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DELAWARE RIVER NEAR ARTIFICIAL ISLAND
1968 - 1976:
A SUMMARY

SALEM NUCLAER GENERATING STATION

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PUBLIC SERVICE ELECTRIC GAS COMPANY
80 PARK PLACE
NEWARK, NEW JERSEY 07101

MARCH, 1980

April 15, 1980

14092

Dr. Harry Allen, Chief
Water Resources Section
USEPA - Region II
26 Federal Plaza
New York, New York 10007

Dear Dr. Allen:

SALEM NUCLEAR GENERATING STATION
ECOLOGICAL SUMMARY REPORT

We have compiled a report, which we referred to during the last quarterly meeting, entitled "An Ecological Study of the Delaware River Near Artificial Island 1968-1976: A Summary". The report will be used as a reference document for the 316(b) Demonstration for the Salem Nuclear Generating Station.

This report summarizes the preoperational data collected near Artificial Island. The main topics covered are phytoplankton, zooplankton, benthos, blue crab, and 13 species of fish.

If you have any questions on this report, please contact Mr. Mark London (201/430-8036).

Very truly yours,

J. A. Shissias
General Manager -
Environmental Affairs

BJ:jb

Enclosure

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HA4/2

An Ecological Study of the Delaware River near Artificial Island 1968 - 1976: A Summary

Prepared for

Public Service Electric and Gas Company
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Newark, New Jersey 07101

by

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February 15, 1980

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CONTENTS

ACKNOWLEDGEMENTS

This report was written by Ichthyological Associates, Inc., Middletown, Delaware. From the beginning of this Program in mid-1968 through the preparation of this Summary, 261 people have been involved at Ichthyological Associates. Victor J. Schuler has been Project Director during the entire period. This report was assembled by the current Ichthyological Associates staff. They include the following principal scientists who did the data collation and the writing of the various sections:

The Delaware River Estuary: Robert A. Tudor

Physical and Chemical Conditions of the Delaware River near Artificial Island: Robert A. Tudor, Robert G. Howells

Phytoplankton - Detritus: Jason E. Krout

Aquatic Invertebrate Fauna: Gary A. Hayes, Richard A. Connelly, Sarah E. Libourel, Donald P. Schwartz, Robert E. Meadows

Aquatic Vertebrate Fauna: Alvin L. Maiden, Scott J. Beck, Douglas A. Randle, Robert G. Howells, Rebecca A. Sleger, Jason E. Krout, Bruce M. Hashinger, Wolfgang J. Konkel, Andrew B. Carrow

Computation and Analysis: Alan W. Wells, Charles C. Miller, Sandra L. Breitenbach, Della M. Wells, Drusilla R. Abrams, Penny J. Gentry.

Holly Jones and Margaret Dilling typed the transcript.

Dr. Edward C. Raney, IA Director, provided overall guidance to the program.

INTRODUCTION

In early 1968, Public Service Electric and Gas Co. (PSE&G) of New Jersey began construction of Unit I, Salem Nuclear Generating Station (Salem) on the Delaware River in Salem County, N.J. Within weeks, they contracted with Ichthyological Associates, Inc. (IA) for the design and implementation of ecological studies as part of the pre-operational Environmental Monitoring Program (Pre-Op) for the planned facility. Early aquatic studies were range-finding, and communities were sampled with a variety of gear and locations. Fishes were emphasized first, and then the planktons and benthos were added to the Study. When data sufficient for planning were available, appropriately standardized programs were initiated. Terrestrial studies were begun in the early 70's and they too have evolved to specific emphases.

During its term the Pre-Op has identified almost all aspects of the local aquatic and terrestrial ecosystems and has explored those considered most important because of intra-community relationships and commercial or recreational importance. It is unique in its duration and in the continuity toward its basic goals. The resultant data base is massive and is of enormous importance to understanding and managing a complex biological system that experiences often drastic short- and long-term fluctuations. This report is a summary of information and knowledge developed during the Pre-Op and does not presume to totally exhaust the data base. This data base is an information resource invaluable to a better understanding of the complex nature of the Delaware Estuary.

Results during the 9 years of study have been described in annual Progress Reports (Raney et al., 1969; Schuler et al., 1970-1977) and periodic bulletins. Collectively, these reports trace the chronological patterns in abundance and distribution of the fishes, plankton, and benthos which utilize the low salinity portion of the Delaware River. The objective of this summary report is to integrate annual results of the various studies into a definitive characterization of the local aquatic community and to relate this area to the total Delaware River Estuary and its biota. Species composition and seasonal and spatial distribution of the estuarine biota are defined, and pertinent information on the life history of "important species" is summarized.

This report considers only data collected after individual program standardization, typically in 1970. The period of standardized study in each of the sampling programs is described in the individual sections of this report.

SCHEDULE OF STUDY

Sampling through 1969 was concentrated on fishes and macroinvertebrates in the river and local tidal tributaries (Table 1). Age and growth studies of certain locally important fishes were begun. In 1970, all sampling was more quantitative. Scheduled collections were taken biweekly to monthly at established locations, and data were collected to demonstrate seasonal and spatial distributions. In 1971, studies of larval crab, benthos, ichthyoplankton, microzooplankton, and inshore vs. offshore distribution of fishes were added. In 1972 and 1973, studies of terrestrial ecology and phytoplankton were begun. From 1973 through 1976, sampling schedules were similar. Where appropriate, procedures were modified in light of the developing data base but care was taken to maintain program continuity.

Table 1

ARTIFICIAL ISLAND ECOLOGICAL STUDY HISTORY

PARAMETERS SAMPLED	YEARS OF INVESTIGATION								
	1968	1969	1970	1971	1972	1973	1974	1975	1976
FISHES									
Ichthyoplankton				X	X	X	X	X	X
Trawls									
Day	X	X	X	X	X	X	X	X	X
Night		X	X	X	X	X	X	X	X
Simultaneous Seine and Trawl				X	X	X	X	X	X
Creek		X	X	X	X	X	X	X	X
Seines									
River	X	X	X	X	X	X	X	X	X
Creek		X	X	X	X	X	X	X	X
Gill nets		X	X	X	X	X	X	X	X
INVERTEBRATES									
Benthos				X	X	X	X	X	X
Zooplankton	X	X	X	X	X	X	X	X	X
Blue Crab	X	X	X	X	X	X	X	X	X
Larval Crab				X	X	X			
PHYTOPLANKTON						X	X	X	X

THE DELAWARE RIVER ESTUARY

This large Coastal Plain estuary indents the Atlantic coastline between New Jersey and Delaware and extends over 200 km from the Fall Line (boundary between the Piedmont Plateau and Coastal Plain) near Trenton, New Jersey to the mouth of Delaware Bay (Fig. 1). It consists of the upstream narrow river and the wide, shallow Delaware Bay.

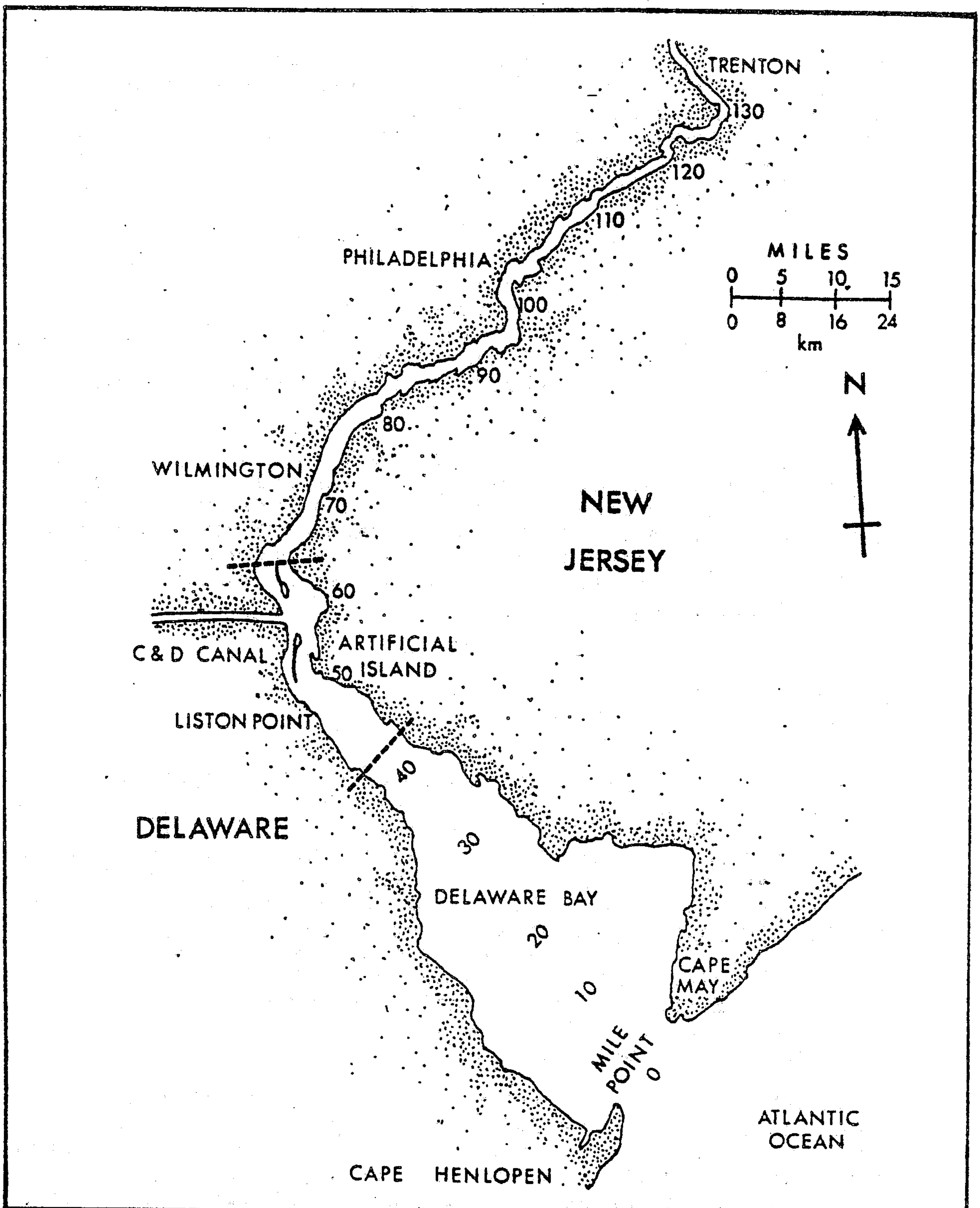
The study area is located in the oligo-mesohaline (0.5-18.0 ppt salinity) reach of the lower River and extends approximately 14 km north and 16 km south of the southern tip of Artificial Island, Salem County, New Jersey (Fig. 2). The Salem station is approximately 80 km from the mouth of Delaware Bay and 3.2 km upriver from the head of the bay which is generally referenced as Liston Point, Delaware (Fig. 1).

The Delaware River in this region is bordered by extensive marshland and occasional small sandy beaches. There is relatively little shoreline development. The closest industrialization begins at approximately 16 km upstream of Delaware City, Delaware and extends to Trenton, and within this region much of the shoreline has been extensively modified and developed.

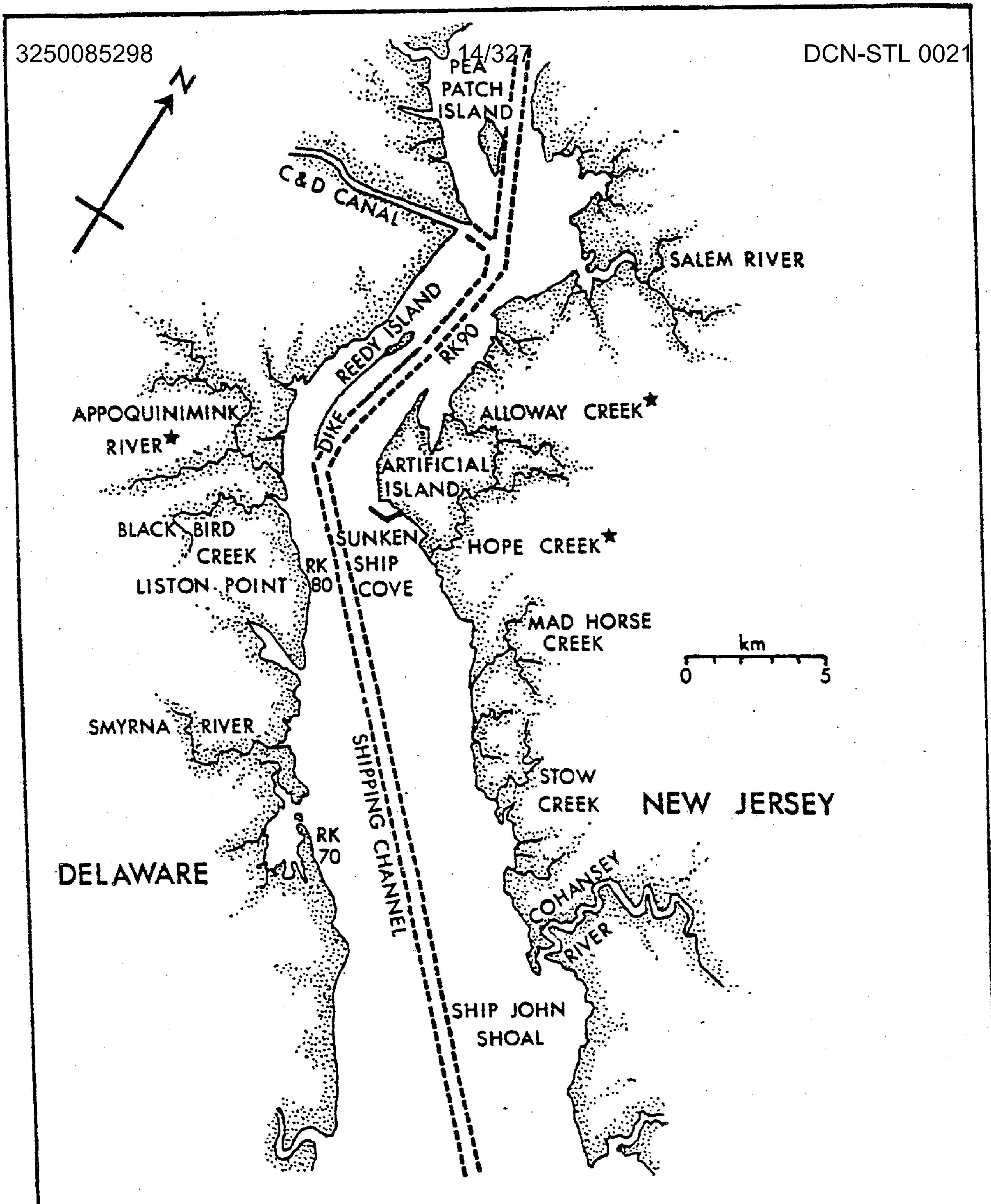
GEOLOGY

The Delaware River Estuary is an excellent example of a drowned river valley (Cronin and Mansueti, 1971). Its shape is closely related to tectonic subsidence, glaciation, and sea level changes which have affected the geology of eastern North America. At the peak of the most recent glacial advance (12-15,000 years ago) what is now the estuary was a relatively narrow freshwater river (Ward, 1958). The estuary was formed as the rising sea level, fed by the melting glaciers, flooded the ancestral Delaware River valley. This process is probably continuing today, resulting in a net landward and upward transgression of the sea over coastal Delaware (Kraft et al., 1974).

Physical processes influencing morphology of the estuary over the short term relative to geologic time include erosion, sedimentation, dredging, and filling. The sediment load carried by the river varies greatly depending on erosion. In the present century human activities associated with agriculture, urban development, highway construction, and channelization have accelerated erosional processes, resulting in increased sedimentation. Sediment deposition



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	The Delaware River Estuary and location of study area.
	Figure 1



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Delaware River reach and local tidal tributaries (★) near Artificial Island in which samples were collected.
	Figure 2

to depths in excess of 1.5 m occurred in a short time near Artificial Island (Homa, 1978). This sediment, in turn, necessitates frequent maintenance dredging. The estuary has been severely modified where it narrows and becomes a river by the dredging of deep channels for shipping. Artificial Island, the site of the Salem and Hope Creek stations, was created early in the twentieth century by deposition of hydraulic dredge spoils in a diked area established around a bar (Annual Progress Report, 1973).

WATER QUALITY

Water quality, in terms of supporting aquatic life, is to a large extent a function of the total oxygen demand of pollutants discharged into the estuary. Oxygen (measured as dissolved oxygen in ppm) is a prerequisite for almost all aquatic life. Trends of dissolved oxygen (D.O.) have varied throughout the present century. They reflect population growth within the Delaware River Basin and variations of depressions in D.O. levels are most pronounced near major municipalities. Kiry (1974), in his historical review of water quality of the Delaware River Estuary, concluded that in the early and middle 19th century the river was in better condition than it is today. This is based on oxygen levels, which during the 1930's and 1940's indicated water quality was at its lowest. Since that time it has improved considerably, due largely to improved sewage treatment in the Philadelphia-Chester, Pensylvania region.

In the river reach between Philadelphia and Chester dissolved oxygen levels still approach zero during the summer (Friedersdorff et al., 1978). However, conditions improve markedly downstream, and in the Delaware River near Artificial Island dissolved oxygen is not considered limiting to aquatic life. Although levels as low as 3 mg/l may occur for short periods when water temperature is highest this reach of the estuary supports an abundant and diverse aquatic community.

HYDROGRAPHY

The hydrography of the Delaware River Estuary is determined principally by the physical shape of the basin, river flow, tidal movements and friction, and climate. Because current, turbidity, salinity, and other physicochemical properties near Artificial Island are controlled or influenced by events and factors occurring beyond the study area boundaries, it is important to characterize the local hydrography in context of the total estuarine system. This is particularly necessary in describing the biology of the study area (and estuary) since changes in composition and abundance of aquatic biota often reflect transitions in the hydrologic and chemical environment.

The Delaware River has a drainage area of 12,765 square miles and its average freshwater discharge into the head of the estuary at Trenton is about 12,000 cfs (AEC, 1973). Mean freshwater flow past Artificial Island is approximately 15,000 cfs. Tidal flow is much greater and ranges from 448,000 to 472,000 cfs. Hence, under average weather and river flow conditions tidal currents are the primary currents in the lower estuary and, for the most part, determine the normal estuarine circulation.

