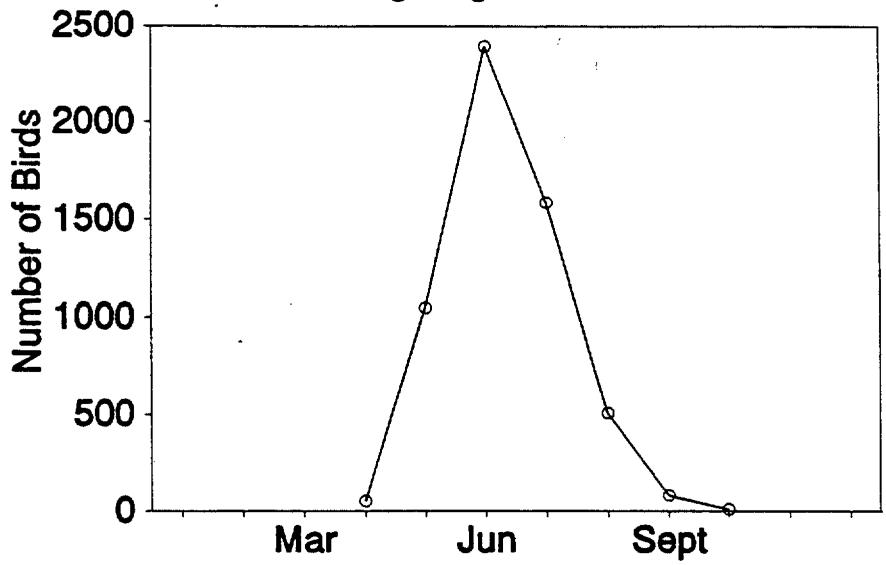


Spatial pattern of gull distribution on Delaware Bay during April-October, 1982. No gulls were counted where there were no numbers shown (from aerial counts).

SOURCE: BURGER AND GALLI (1987)

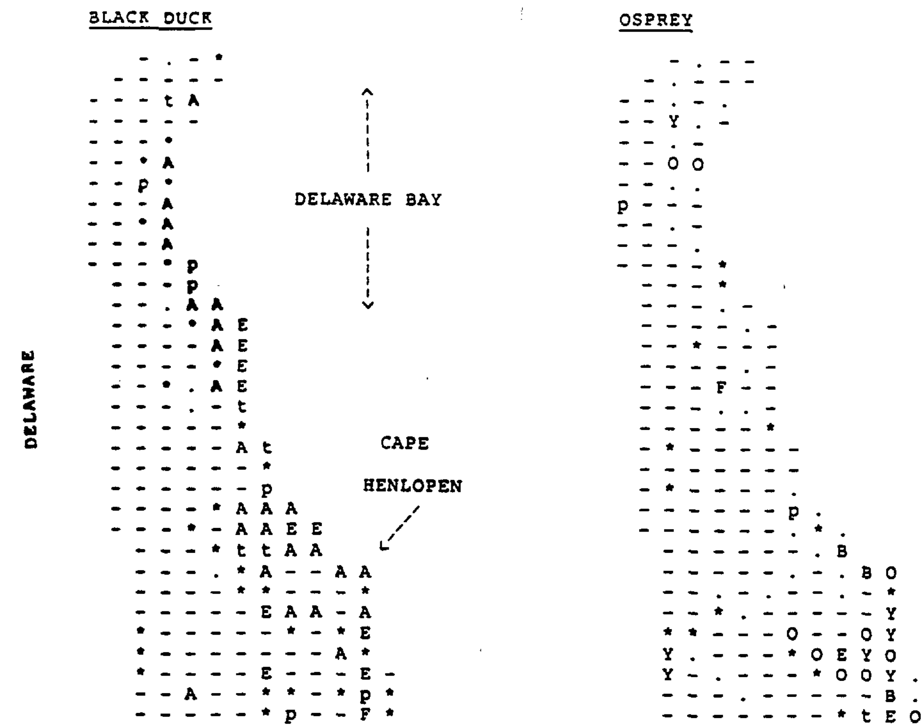
Figure 75

Laughing Gulls



Source: Burger and Galli 1987

Figure 76



Confirmed Breeding:
- A= Attending young
- F= Fledged young
- E= Nest with eggs
- O= Occupied nests
- B= Nest building

Probable Breeding:
- p= Pair observed
- t= Bird on territory(same place on 2 census trips)

Possible Breeding:
- *= Species detected in suitable habitat during breeding season (and outside normal migration or movement periods).

Incidence:
- .= Observed in block, but no breeding evidence

Examples of spatial distribution information available from a breeding bird atlas project conducted in Delaware during 1983-1987. Figure is representitive of the state of Delaware. Each individual block corresponds to one sixth of a U.S. Geological Survey quadrangle (7.5 minute series). Data document incidence of confirmed, probable or possible breeding for each species, within each block.

SOURCE: WEST ET AL. IN PRESS

CONCLUSIONS

This assessment of the key biological resources of The Delaware estuary included representatives of nearly all of the biological communities living in or around the estuary. Despite years of research, ecological science has not yet provided us with the means to rank the biological components of an estuary individually with regard to their relative importance to the whole system. Interactions between communities, let alone between individual species, are largely unknown and may be quite variable depending upon environmental conditions. Without understanding these interactions, every biological community must be considered a key resource.

However, whereas all communities may be ecologically important, all species are not. The species identified here as important are those generally valued by man as having commercial or recreational value, or some aesthetic quality. Specific ecological roles in the estuary are shared and duplicated by a number of species, so that no community or important species is dependent upon a single other species; therefore, we could not specifically identify ecologically key species for the Delaware estuary. The exception may be the dependency of migratory shorebirds on the spring spawning of horseshoe crabs in the lower bay.

For most communities in the Delaware estuary, the existence of specific species is less important than the presence of specific types of species. The types of species desired are parts of food webs that support the commercially or recreationally important species, or those with aesthetic value. Thus, it is probably less important that *Skeletonema costatum* is a dominant member of the winter phytoplankton community, than that diatoms remain the dominant type of phytoplankton in the important winter-spring bloom period. Similarly, it is less important that *Acartia tonsa* remains the dominant zooplankton in the bay, than that the zooplankton continues to be dominated by macrozooplankton, like copepods, instead of microzooplankton, like rotifers. Diatoms and copepods are preferred because a plankton community dominated by these forms is generally thought to support greater secondary production of fish.

Historical changes to the biological resources of the Delaware estuary generally are associated with the activities of man. The overwhelming influence of man on the estuary's biological resources originates from the heavy concentration of urban and industrial activity in the transition and tidal fresh regions of the estuary. Water quality in these regions has changed dramatically during the last 100 years, and these changes are reflected, in the trends for biological resources. Based upon the limited historical information discovered for this review, we expect that further improvements in the water quality of the estuary will continue to be reflected in the recovery of its biological communities.

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