As is typical of most Atlantic Coastal Plain estuaries, tides in the Delaware River Estuary are semidiurnal. The mean tidal range is from 1.3 m at the Bay mouth to 2.0 m at Trenton. Harleman (1966) determined that variation in tidal amplitude with distance along the estuary is due to opposing effects of convergence of the sides of the estuary, which tends to increase the amplitude, and friction, which tends to decrease it. In the vicinity of Artificial Island the normal daily tidal amplitude is 1.8 m. However, variations in water level are highly dependent on local conditions of wind speed and direction. Tides to 4.3 m have been reported during periods of extreme flood and ebb conditions.

The current speed and direction throughout the Delaware River Estuary is also dominated by tide generating forces and, consequently, varies with tidal stage. Non-tidal features such as freshwater runoff, meteorological conditions, and salinity gradients also have effects. River currents are generally directed along the longitudinal axis of the estuary. Maximum surface velocities in the channel off Artificial Island range from 0.9 to 1.4 m/s during flood tide and 0.7 to 1.5 m/s during ebb tide (NOAA, 1977).

Salinity along the length of the estuary varies from freshwater (0.1 ppt) in the tidal river to about 32 ppt at the mouth of the bay. The extent of saltwater intrusion is directly related to tidal height and freshwater flow, but is also affected by mean sea level and local meteorological conditions such as wind stresses on the surface, barometric pressure, and precipitation.

The salinity regime near Artificial Island is primarily a function of the seasonal variation in freshwater discharge. Generally, saltwater intrusion up the estuary is greatest during periods of low flow (June-October) and is least when runoff is greater in late fall and spring. Tide-induced mixing keeps local vertical salinity stratification to a low degree. Generally, an essentially homogenous vertical salinity profile is the case, but occasionally gradients as high as 2 ppt per meter have been observed (EG&G, 1976). The degree of stratification anywhere in the estuary is dependent on both location and tide stage. Cronin et al. (1962) described the Delaware River Estuary as moderately stratified in spring during high freshwater discharge and well-mixed during low flow in summer.

If dissolved oxygen determines if aquatic life can occur, salinity is the primary factor influencing the distribution of estuarine aquatic biota, and aquatic communities often correlate with salinity range. The estuary is generally polyhaline (18-30 ppt) from the mouth up to the vicinity of the Leipsic River (RK 55; RM 34) (Watling and Maurer, 1976), mesohaline (5-18 ppt) from the Leipsic River to around the Smyrna River (RK 70; RM 44), and oligohaline (0.5-5.0 ppt) from the Smyrna River to around Marcus Hook (RK 127; RM 79). The tidal river or limnetic zone (0.0-0.5 ppt) generally extends from about Marcus Hook to Trenton. It should be noted that these "zones" of salinity may be displaced in different directions depending upon freshwater flow, tidal height and stage, and local meteorological conditions. For example, the portion of the river adjacent to Artificial Island is a temporary part of the mesohaline zone during periods of low flow and of the oligohaline zone during all others.

The Delaware River Estuary is extremely turbid. An estimated 1.4 million tons (U.S. Army Corps of Engineers, 1975) of sediment is deposited in the tidal portion of the river each year. As with most large coastal plain estuaries the highest concentration of suspended sediment occurs in the low salinity region (Cronin and Mansueti, 1971). Turbidity generally increases from the head of the estuary downstream to the lower river and upper bay (Kiry, 1974; Acherman and Sawyer, 1972). From this point it decreases as a result of the flocculating effect of saline water and the reduction in strength of river flow associated with the exponential increase in Bay width and crossectional area (Klemas et al., 1974). Wind and wave induced resuspension and redistribution of sediments result in higher turbidity near shore.

CLIMATE

The region has a continental climate which is highly humid, reflecting its proximity to the Atlantic Ocean, Delaware River and Bay, and Chesapeake Bay. Summers are warm and humid and winters are usually mild.

The local climate is primarily controlled by alternating high and low pressure systems, especially in winter. High pressure systems generally bring westerly or northwesterly winds, cooler temperatures, and clearing weather. Low pressure systems bring southerly and easterly winds, warmer temperatures, cloudiness, and rain or snow depending on the season and temperature.

Although the predominant wind direction is from the northwest and west-northwest, winds from these directions are much more frequent in winter than summer. Summer is typified by warm moist air emanating from the south and southwest. Wind velocities are lower in summer than they are in winter. Average windspeed is about 14 kph but winds of 80 to 96 kph have occurred during severe storms.

Maximum daily summer temperature, usually 27-32 C (80's F), is most common in late July. Temperatures higher than 38 C (100 F) occur about once every five to six years. During the coldest part of the year, late January and early February, the normal daily average is 0 C (32 F). Temperatures lower than -18 C (0 F) occur about once every three to five years.

Annual precipitation averages about 112 cm. Precipitation is well distributed throughout the year with more than 7.6 cm generally occurring each month. The driest time is October and November (6.4-7.6 cm) while the wettest is July and August when slightly more than 12.7 cm usually falls. Summer rainfall typically occurs in the form of thunderstorms. Most winter precipitation falls as rain. Seasonal snowfall averages about 53 cm although it can vary greatly between years. Snow is frequently mixed with rain and sleet and seldom remains on the ground more than a few days. Winter precipitation most often comes in general storms that cover a large area and last for several days (USDA, 1970).

Relative humidity is quite high (70 percent). It is generally lowest in February, March, and April and highest in August, September, and October. During the summer the average relative humidity is approximately 75 percent. Fog is frequent and may occur in any month.

PHYSICAL AND CHEMICAL CONDITIONS OF THE DELAWARE RIVER NEAR ARTIFICIAL ISLAND

INTRODUCTION

This section describes temporal trends of environmental parameters regularly measured during biological sampling; water temperature, salinity, dissolved oxygen, and transparency. These, and others such as substrate type, nutrients, current, etc., determine the occurrence and distribution of estuarine organisms. Variations in abundance and activity of ecologically important species relative to abiotic factors are addressed in subsequent sections of this report.

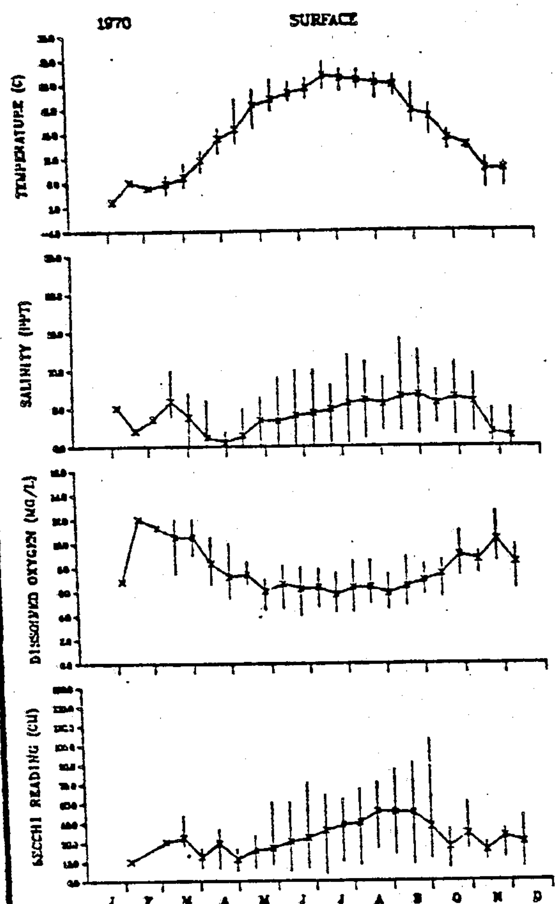
MATERIALS AND METHODS

Surface water samples for physicochemical measurements were collected either with a 9-liter plastic bucket or by placing instrument probes directly in the water. Bottom samples were collected with Kemmerer, Niskin, or Van Dorn water bottles.

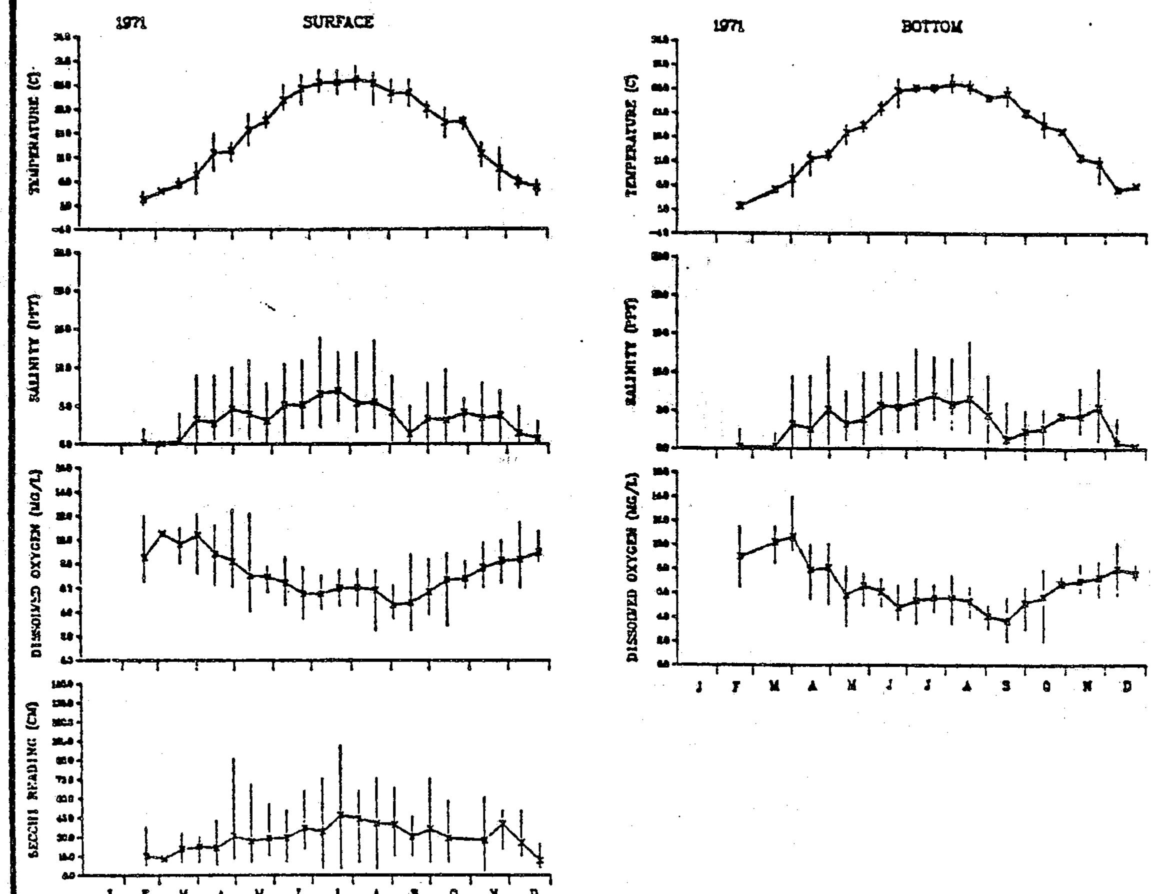
Water temperature (nearest 0.1 C) and dissolved oxygen (nearest 0.1 ppm) were determined with a Yellow Spring Instrument Company Model (YSI) No. 51 dissolved oxygen meter. Air temperature (nearest 0.5 C) was measured with a mercury bulb field thermometer. Salinity, determined from 50 ml of water returned to the lab in a plastic vial, was measured (nearest 0.5 ppt) with an American Optical Corporation refractometer. Water transparency (nearest 2.5 cm) was measured with a Secchi disc. All measurement instruments were regularly calibrated against a known standard.

RESULTS AND DISCUSSION

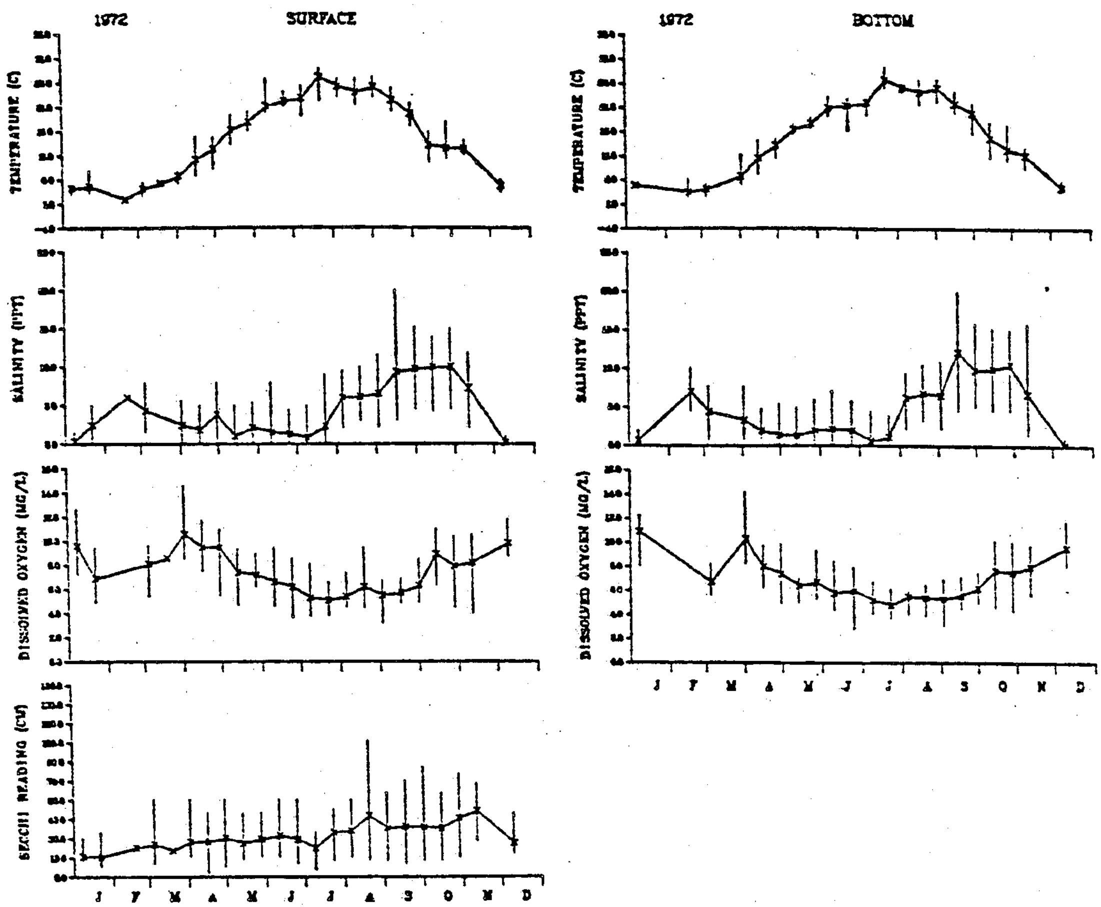
The biweekly mean and range of water temperature, salinity, dissolved oxygen level, and water transparency for 1970 through 1976 are shown in Figures 3 through 9. All reference to mean levels refers to these data. The annual pattern of each of the parameters was generally similar among years. The somewhat anomalous levels of physicochemical measurements in 1972 may reflect effects of Hurricane Agnes.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Biweekly mean and range of physicochemical parameters, 1970 - surface and bottom.
	Figure 3



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Biweekly mean and range of physicochemical parameters, 1971 - surface and bottom.
	Figure 4

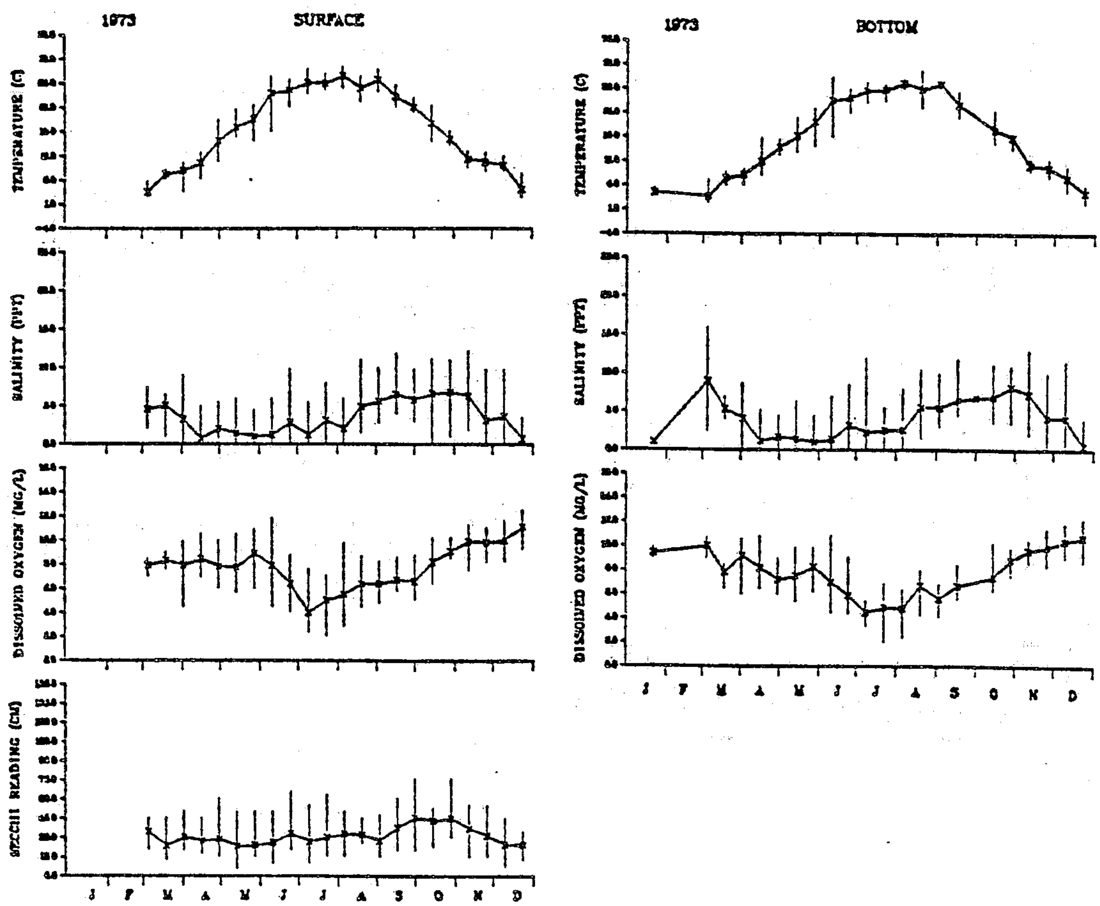


PUBLIC SERVICE ELECTRIC AND GAS COMPANY

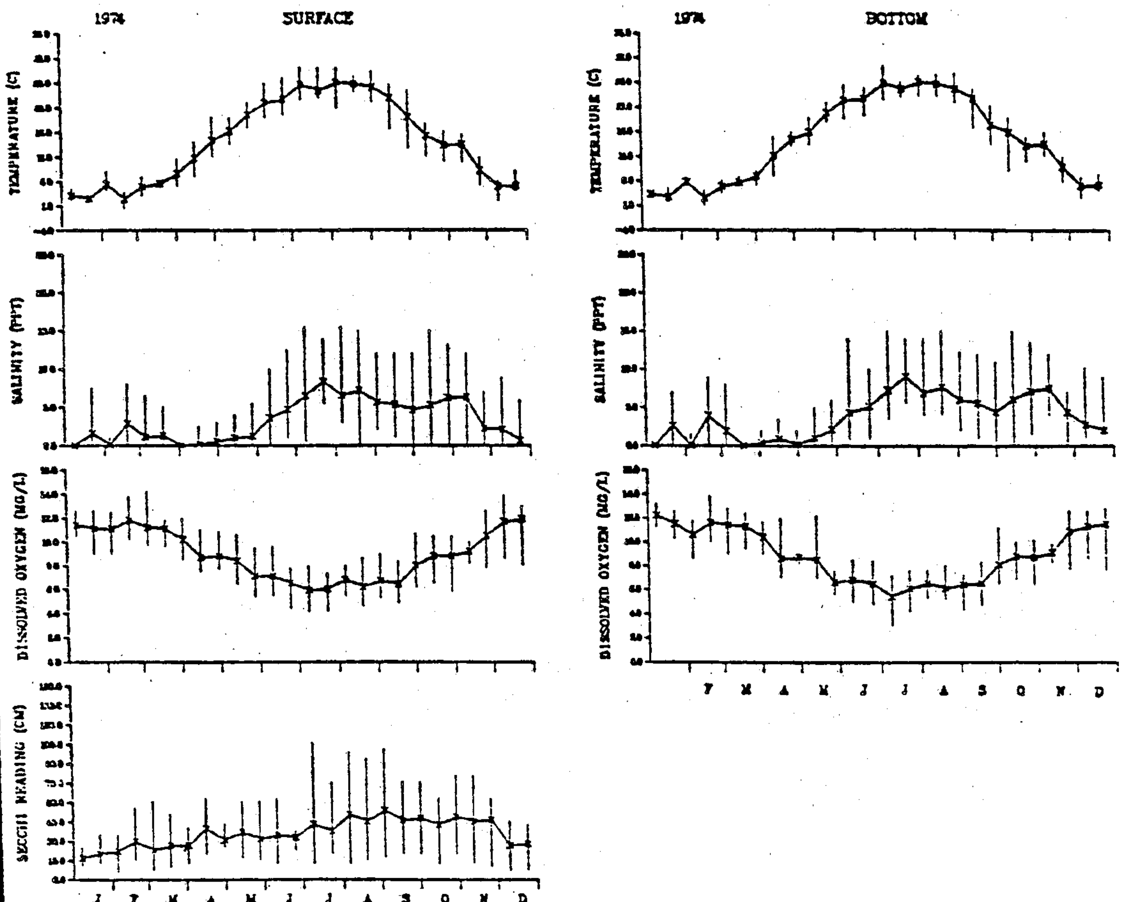
ARTIFICIAL ISLAND STUDIES

Biweekly mean and range of physicochemical parameters, 1972 - surface and bottom.

Figure 5



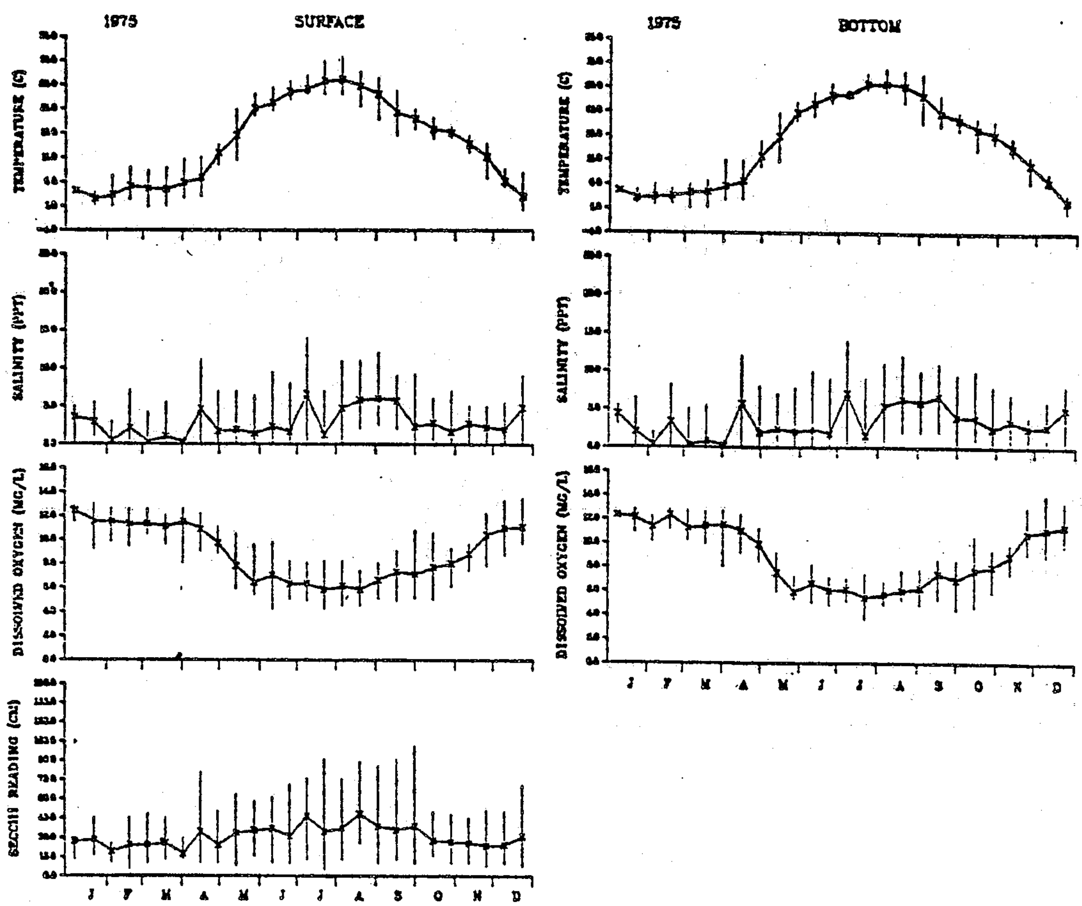
PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Biweekly mean and range of physicochemical parameters, 1973 - surface and bottom.
	Figure 6



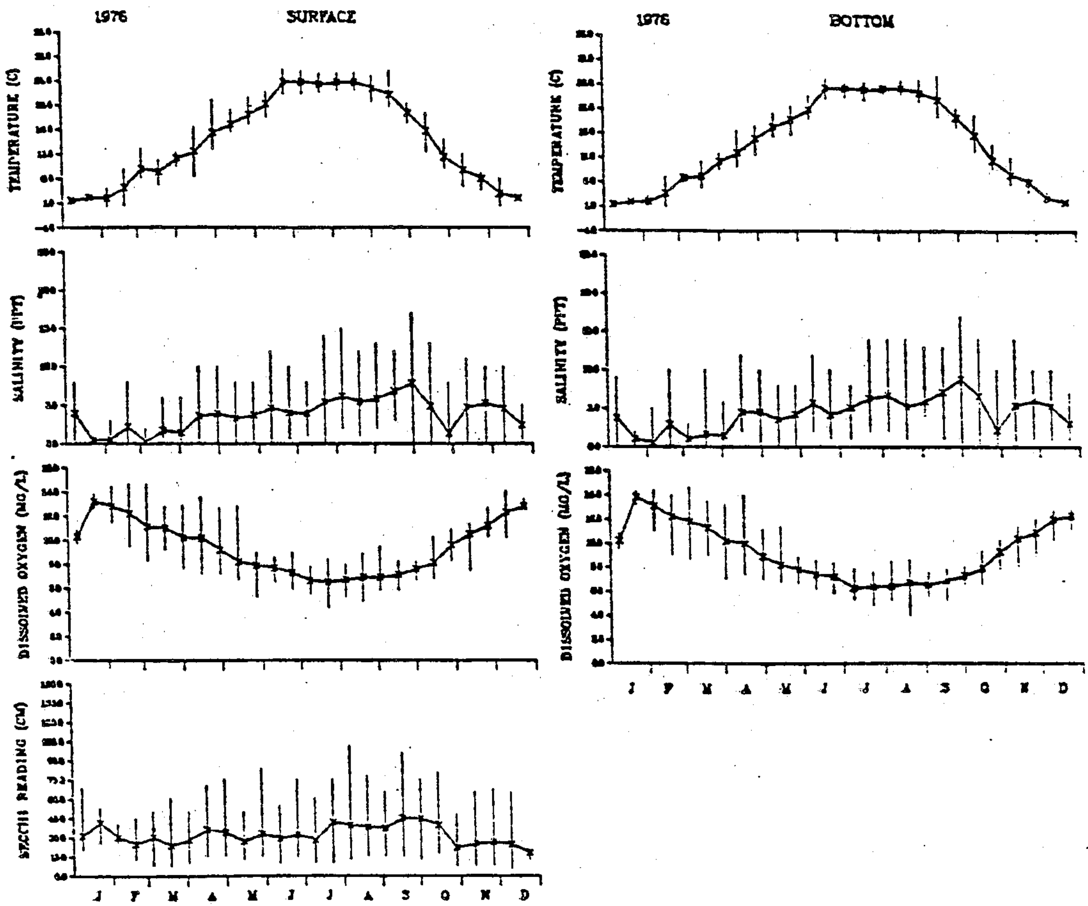
PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ARTIFICIAL ISLAND STUDIES

Biweekly mean and range of physicochemical parameters, 1974 - surface and bottom.

Figure 7



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Biweekly mean and range of physicochemical parameters, 1975 - surface and bottom.
	Figure 8



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Biweekly mean and range of physicochemical parameters, 1976 - surface and bottom.
	Figure 9

Water Temperature

The annual pattern of surface and bottom water temperature was typical of a mid-Atlantic estuary. Annual range was generally from about 0.5 C to 28-30 C. Mean water temperature was typically below 10 C from December through March and exceeded 20 C from June through September.

This reach of the estuary was essentially homothermous throughout the year. Water temperature difference between north and south portions of the study area always was slight. Occasionally, temperature was slightly higher (ca. 1 C) upstream during spring and summer months. Vertical gradients of a few tenths degree centigrade were usually the maximum observed. Occasionally, surface and bottom temperature varied by 1-2 C degrees but such occurrences were neither regular nor predictable. Surface temperature, which reflected short term weather changes earlier and to a great extent, was usually the higher from mid-April through late September. Bottom temperature was the higher from early November through late February or early March.

Biweekly mean water temperature ranged from 1.4 C (January, 1970) to 27.7 C (June, 1976) at the surface and from 1.3 C (January, 1970) to 27.6 C (June, 1976) at the bottom. Discrete measurements ranged from 0.2 C (December, 1975 and February, 1976) to 32.0 C (July, 1976) at the surface and from 0.2 C (December 1975) to 30.0 C (July, 1975) at the bottom. The annual temperature span ranged from 27.0 C (1973) to 31.8 C (1975) at the surface and from 26.0 C (1970) to 29.8 C (1975) at the bottom.

Salinity

Seasonality of the salinity regime is dependent primarily upon the amount of upstream freshwater discharge and the extent of saltwater intrusion from downbay. Mean salinity typically ranged from near 0 ppt during high river runoff in winter and spring to 10-12 ppt during low river runoff in summer and fall. Salinity was most frequently below 3 ppt from December through May and exceeded 6 ppt most frequently from August through October. Salinity was usually higher at bottom than at surface.

Daily salinity differences, both longitudinal and vertical, were more pronounced than temperature differences. Occasionally, gradients to 11 ppt were measured between up- and downstream stations, most often during summer and fall. Vertical differences essentially did not occur from November through March; however, from late April through September differences as great as 2.0 ppt per meter depth occasionally existed (EG&G, 1976). Generally, the salinity profile varied in a gradient fashion, although occasional abrupt increases with depth indicated marked temporary stratification. These conditions often were non-existent several hours later.

Biweekly mean salinity ranged from less than 0.1 ppt (February-March 1971 and January, March-April 1974) to 10.0 ppt (October-November 1972) at the surface and from 0.0 ppt (January 1974) to 12.0 ppt (February 1977) at the bottom. Discrete values ranged from less than 0.1 ppt (January through December) to 20.0 ppt (September 1972) at both surface and bottom. Near zero levels were measured in each of the 12 months but not necessarily during the same years. The annual salinity span ranged from 12.2 ppt (1973) to 20.0 ppt (1972) at the surface and from 14.0 ppt (1971) to 20.0 ppt (1972) at the bottom.

Dissolved Oxygen

Dissolved oxygen (D.O.) level varies seasonally being largely, if not primarily, related to water temperature and salinity. It is also affected by photosynthesis, surface agitation, and municipal and industrial waste discharge. In general, D.O. levels of 9 ppm or greater occurred from late November through late March, the period of low temperature and salinity. Dissolved oxygen to 6 ppm usually occurred from June through September when both salinity and water temperature were high. Only occasionally were levels as low as 2-3 ppm measured, but these were of short duration and appeared not to restrict utilization of the system by aquatic organisms.

Dissolved oxygen concentration was essentially homogeneous. Surface levels were usually higher, but rarely by more than 1.0 ppm, at surface than bottom. Occasionally, D.O. levels were greater downstream than up, reflecting remoteness from upstream urban areas.

Biweekly mean dissolved oxygen level ranged from 4.0 ppm (July 1973) to 13.2 ppm (January 1976) at the surface and from 3.7 ppm (September 1971) to 13.8 ppm (January 1976) at the bottom. Discrete measurements ranged from 2.1 ppm (July 1973) to 14.6 ppm (April 1972 and February-March 1976) at the surface and 2.0 ppm (September 1971) to 14.7 ppm (March 1976) at the bottom. The annual D.O. span ranged from 8.6 ppm (1970) to 11.4 ppm (1972) at the surface and from 8.5 ppm (1970) to 11.4 ppm (1972) at the bottom. The great span in 1972 may reflect effects of Hurricane Agnes.

Water Transparency

Seasonality of water transparency is primarily related to silt and detritus associated with freshwater runoff, but also reflects occurrence of storms, and plankton blooms. Secchi disc reading in this high turbity reach typically ranged from 15 to 76 cm during high river runoff in winter and spring and from 15 to 102 cm at times of low runoff in summer and fall. Mean transparency was usually less than 30 cm from December through February and usually exceeded 38 cm from July through September.

Transparency in upstream portions of the study area was occasionally less than downstream, but these differences were usually slight. Higher readings generally occurred near high tide. Transparency near shorelines, especially over mud and silt bottoms, was often less than in mid-channel areas.

Biweekly mean water transparency ranged from 11.7 cm (December 1971) to 53.1 cm (August-September 1970). Discrete measurements ranged from 2.5 cm (October 1971 and March 1972) to 109.2 cm (September-October 1970). The annual span ranged from 71.1 cm (1973) to 104.1 cm (1971 and 1974).

PHYTOPLANKTON - DETRITUS

INTRODUCTION

Phytoplankton are microscopic plants which live suspended in water, with little or no mobility, and whose distributions are determined largely by local water movements. They are the primary producers and, together with waterborn detritus, form the basis of the local estuarine food web. The study of the phytoplankton was initiated in March 1973 and continued into December 1976. It consisted of pigment, taxonomic, and productivity studies. Seasonal and spatial trends were determined for size, photosynthetic rate, and composition of the standing crop, and for the relative abundance of detritus. This discussion integrates and summarizes annual results.

MATERIALS AND METHODS

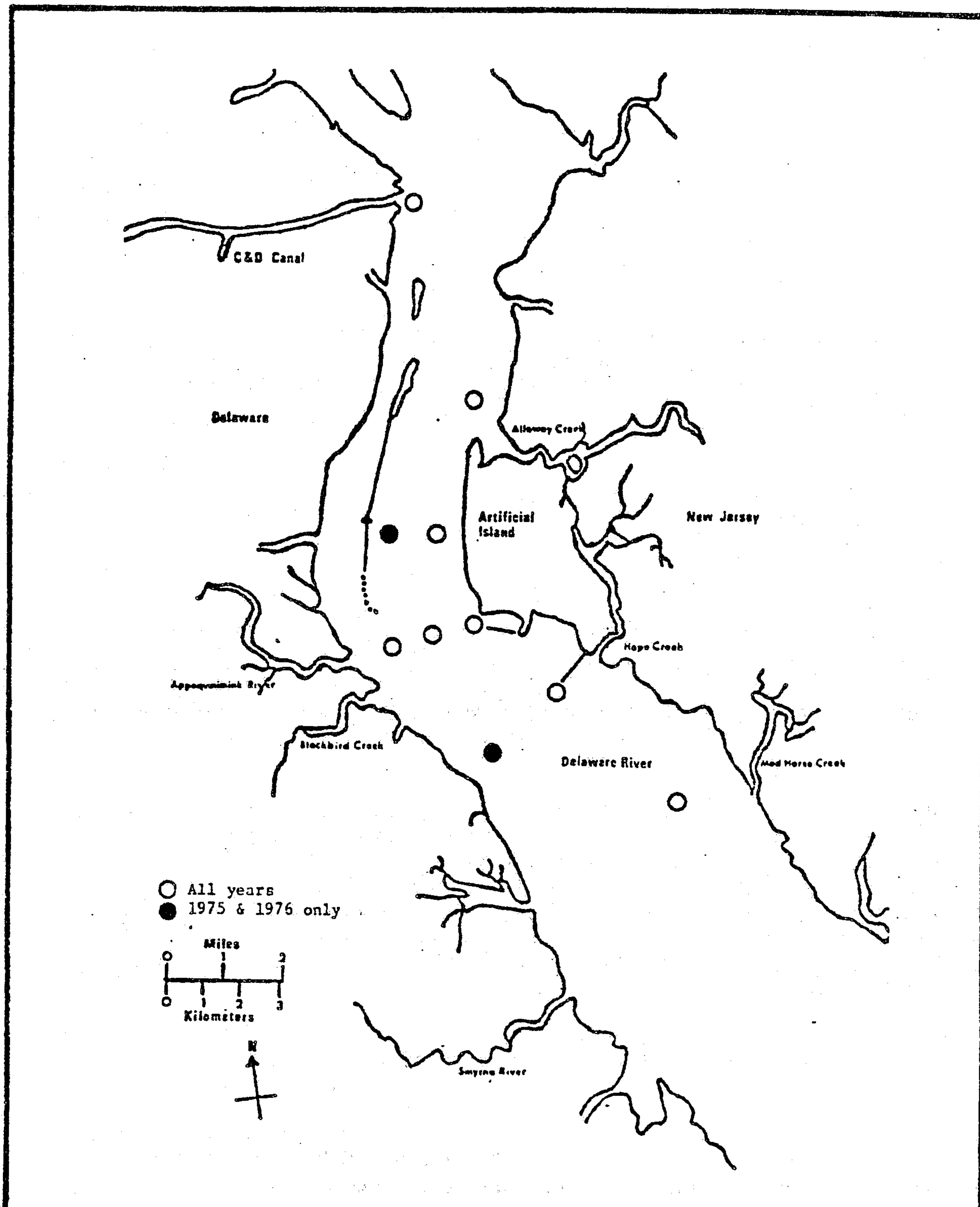
Sampling Schedule

During 1973 through 1976 samples were taken at 8 stations in the study area (Fig. 10). From early 1975 through 1976 two additional stations were sampled to better balance the sampling design. For a complete description of schedules, gear, and procedures refer to the annual Progress Reports. The following is a brief summary.

From July through December 1973 pigment study samples were collected monthly near the surface and/or bottom at all stations, conditions permitting. Beginning in January 1974, two replicate samples were collected at each station biweekly. Additionally, from May through October 1975, samples were taken at ca. 2-hr intervals during a 12-hr period at the three stations on the transect extending west of Salem.

From April through December 1973, qualitative taxonomic study was done on aliquots from surface pigment samples collected at the eastern station on the transect off Salem. Beginning in 1974, aliquots from surface samples collected at the other two stations on the transect were examined for quantitative definition; in 1975 and 1976 aliquots of surface and bottom samples were examined.

Productivity study samples were taken monthly from April through June 1973 at depths of 0.0, 0.5, 1.0 and 2.0 meters



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Phytoplankton sampling stations, 1973-76. Figure 10

at the eastern station on the transect extending west of Salem. Beginning in July 1973 samples were also taken at the western station on the transect; beginning in July 1974 samples were collected bimonthly at both stations on the same day.

Water temperature, dissolved oxygen, salinity, and transparency were measured with each collection.

In the course of additional sampling during July through September 1974 downbay near Ship John Shoal (ca. 17 RK south of Artificial Island), concurrent and comparable pigment and taxonomic samples were taken with those near Artificial Island.

Field and Laboratory Techniques

Sample collection and processing were done with approved equipment and techniques. All samples were collected with an 8.1-liter Van Dorn bottle.

Chloroplyll a and phaeo-pigments were extracted with 90 percent acetone. Light absorption was measured before and after acidification at 665 and 750 nm (after Lorenzen, 1967) on a Bausch & Lomb Model 70 or Perkin-Elmer Colman 46 Spectrophotometer.

Sample aliquots for taxonomic studies were preserved with Lugol's solution (Vollenweider, 1969). Taxa were enumerated to the lowest practicable level, typically genus or species, in a Palmer-Maloney cell with a Nikon (Model SKE) compound microscope at 200X magnification.

Samples for productivity studies were suspended at their collection depths for a 4-hour incubation period, typically between 1,000 and 1,400 hr; oxygen concentration was measured either by Winkler titration (APHA, 1971) or with a B.O.D. probe, and converted to carbon equivalents ($mgC/m^3/hr$).

Data Reduction

Preliminary analysis of the pigment and productivity data indicated that the log 10 transformation was the best mode for further analysis. The best model for expresssing the relationship between log 10 transformed chlorophyll a concentration (1973-1976 data, depths combined) and physicochemical parameters (eg. water temperature and salinity) was selected with a stepwise multiple regression procedure (maximum R^2 option; Barr et al., 1976). Using this model, a contour plot of chlorophyll a distribution as a function of water temperature and salinity was generated. Previous analysis had indicated that secchi disc readings, which are relatively constant throughout the year, did not contribute significantly to the model. A similar model and contour plot were generated for surface net productivity values.

RESULTS AND DISCUSSION

Taxonomic Composition and Relative Abundance

From March 1973 through mid-December 1976 a total of 101 genera representing six divisions was identified in over 300 samples taken at stations on the transect immediately west of Salem (Table 2). These included 43 genera of diatoms (Bacillariophyta), 37 of green algae (Chlorophyta), 10 of blue-green algae (Cyanophyta), 6 of dinoflagellates (Pyrrophyta), 4 of euglenoids (Euglenophyta), and a single genus of yellow-brown algae (Chrysophyta).

Daily phytoplankton density varied almost 20-fold during 1974 through 1976. The lowest density was measured on February 21, 1975 (mean 772 cells/ml; range 552-992 cells/ml); common taxa included the diatoms (93.0 percent of the phytoplankton community), particularly Skeletonema costatum and the genus Melosira, the phyto-flagellates (3.5 percent), and the green algae (3.1 percent). The highest density was measured on May 28, 1976 (mean 14,686 cells/ml; range 9,914-21,708); common taxa included the diatoms (85.1 percent of the phytoplankton community), particularly S. costatum and the genus Nitzschia, the phyto-flagellates (11.6 percent), and the green algae (3.0 percent). However, the annual mean density varied less than 2-fold; it was greater in 1975 (6,405 cells/ml) than in either 1974 and 1976 (3,525 and 5,347, respectively).

The pattern of seasonal change in phytoplankton abundance was similar each year. Mean density was typically low in January and February (range 772-2,033 cells/ml) (Fig. 11). It increased in March (range 2,516-6,024 cells/ml) and peaked as early as April (14,493) in 1976 and as late as July (7,093) in 1974. Mean density fluctuated but generally decreased from August through December (range 1,150-6,932 cells/ml).

TABLE 2

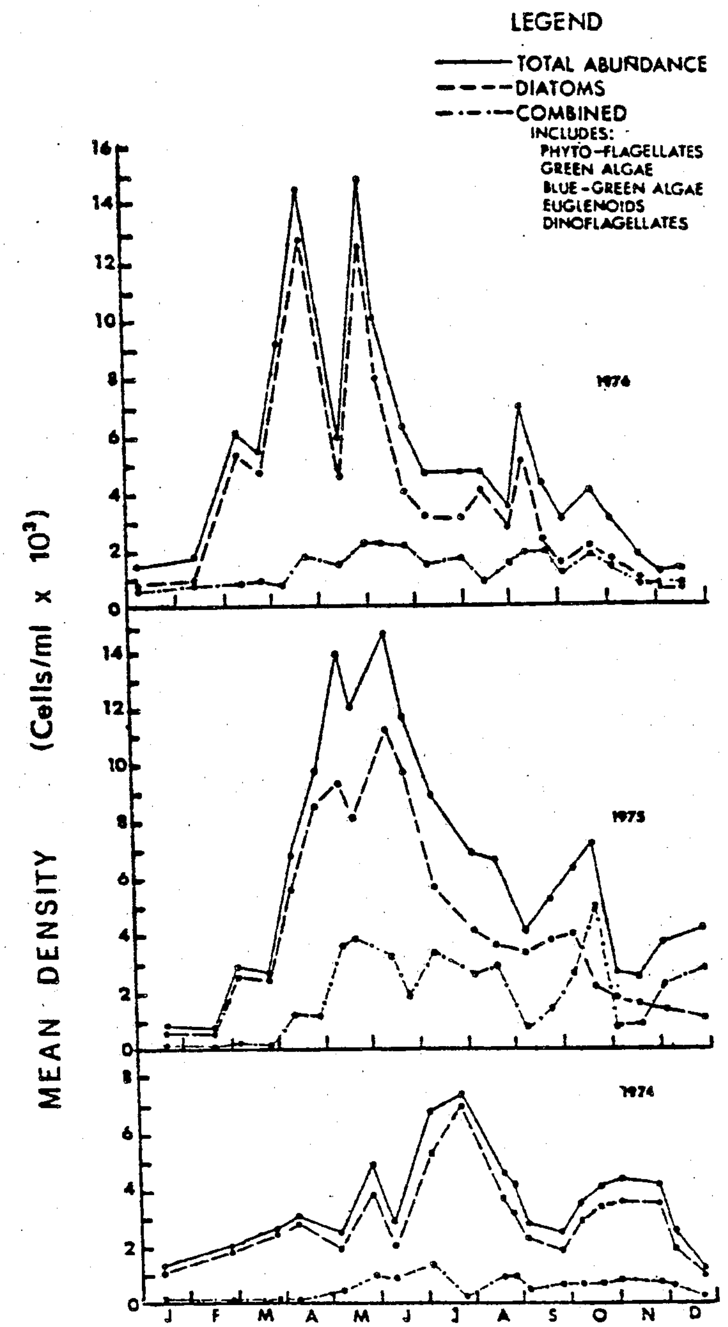
MONTHLY OCCURRENCE OF PHYTOPLANKTON TAXA. NUMERALS INDICATE YEAR(S) OF OCCURRENCE AS FOLLOWS: 3 (1973), 4 (1974), 5 (1975), AND 6 (1976).

Month	January	February	March	April	May	June	July	August	September	October	November	December
CYANOPHYTA (Blue-green algae)												
Agmenellum spp.	-	-	-	-	-	6	4,5	6	-	6	-	-
Anabaena spp.	-	5	5	5	-	4,5	4	-	-	3,4	-	-
Anacystis spp.	6	6	5,6	5,6	4,5,6	5	4,5	4,5,6	4,5,6	4,5*,6	4,5,6	4,5,6
Arthrospira sp.	-	-	-	5	5	-	-	-	-	-	-	-
Dactylococcopsis sp.	-	-	-	-	-	-	-	5	-	-	-	-
Gloeotrichia sp.	-	-	-	-	-	5	-	-	-	-	-	-
Gomphosphaeria spp.	-	-	-	5,6	5	5	-	-	-	5	-	-
Lyngbya sp.	-	-	-	-	5	-	3	4	-	-	-	-
Oscillatoria spp.	5,6	5,6	4,6	3,5,6	4,5,6	4,5	3,4,5	3,4,5,6	3,4*,5,6	3,4,5,5	4,5*,6	3,4,5,6
Spirulina sp.	-	-	-	-	-	-	-	-	-	6	-	-
Unidentified colonies	-	-	-	5	6	-	-	5,6		-	-	-
Unidentified filaments	5,6	6	5,6	5	5,6	5	5	4,5	5,6	4,5	5,6	5,6
CHLOROPHYTA (Green algae)												
Actinastrum hantzschii	-	-	-	-	4,6	5,6	3,5	5	5	5	5	-
Ankistrodesmus falcatus	5,6	5,6	5,6	3,5,6	3,4*,5,6	3,4*,5,6	3,4*,5,6	3,4*,5,6	4*,5,6*	3,4*,5,6*	3,4*,5,6°	4*,5,6*
Botryococcus braunii	-	-	-	-	-	-	-	-	-	-	6	-
Characium sp.	-	-	5	-	-	-	-	-	-	-	-	-
Chlamydomonas spp.	-	5,6	5,6	5	5	5	5*,6	4,5*,6	5,6	4,5*,6	4,5,6	4,5*,6
Chlorella vulgaris	-	-	-	-	6	-	4	-	6	4	-	-
Chlorella spp.	4,5	4	3,4,5,6	4,5,6	3,4,5,6	3,4,5,6	3,4,5	3,4,5	4,5,6	3,5,6	3,4,5,6	4,5
Cladophora sp.	-	-	-	-	4	-	-	-	-	-	-	-
Closteriopsis longissima	5	-	-	-	-	-	-	-	-	-	-	-
Closterium sp.	-	-	-	5	5	3	-	-	-	5	-	5
Crucigenia quadrata	-	5	-	-	5	5	-	-	-	4	4,5	-
C. rectangularis	-	-	-	-	5	-	-	-	-	4	-	-
C. tetrapedia	-	-	-	-	5	5	6	5,6	6	4	-	5
Crucigenia spp.	-	-	-	4	3,5	5,6	4,5,6	5	5	4,5	5,6	5
Dactylococcus sp.	-	-	-	-	-	-	-	-	-	-	-	5
Dictyosphaerium pulchellum	-	-	6	5,6	5,6	4,5,6	5,6	4	4	5,6	4,5,5	4
Desmidium sp.	-	-	-	-	-	-	-	-	6	-	-	-
Dimorphococcus sp.	-	-	-	-	-	-	-	-	-	-	5	-
Eudorina sp.	-	-	-	5	-	-	-	-	-	-	5	-
Franceia droescheri	-	-	-	-	5	-	5	4	-	-	-	-
Franceia sp.	-	6	-	-	5	5	-	-	-	5	6	5
Gloeocystis sp.	-	-	-	5	5	5	5	5	5	5	5	5
Golenkinia radiata	-	-	-	-	6	-	6	4	-	-	5	-
Golenkinia sp.	-	-	-	5	4	4	-	4	-	-	-	-
Gonium sp.	-	-	-	-	-	-	-	-	-	5	-	5
Hydrodictyon sp.	-	-	-	-	-	-	-	-	-	5	-	-
Kirchneriella sp.	-	-	-	-	-	3	-	-	-	-	-	-
Lagerheimia quadriseta	-	-	6	-	-	-	-	-	-	-	-	-
L. subsalsa	-	-	-	-	-	-	-	-	6	-	-	-
Lagerheimia sp.	-	6	-	5	5,6	5	6	4,6	-	5	5	5,5
Micractinium sp.	-	-	-	-	5	5	-	-	-	-	6	5
Oedogonium sp.	-	-	-	-	5	-	-	-	-	-	-	-
Oocystis spp.	-	-	-	5	5	5	-	5,5	5	5	5	-
Pediastrum boryanum	-	-	-	-	4	-	-	-	-	-	6	-
P. duplex	-	5	5	-	4	5	4,6	-	5	5	5	4
P. simplex	-	-	-	-	4	-	4	-	-	-	5,5	5
P. tetras	-	-	-	-	-	-	5	-	-	-	4	-
Pediastrum spp.	-	-	-	5	5,5	3	3,4,6	3	-	-	-	4
Scenedesmus abundans	-	6	5	5,6	5,5	5	5	5	5	5	5,6	5
S. acuminatus	-	-	5	-	-	5	-	-	-	-	4	5
S. armatus	-	-	-	4	5	5	-	-	-	-	4	5
S. bijuga	-	5	-	-	5	5	5,6	5	6	-	5	4
S. dimorphus	-	-	5	-	4,5,6	6	-	4	4	4,5	6	4,6
S. obliquus	-	-	-	-	4	4	-	4,6	-	6	-	-
S. quadricauda	5,6	5	5,5	5,6	4,5,6	4,5,6	4,5,6	4,5,6	4,5,5	4,5,5	4,5,5	4,5,5
Scenedesmus spp.	6	-	5	3,5,6	3,4,5,5	3,4,5,5	3,4,5,5	3,4,5,6	3,5,5	4,5,5	5,5	5,5
Schroederia judayi	-	-	-	-	4	4	5	5	-	-	-	-
Schroederia sp.	-	-	-	-	-	-	-	5	-	5	-	5
Selenastrum sp.	-	-	5	-	-	4	-	-	-	-	5	5
Sorastrum sp.	-	-	-	-	-	5	-	-	-	-	6	-
Sphaerocystis sp.	-	-	-	5	-	-	-	-	-	5	-	5
Staurastrum sp.	-	-	-	-	5	-	-	-	-	-	5	5
Tetraedron caudatum	-	-	-	-	6	-	-	-	-	-	-	-
T. elegans	-	-	-	-	-	-	-	-	-	-	6	5
T. minimum	-	-	-	-	-	-	4	4	-	-	-	-
T. regulare	-	-	-	-	5	5	-	-	-	-	4	-
T. trigonum	-	-	-	-	-	5	-	-	6	5	-	-
Tetraedron spp.	-	-	-	-	5	5	5,6	5	6	5	6	5
Tetrastrum elegans	-	-	-	-	6	-	-	-	-	4	4	4
T. staurogeniaeforme	-	-	-	-	-	-	-	-	-	-	5	6
Tetrastrum sp.	-	-	-	-	-	5	-	-	-	-	-	-
Treubaria sp.	-	-	-	-	-	-	-	4	6	-	-	-
Ulothrix sp.	5,5	6	-	5	5°	3,4,5	3,5	3	3,4	3	3,4	2,4
[illegible] sp.	-	-	-	-	4	3,4	-	-	-	-	-	-
Unidentified colonies	-	-	5	5,6	5	5,5	5,5	5,5	5,5	5	5,5	5
Unidentified filaments	-	5	-	5	4,5	4,5,6	4,5	5	4,5,5	5	5	5

TABLE 2
CONTINUED

Month	January	February	March	April	May	June	July	August	September	October	November	December
EUGLENOPHYTA (Englenoids)												
Euglena spp.	-	-	5	4,5	4,5,6	5,6	4,5	4,5,6	4,5,5	4,5,6	4,5,6	4,5,6
Lepocinclis spp.	-	-	-	-	6	-	-	-	-	-	-	6
Phacus spp.	-	-	5	5	-	4	4,5	4,5,6	4,5	4,5	4,5	4,5
Trachelomonas spp.	-	-	5	5	5	5,6	5,6	5	5	5,6	5,6	4,5
CHRYSOPHYTA (Yellow-brown algae)												
Dinobryon sp.	-	-	6	-	4	-	-	-	-	-	-	-
BACILLARIOPHYTA (Diatoms)												
Centric												
Biddulphia spp.	4,5	4	3,4,5	-	-	-	4,5	5	3	5	4	5
Chaetoceros affinis	-	-	-	-	-	-	-	4	4	4	4	4*
Chaetoceros spp.	5	-	5	5	4,6	4,5,6	4,5*,6*	3,4,5*,6	3,4,5,6	3,4,5,6	4*,5,6*	4*,5,5
Coscinodiscus lineatus	-	-	-	-	4	-	4	-	-	4	-	-
C. marginatus	-	-	-	4	-	-	-	-	-	-	-	-
C. radiatus	-	-	5	-	4	4	-	-	-	-	-	-
Coscinodiscus spp.	4,5,6	4,5,6	3,4,5,6	3,4,6	4,5,6	3,4,5	3,4,5,6	3,4,5,6	3,4,6	3,4,5,6	3,4,5,6	3,4,5,5
Cyclotella spp.	4*,5*,6	4*,5,6	3,4,5,6*	3,4,5,6*	3,4*,5,6*	3,4,5,6	4,5,6	4,5,6	4,6	4,5,6	4,5,6	3,4,5,6*
Ditylum brightwellii	-	-	-	6	-	-	-	-	-	4	-	-
Melosira granulata	5*	5*	4,5	4*	4*	4*	4	6	-	4	4	4*
M. sulcata	-	6	4	4*	4*	-	4	4	-	4	4	4,6
Melosira spp.	4*,6*	4*,5*,6*	3,4*,5*,5	3,4*,5,6	4*,5*,6	3,4*,5,6	3,4,5,6	3,4,5,6	3,5,6	3,5,6	3,5*,6*	3,5*,6*
Rhizosolenia setigera	-	-	6	-	-	-	-	-	-	-	-	-
Rhizosolenia spp.	-	5	3,4,5,6	6	4,5	4	-	-	5	-	4,6	4,5
Skeletonema costatum	4*,5,6*	4*,5*,6*	3,4*,5*,6*	4*,5*,6*	4*,5*,6*	4*,5*,6*	4*,5*,5*	4*,5*,6*	4*,5*,6*	3,4*,5*,5*	3,4*,5*,5*	3,4*,5*,5*
Stephanodiscus spp.	-	-	-	-	4	4	4	4	4	6	4	4
Thalassionema spp.	-	-	-	5	-	-	-	-	-	-	-	-
Thalassiosira spp.	6	5*,6	5,6	5,6	-	-	-	6	4,5,6	4,6	4,5,6	6
Pennate												
Achnanthes sp.	4,5,6	4,5,6	3,4,5*,6	3,4*,5,5	3,4*,5,6	3,4,5	3	-	-	-	4,6	3,4*,5,6
Asterionella formosa	4,5,6	4,5,6	3,4,5*,6	3,4*,5,6	3,4*,5,6	3,4,5	3	-	-	-	4,6	3,4*,5,6
Asterionella japonica	-	5	6	6	4	-	-	-	-	-	4	4,5
Amphiprora spp.	5	5	5	5	5	5	5	5	5	5	5	5
Amphora sp.	-	4	4	4,5	-	-	-	-	-	-	4	-
Campylodiscus sp.	-	-	3,5	-	-	-	-	-	-	-	-	3,5
Cocconeis spp.	4*,5	4,5	3,4	3,4,6	4,5	5	3	4,5	-	5	4,5,6	4
Cymbella spp.	4,5	5	3,4,5	4,6	4,5	4,5	5	5	5,6	5	4,5,6	4,5,5
Denticula sp.	-	-	-	5	-	-	5	-	-	5	-	-
Diatoma vulgare	-	-	-	4	-	-	-	-	-	-	-	-
Diatoma spp.	5,6	6	3,5	5,6	4,5	4,5	4	6	-	-	5	3,5
Diploneis spp.	5	5	-	5	4,5	3,5,6	3	-	-	-	5	5,6
Epithemia sp.	-	4	-	-	-	-	-	-	-	5	5	-
Eunotia sp.	6	6	5	5	5	-	-	-	6	-	-	-
Fragilaria crotonensis	5	-	-	4	-	-	-	-	-	-	-	6
Fragilaria spp.	4,5,6	4,5,6	3,4,5,6	5,6	3,4	3,4,5	3,4	4,6	3,6	5	3,4,5	4,6
Frustulia rhomboides	-	-	-	-	-	-	-	6	-	-	-	-
Frustulia sp.	-	-	-	-	3,6	3	-	6	-	-	-	-
Gomphoneis sp.	-	-	3	-	-	-	-	-	-	-	-	-
Gomphonema spp.	5	-	-	4,5	4,5	-	5	-	5	5	-	-
Grammatophora sp.	-	5	-	-	-	-	-	-	-	-	-	-
Gyrosigma spp.	4	4,5,6	4,5,6	6	4,5	6	4	4,6	-	4	3,4,6	4,6
Hantzschia spp.	5	-	4,5	4,5	4,5	4,5	3,4	4	4,6	5,6	4,5	5,6
Mastogloia sp.	-	-	5	-	5	5	-	-	-	-	-	-
Meridion spp.	-	-	3,4,5,6	5,6	4	4	-	4	5	-	6	-
Navicula spp.	4*,5,6	4*,5,6	3,4*,5,6	3,4*,5,6	3,4*,5,6	3,4,5,6	3,4,5,5	3,4,5,5	3,4,5,6	3,4*,5,6	3,4,5	3,4,5,5
Nitzschia closterium	-	-	-	4	-	-	-	4	4	4	4	-
N. linearis	-	-	-	-	4	-	-	-	-	-	-	-
N. longissima	5	-	4	4	-	4	4	-	4	4	4	4
N. palea	-	-	-	4	4	4	-	4	-	-	-	-
N. pungens	-	-	-	-	4	-	-	-	4	4	4	4
Nitzschia spp.	4*,5,6	4,6	3,4,5,6	3,5,6	3,4,5,6*	3,4,5,6*	3,4,5,6	3,4,5,6	3,5,6*	3,5,6*	3,4,5,5	3,4,5,5
Pinnularia spp.	4	4	3,5	4,5	4,5	-	-	-	5	3,4	5	3,5
Plagiogramma sp.	-	-	-	-	-	-	-	-	-	5	-	-
Pleurosigma spp.	-	4	4,5	-	-	-	-	4	5	-	-	4,5
Rhaphoneis spp.	5	4,5	4,5	5,6	4,5	4	4	4,5	-	4,5,6	4,5,6	4,5
Rhoicosphenia curvata	-	6	-	-	-	-	-	-	-	6	-	-
Surirella spp.	5	5	5,6	4,5,6	4,5	-	-	-	6	3,4	4	6
Synedra spp.	4,5,6	5,6	3,4,5,6	3,4,5,6	3,4,5,6	3,4,5,6	3,4,6	4,6	4,6	4,5	5,6	4,6
Tabellaria fenestrata	6	4,6	4,6	4,6	4,6	4	4	-	-	-	-	6
Tabellaria spp.	6	-	3	3	3,5	3	-	4	-	-	6	3
Thalassiothrix spp.	-	-	-	4,5	4	-	-	-	-	-	5	5
PYRROPHYTA (Dino-flagellates)												
Amphidinium sp.	-	-	-	-	-	-	-	-	-	-	-	6
Ceratium sp.	-	-	-	-	-	-	-	-	-	5	-	-
Glenodinium sp.	-	-	-	-	-	-	-	-	-	4	-	-
Gymnodinium spp.	-	6	4,5	-	4,6	4,6	6	4,5	3,5	6	6	-
Gyrodinium spp.	-	-	-	-	-	-	-	-	-	-	5	-
Peridinium spp.	-	-	-	-	4	4	4	-	-	-	5	-

* Dominant taxa (≥5% of the total mean density).



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Semimonthly mean density of total phytoplankton, diatoms, and combined taxa.
	Figure 11

Seasonal distributions of diatoms and total phytoplankton were closely parallel (Fig. 11). Diatoms were the most abundant (68-83 percent) constituent of the community throughout each year; mean density ranged from 2,930 to 4,365 cells/ml (Fig. 12). Skeletonema costatum, a chain-forming diatom that inhabits brackish and marine waters, was the most abundant phytoplankton species. It comprised 49 to 57 percent of each annual community; mean density ranged from 1,739 to 3,184 cells/ml. Seasonal distribution of S. costatum was similar to that of total diatom density (Fig. 13). It has also been abundant or dominant in lower Delaware Bay (Watling et al., 1979), Chesapeake Bay (Mulford, 1972), and in oligohaline waters of the Chesapeake and Delaware Canal (Krout and Unruh, 1976).

Other diatom genera, particularly Melosira, Cyclotella, Navicula, Nitzschia, Synedra, and Coscinodiscus occurred throughout each year (Table 2). Asterionella and Chaetoceros occurred annually in different seasons.

The phyto-flagellates, which could not be identified due to condition of specimens subsequent to preservation, annually comprised 2 to 19 percent of the phytoplankton community, with mean density ranging from 73 to 1,016 cells/ml. These probably include green algae, yellow-brown algae, dinoflagellates, and cryptomonads (unicellular flagellates).

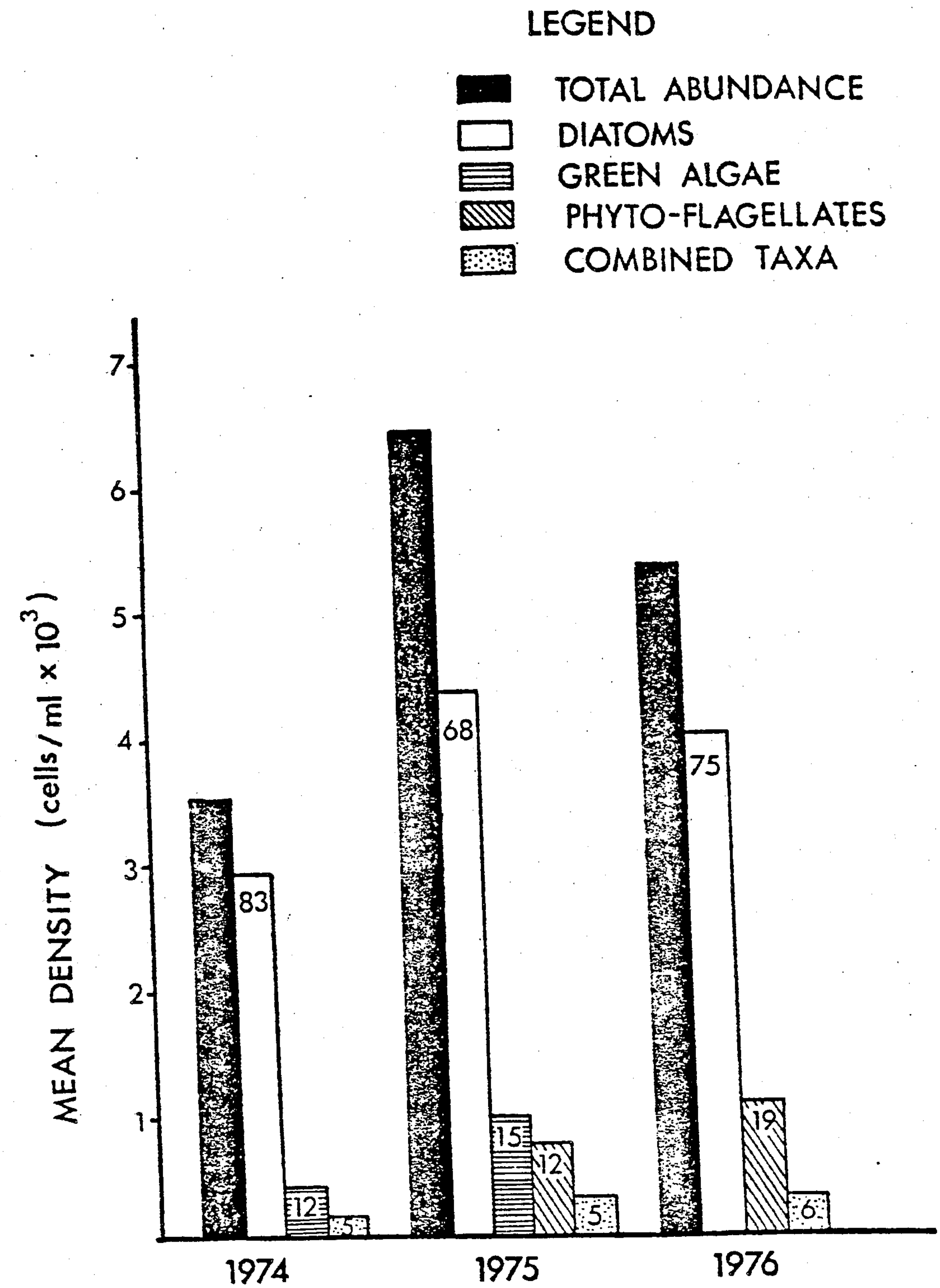
The green algae annually comprised 5 to 15 percent of the community, with mean density ranging from 267 to 966 cells/ml. Ankistrodesmus, Chlamydomonas, and Scenedesmus, the most abundant genera, were usually present throughout the year.

The blue-green algae annually comprised only 1 to 4 percent of the phytoplankton community, with mean density ranging from 41 to 247 cells/ml. Oscillatoria and Anacystis were the most abundant genera; they generally occurred throughout the year.

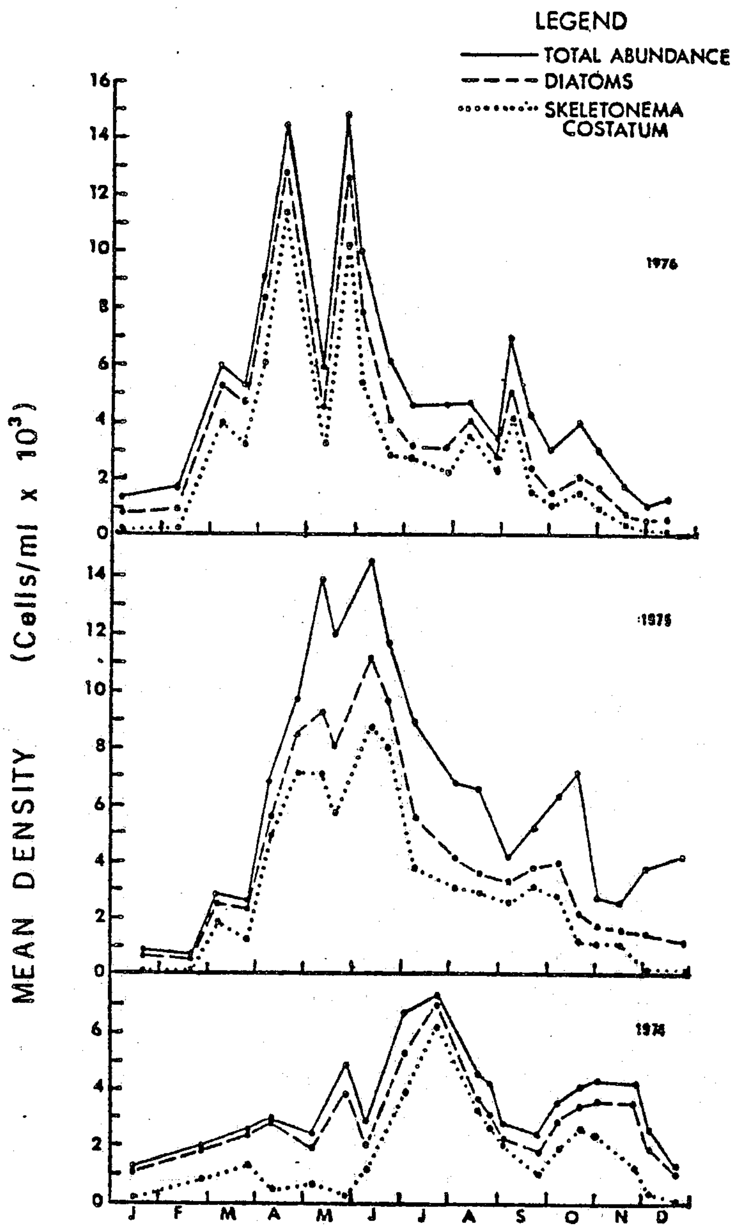
Euglenoids annually comprised to 1 percent of the phytoplankton community, with a mean density to 79 cells/ml. Euglena and Trachelomonas were the most common genera.

Dinoflagellates and yellow-brown algae comprised less than 1 percent of the annual phytoplankton community; mean density of the two divisions ranged to 8 cells/ml. Gymnodinium, Peridinium, and Dinobryon were the most common genera.

From July through September 1974, 36 and 28 genera, respectively, were identified near Artificial Island and Ship John Shoal (located about 19 km south of Artificial Island); 26 genera were common to both areas. The mean phytoplankton density was also greater near Artificial



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Mean density and percent composition of phytoplankton (taxa comprising < 5 percent of total abundance are combined). Figure 12



PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ARTIFICIAL ISLAND STUDIES

Relative mean density of the diatom, _Skeletonema costatum_, vs. total phytoplankton and diatoms.

Figure 13

Island (4,684 cells/ml) than near Ship John Shoal (670 cells/ml). In both areas, diatoms were the most abundant division and *S. costatum* was the dominant species.

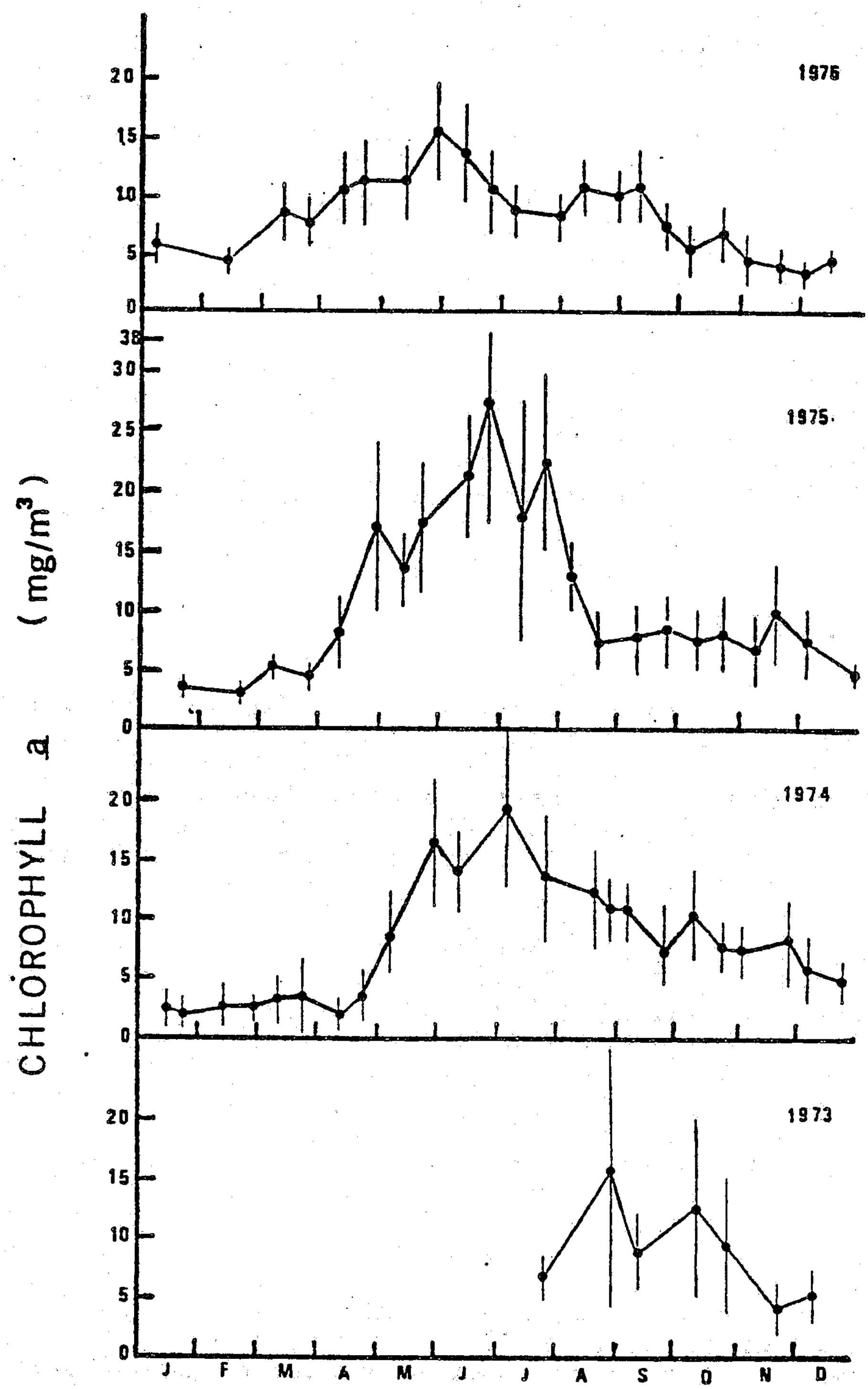
From May 1974 to May 1975 the seasonal pattern of phytoplankton occurrence near Artificial Island differed from that reported by Watling et al. (1979) for lower Delaware Bay. Instead of diatoms, small flagellates dominated the Bay community during the summer and early fall months of 1974; diatoms, particularly *Thalassiosira* sp. and *S. costatum*, were most abundant only from October to May. Additionally, phytoplankton density was greatest during fall and early spring blooms, while near Artificial Island peak density occurred in summer (July, 1974) and in late spring 1975.

In fresh or nearly fresh waters north of Artificial Island near Edgemoor, Delaware, diatoms were the most abundant taxa during the year; however, freshwater forms such as *Cyclotella* spp., *Melosira* spp., and *Tabellaria* sp. predominated (Unruh & Krout 1975, 1976).

Standing Crop

Standing crop, or the instantaneous phytoplankton density present at time of sampling, is expressed as mean chlorophyll *a* concentration (mg/m^3). This discussion is based on some 2900 pigment samples taken between mid-1973 and December 1976. About 450 of these were taken in 12-hour studies on the transect west of Salem from May through October 1975.

Annual mean concentration of chlorophyll *a* was 8.0 mg/m^3 in 1974, 8.3 in 1976, and 11.4 in 1975. Patterns of seasonal change were annually similar. Standing crop was typically low (range 2.0 - 8.7 mg/m^3) from January through March in all years (Fig. 14). Mean chlorophyll *a* levels increased in April - early May and peaked (range 15.5 - 27.2 mg/m^3) between late May and July; levels fluctuated but were usually low (range 3.2 - 12.9 mg/m^3) between August and December. This pattern of seasonal change near Artificial Island was similar to that defined further upriver near Edgemoor, Delaware (Unruh & Krout, 1976), in the eastern end of the Chesapeake and Delaware Canal (Krout & Unruh, 1976) and near the mouth of the Broadkill River, lower Delaware Bay (Ashton et al., 1975). However, the timing of peak abundance offshore in lower Delaware Bay was different, at least in 1974-1975: chlorophyll *a* peaked in August, October, and in the following March (Maurer et al., 1978).



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Semimonthly mean levels, and standard deviation, of chlorophyll a concentration.
	Figure 14

Chlorophyll a levels are expected to vary with environmental conditions. Water temperature and salinity explained approximately half of the variance ($R^2 = 0.498$) near Artificial Island. This relationship may be expressed by the following equation:

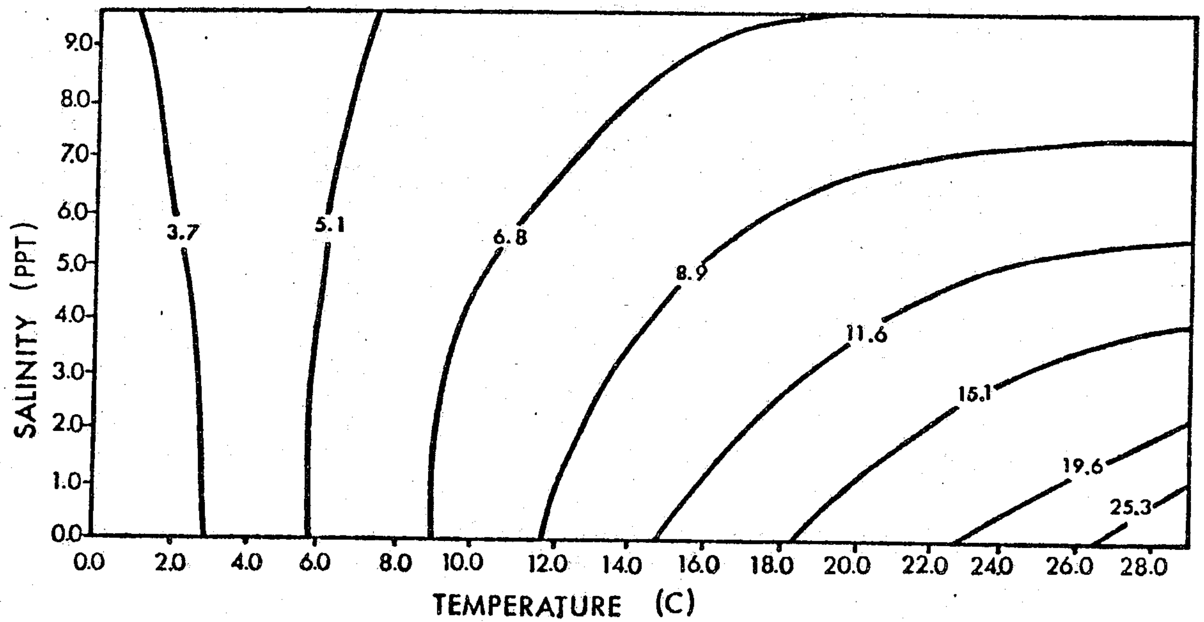
$$\log_{10} (\text{chlorophyll } a + 1) = 0.5462 + (0.1140 \times \text{salinity}) + (0.0436 \times \text{water temperature}) - (0.0004 \times \text{water temperature}^2) - (0.0024 \times \text{water temperature} \times \text{salinity})$$

The contour plot generated from this model indicates that to about a temperature of 12 C chlorophyll a concentration increased with temperature and salinity had little effect (Fig. 15). Above 12 C, to at least 28 C, chlorophyll a levels continued to increase but rate of increase declined with increasing salinity over the range 0-9 ppt. Salinity may be associated with nutrient levels which are probably higher when freshwater runoff from the Delaware River and its tributaries result in low salinities in the study area.

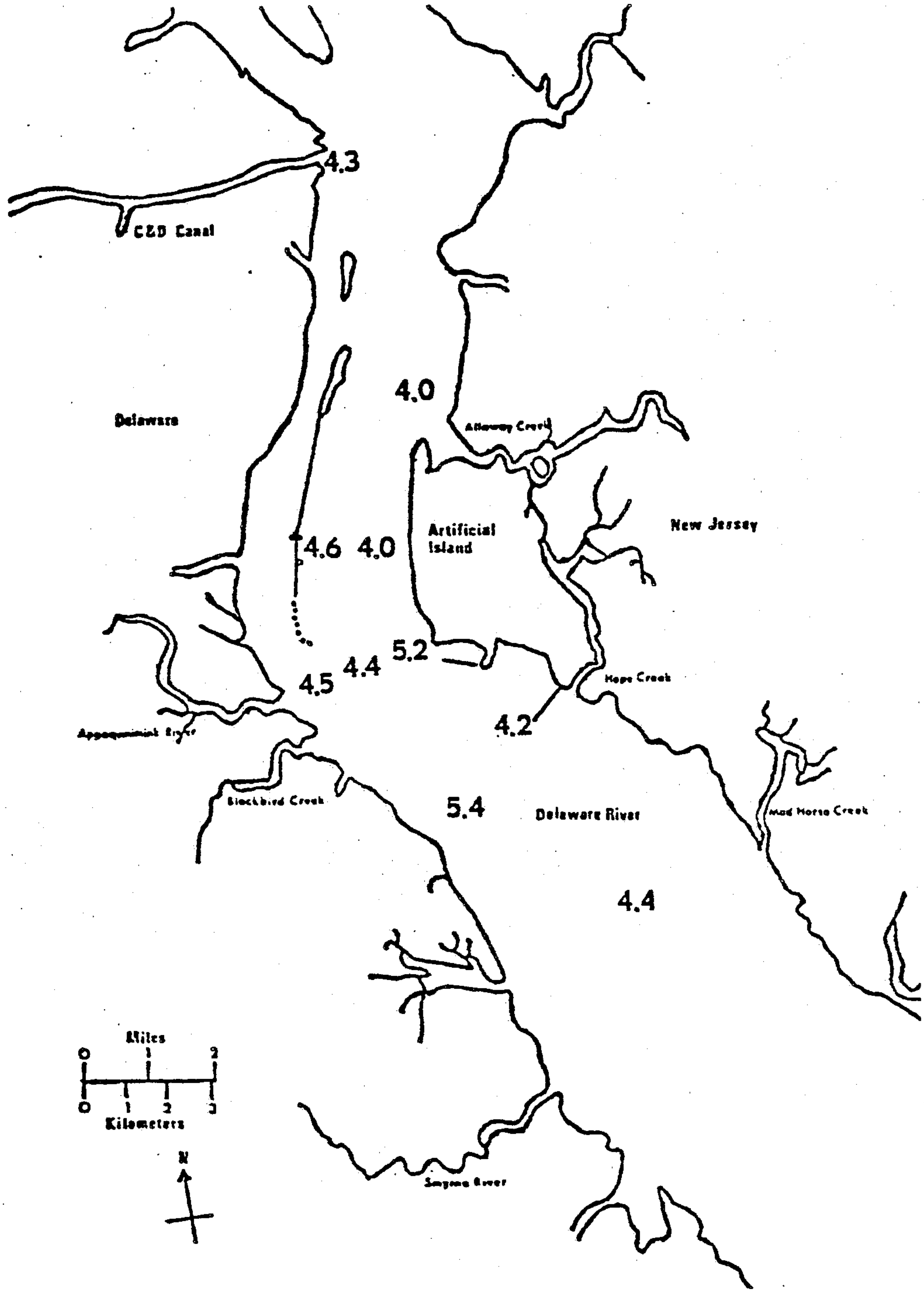
Spatial patterns in the distribution of standing crop among stations also varied seasonally near Artificial Island (1974-1976 data combined quarterly) (Figs. 16-19). Mean levels of chlorophyll a were similar at all stations (range 4.0-5.4 mg/m^3) from January through March. From April through June standing crop varied among stations but no distributional trends were apparent. From July through December mean levels generally decreased from north to south, reflecting at least in part dilution. From July through September 1974 mean chlorophyll a concentration was greater (12.4 mg/m^3) near Artificial Island than further south near Ship John Shoal (5.8), but similar (10.9) to that in lower Delaware Bay (monthly data in Maurer et al., 1978). Regional differences in standing crop are expected because of differences in environmental conditions (eg. salinity, nutrients, turbidity, etc).

Standing crop fluctuated with tidal stage near Artificial Island, but for reasons not apparent it was generally least on the early ebbing tide (Fig. 20). In May and June chlorophyll a levels varied by about 2-fold during each 12-hr period; from July through September by about 1.3-fold. Generally, the variation of chlorophyll a values over 12-hr periods were similar to those over 2-3 hr routine sampling cruises in the study area (Figs. 14 and 20).

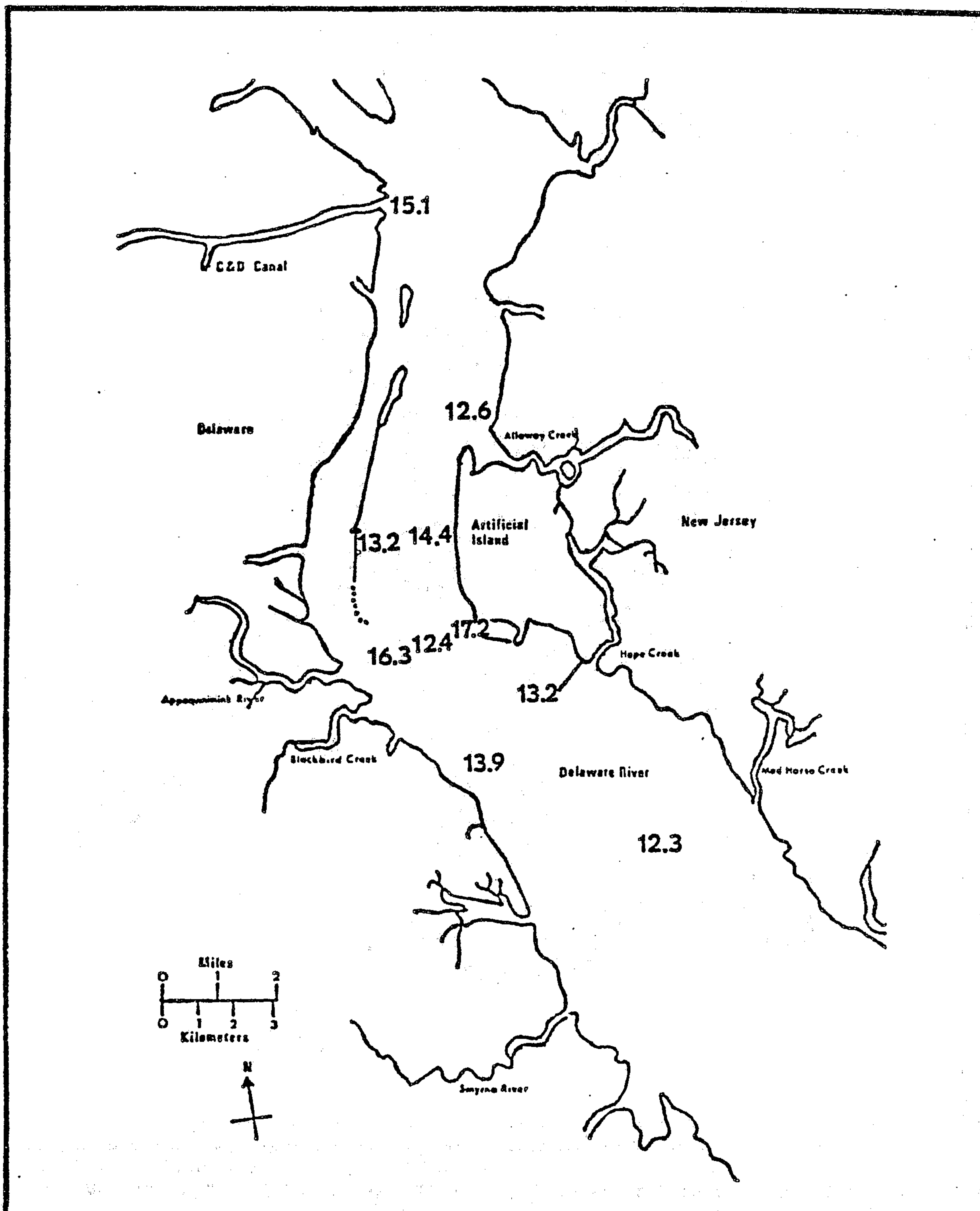
Annual mean concentration of chlorophyll a varied by 0.1-0.2 mg/m^3 between surface and bottom from 1974 to 1976.



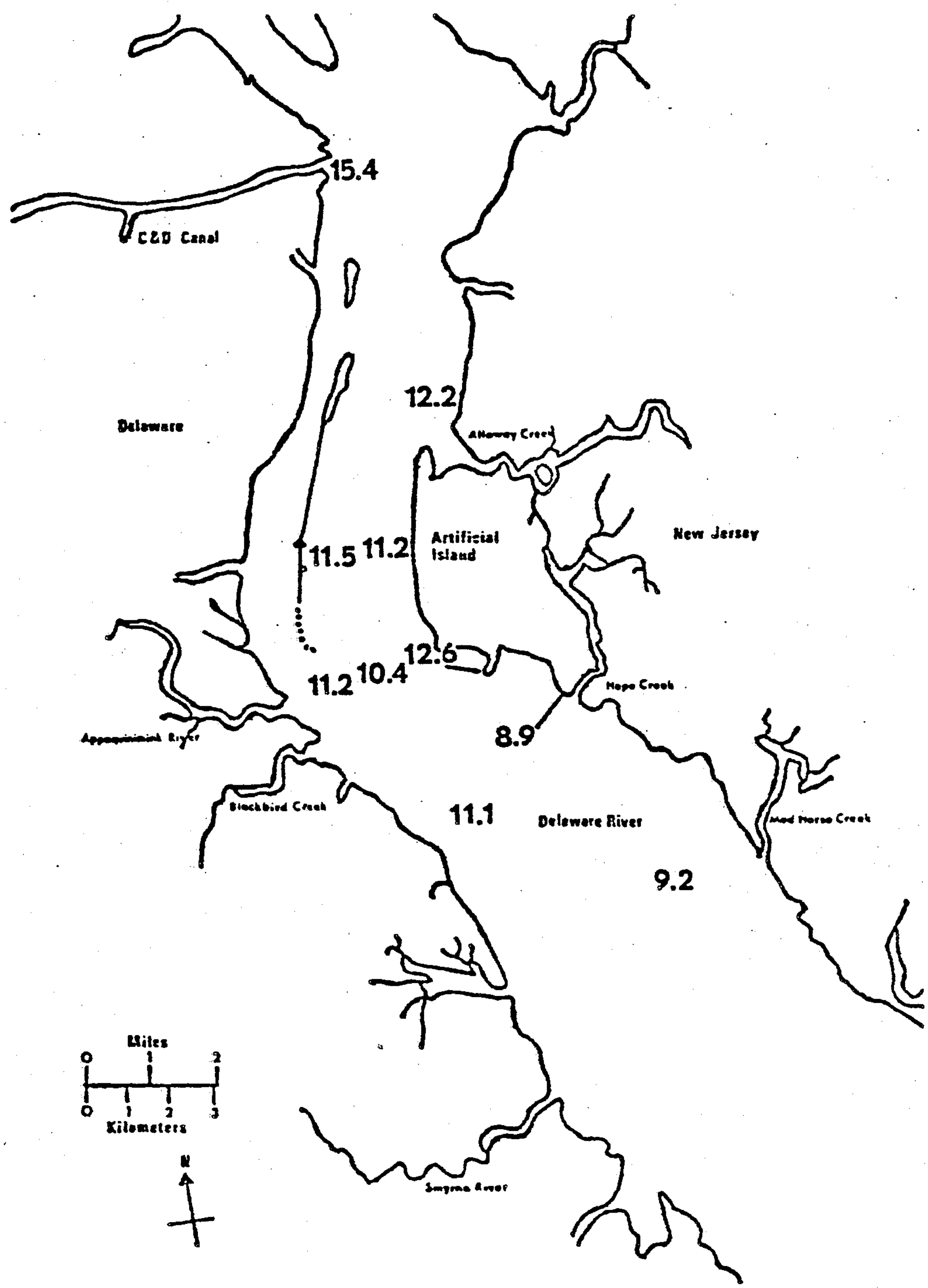
PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Regression of chlorophyll a concentration (mg/m^3) on temperature and salinity, 1973-1976.
	Figure 15



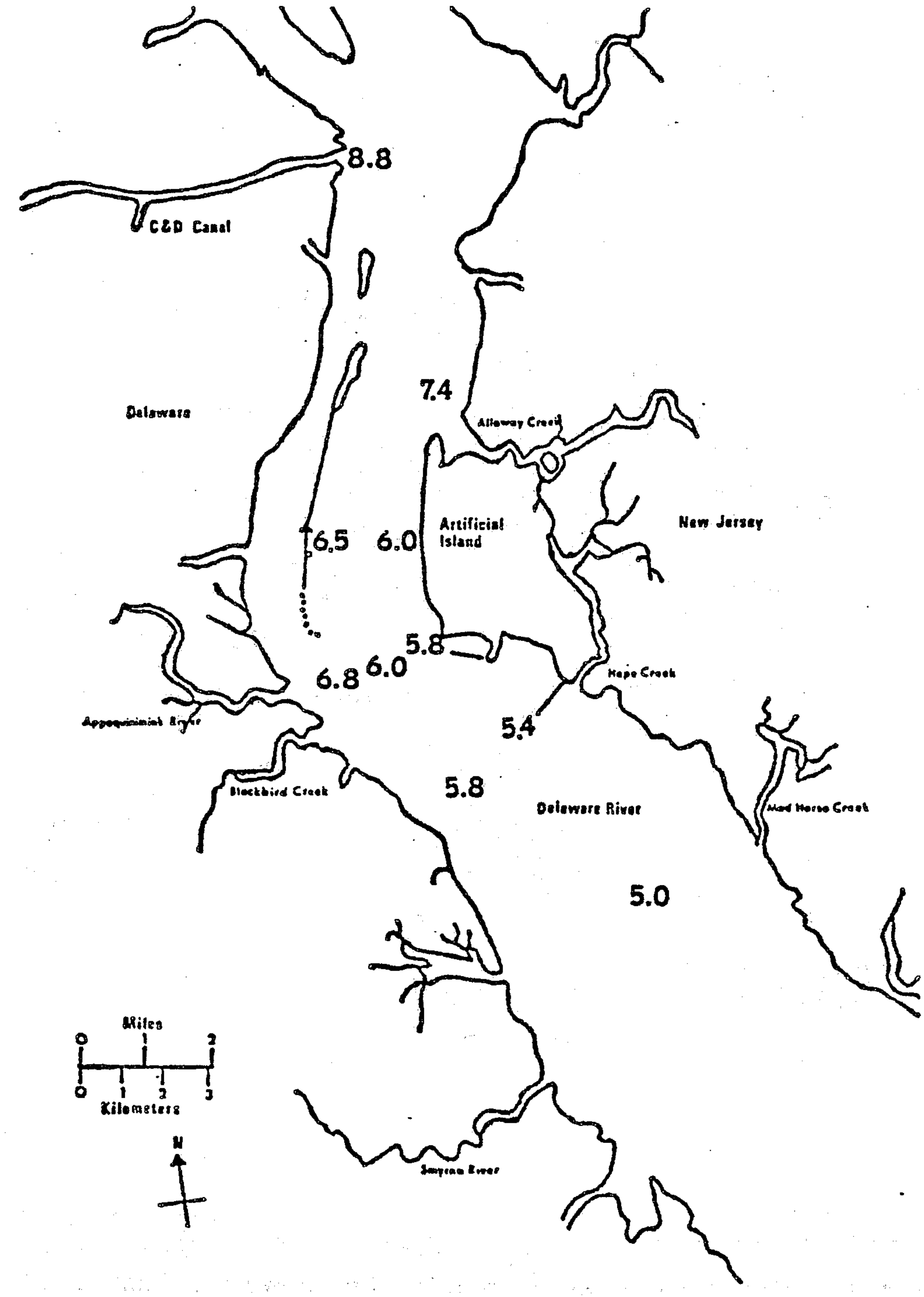
PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Mean chlorophyll a concentration (mg/m^3) by station, January-March 1974-1976. Figure 16



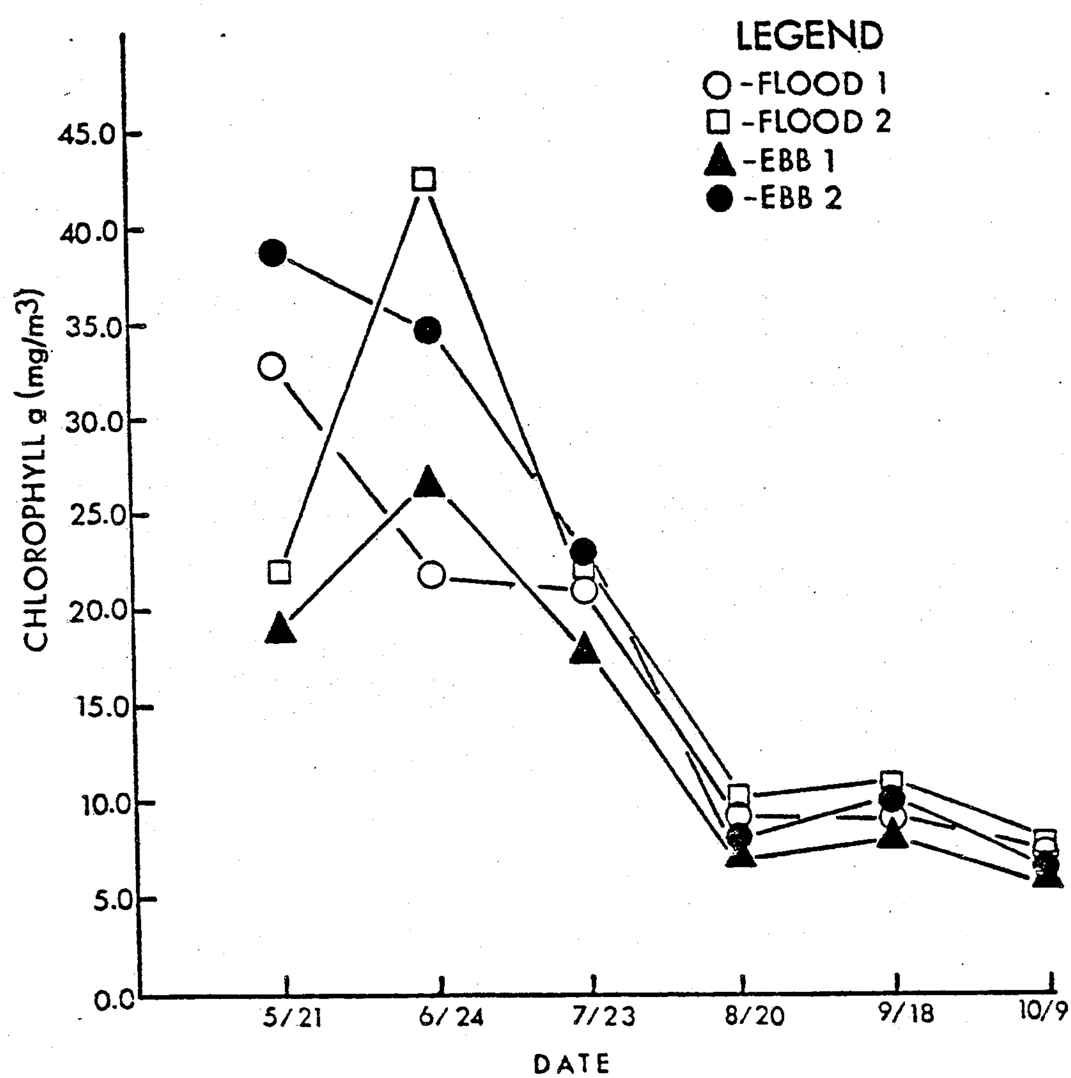
PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Mean chlorophyll *a* concentration (mg/m^3) by station, April-June 1974-1976.
	Figure 17



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Mean chlorophyll _a_ concentration (mg/m^3) by station, July-September 1974-1976.
	Figure 18



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Mean chlorophyll a concentration (mg/m^3) by station, October-December 1974-1976.
	Figure 19



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Mean chlorophyll a concentration by tidal stage, May-October 1975.
	Figure 20

Vertical differences in chlorophyll a concentration did occur, but were not consistent because of tide induced turbulence and changing patterns of plankton patchiness. Neutral or selective buoyancy mechanisms of plankton organisms may also retard sinking and subsequent accumulation in the bottom waters (Smayda, 1970).

Production

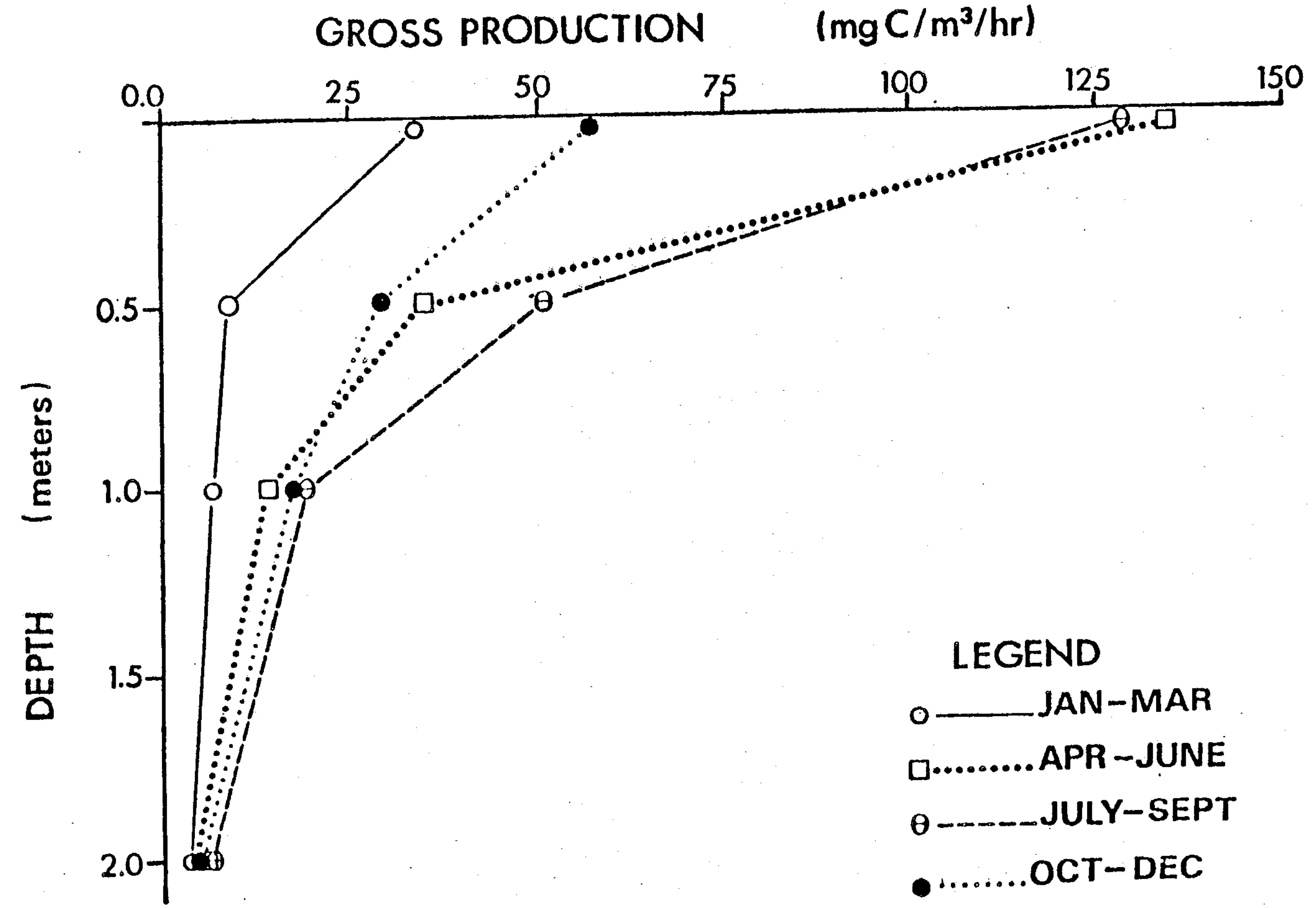
Gross production (productivity), or the rate of photosynthetic increase in the size of the standing crop, is measured in terms of oxygen evolved ($mgO_2/L/hr$) and converted to carbon equivalents ($mg\ Carbon/m^3/hr$). Net production, which is gross production corrected for the rate of respiration, is the net gain in standing crop per unit time. Mean quarterly gross, as well as net production values (1973-1976 data combined) were greatest near the surface and decreased with depth to about 1.0 and 2.0 meters (Fig. 21). This was consistent with implications of Secchi readings of 10-74 cm, i.e., highly turbid waters. Hull (1964) also found that productivity values were restricted to near-surface (upper 0.5 m) waters because of turbidity at locations north of Artificial Island from Reedy Island to the Burlington-Bristol Bridge.

From November through March of each year levels of surface net production were low ($\leq 67.0\ mgC/m^3/hr$), but increased by late May and were typically greatest during summer (Fig. 22). Annually, production was highest between June and August, ranging from $110\text{-}301\ mgC/m^3/hr$. Stross and Stottlemyer (1965) in the Patuxent River and Flemer (1970) in the upper Chesapeake Bay observed similar seasonal patterns in turbid oligohaline water.

As expected, surface net production was correlated ($R^2 = 0.65$) with chlorophyll a concentration (Fig. 23). The correlation was less than perfect because of sampling error and because the production rate may respond more rapidly than the chlorophyll a concentration to changing environmental conditions. The relationship may be described by the following linear regression equation:

$$\text{surface net production} = 16.6 + 4.6\ (\text{chlorophyll } a)$$

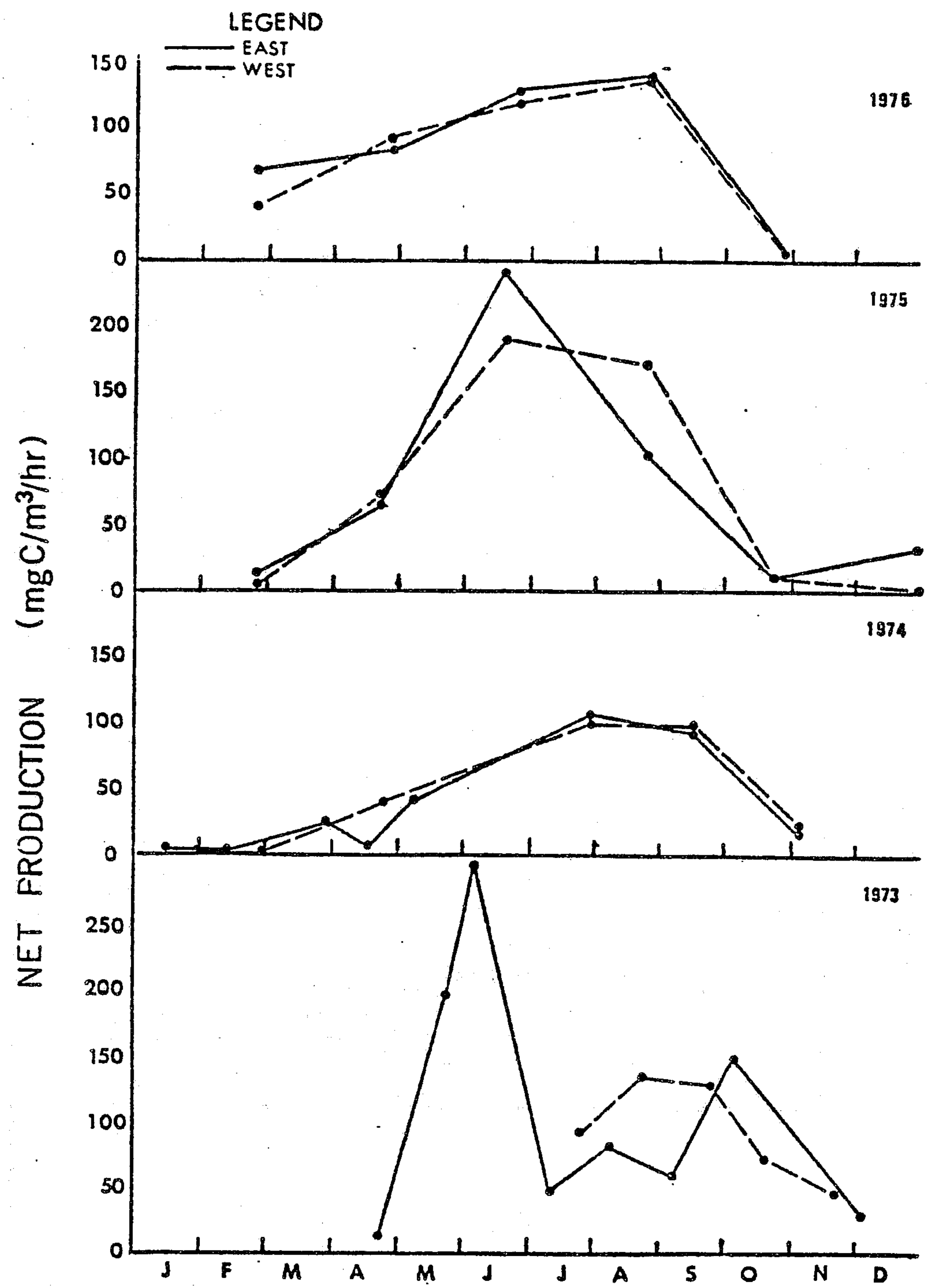
Surface net production rates were related to water temperature and salinity ($R^2=0.58$). This relationship may



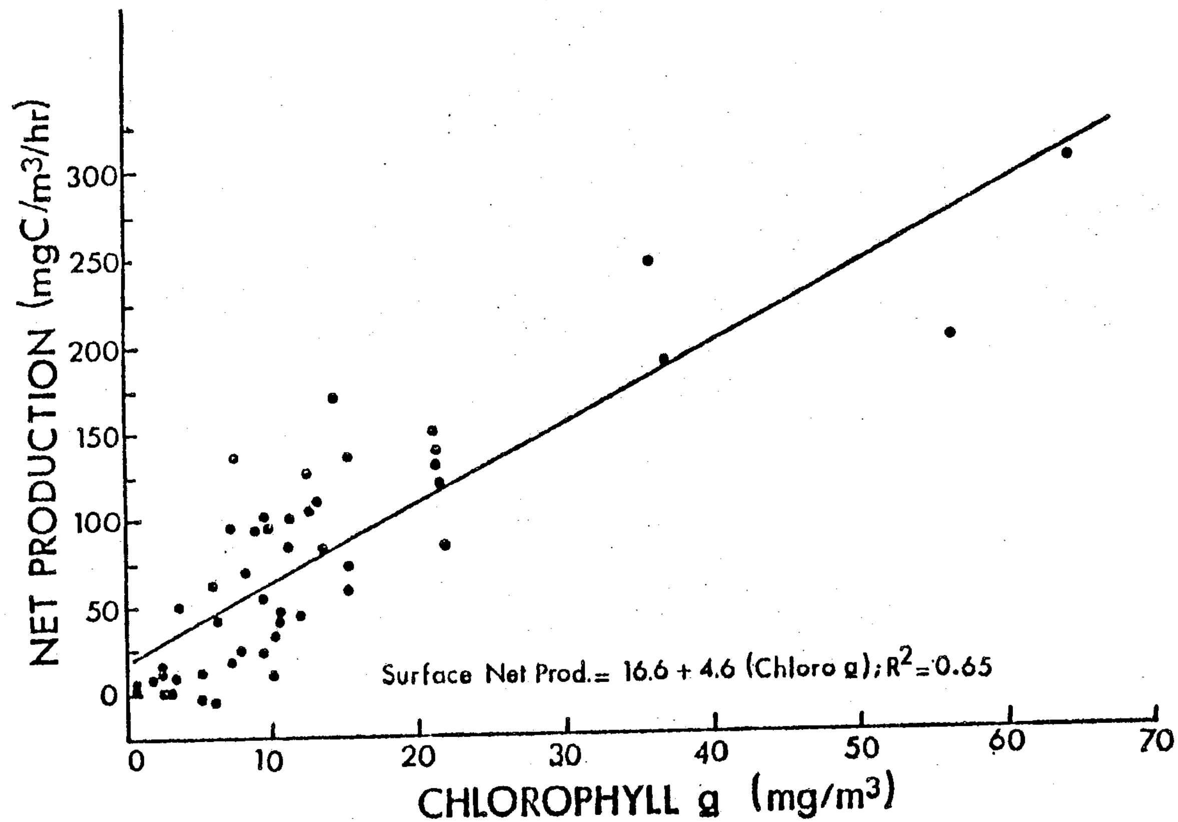
PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ARTIFICIAL ISLAND STUDIES

Mean quarterly gross production versus depth, 1973-1976.

Figure 21



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Surface net production by phytoplankton through time.
	Figure 22



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ARTIFICIAL ISLAND STUDIES

Regression of surface net production on chlorophyll a concentration, 1973-1976.

Figure 23

be expressed by the following equation:

$$\log_{10} (\text{net production} + 1) = 0.3654 + (0.0729 \times \text{water temperature}) + (0.1763 \times \text{salinity}) - (0.0079 \times \text{water temperature} \times \text{salinity})$$

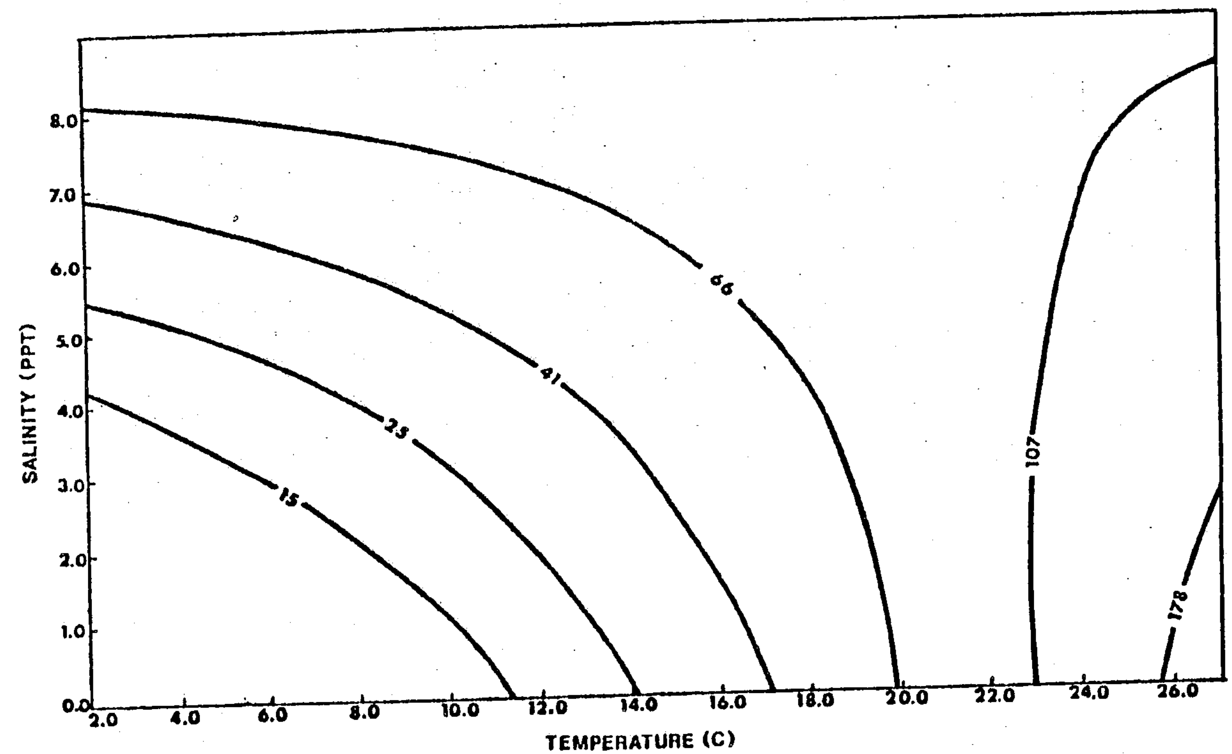
The contour plot generated from this model indicates that net production increased as water temperature and salinity increased (Fig. 24). The rate of increase also increased with rising temperatures. At water temperature higher than 22 C production rates were high ($\geq$107 mgC/m^3/hr) over a wide range of salinity values (0-8 ppt.).

Surface net production was similar between stations, except in June and in August 1975 when the difference was about 60 mgC/m^3/hr (Fig. 22). Chlorophyll a levels and Secchi readings were similar and reasons for this difference were not apparent.

Community Relationships

While some 100 phytoplankton genera have been identified near Artificial Island, only a few taxa, particularly *Skeletonema costatum*, consistently dominated the annual local community. However, the nannoplankton (i.e., measuring less than 10 m) also contribute to the productivity of the system, especially in the warmer months, but are often overlooked taxonomically because of their size. Van Valkenburg and Flemer (1974) reported that the nannoplankton fraction contributed an average of 65-75 percent of total production during a study near Calvert Cliffs in the Chesapeake Bay. Durbin et al. (1975) observed that a slightly large sized fraction ($\leq$ 20 m) was equally as important as the larger net plankton, e.g., chain forming diatoms, in Narragansett Bay. Therefore, while the net plankton, such as *S. costatum*, *Melosira* spp. and *Chaetoceros* spp. appear to be the most important producers near Artificial Island, the smaller plankton taxa are probably at least as important. Since chlorophyll a is extracted from the entire population sampled regardless of cell size, it is probably a better estimator of standing crop (and production) than cell density.

Seasonal trends in annual phytoplankton standing crop and productivity were generally similar near Artificial Island.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY

ARTIFICIAL ISLAND STUDIES

Regression of surface net production ($mgC/m^3/hr$) on temperature and salinity, 1973-1976.

Figure 24

The most productive periods were the warmer months when standing crop was maximum; production was less or negligible in the colder months when standing crop levels were minimum. Additionally, the greatest rate of production occurred always at the surface; rate decreased with depth to about zero at the 2-meter level. This all suggests that local phytoplankton production, being seasonal and restricted to a relatively shallow euphotic zone, supplies only part of the total local primary food base.

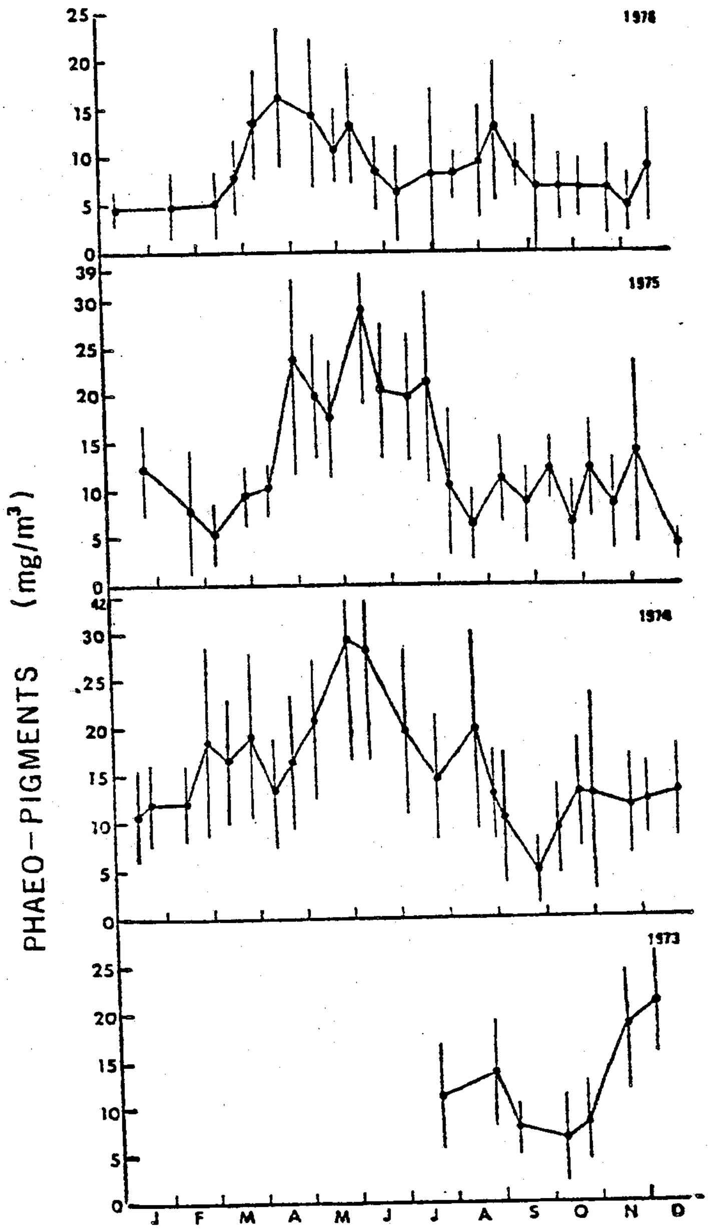
Under optimal conditions of temperature, salinity, incident radiation, and nutrients, phytoplankton increases of 0.5 to 3.0 doublings per day are possible (Eppley, 1972). Even though natural conditions are often unfavorable for such rapid growth, the phytoplankton community is not solely dependent on local populations but is largely augmented by input from up- and downriver regions of the Delaware Estuary. Freshwater species (such as Ankistrodesmus falcatus, Melosira spp. and Cyclotella spp.) and marine species (such as S. costatum and Chaetoceros sp.) were present in the study area.

Detritus

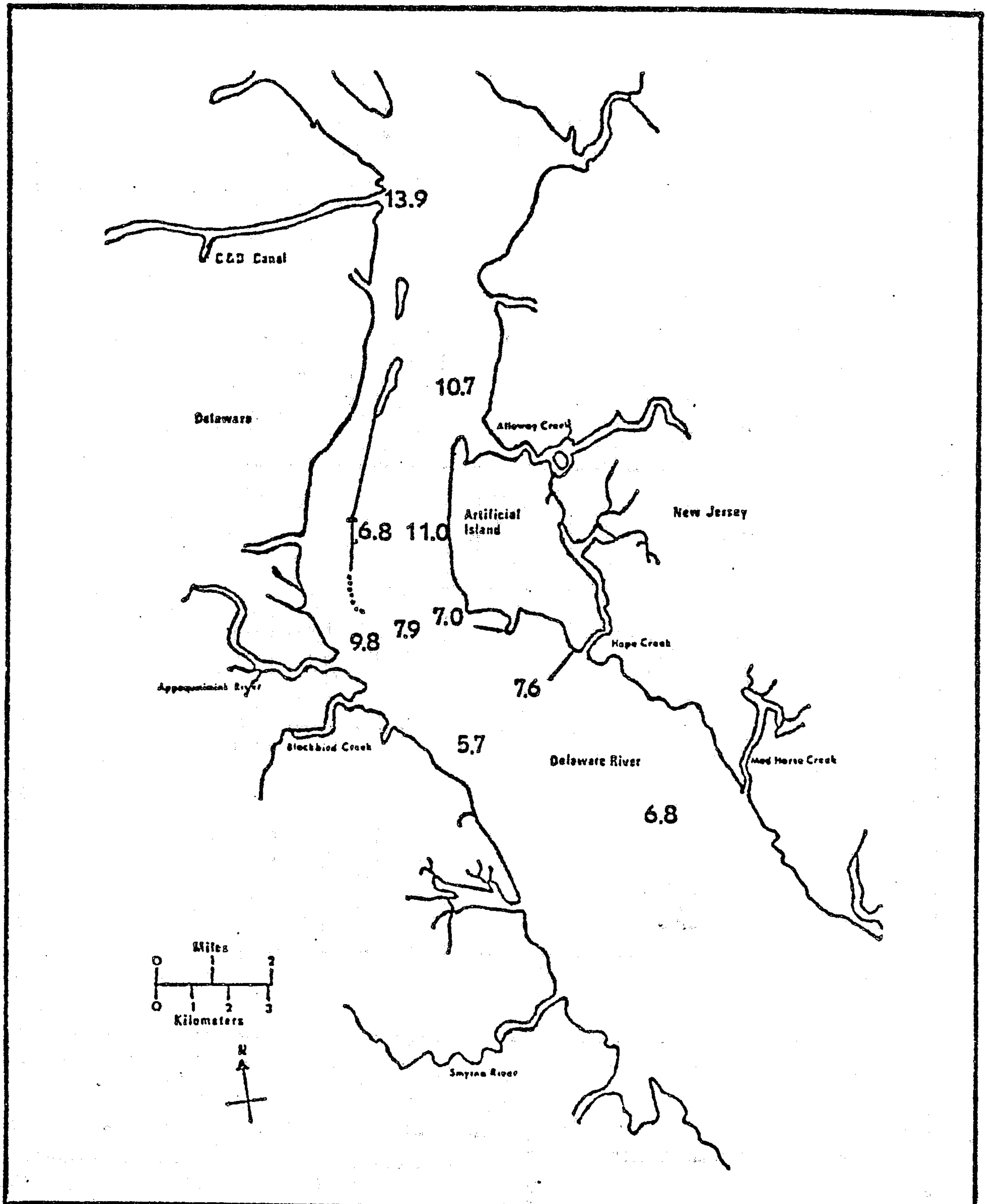
Water-born plant detritus with its associated micro-flora also contributes to the local food base. It consists of particulate organic matter in various stages of decay. Local sources include vascular plant and phytoplankton remains and zooplankton fecal pellets. The phaeo-pigments which are decomposition products of chlorophyll a and are representative of the micro-sized fraction of detrital load were studied in some 3000 samples collected between mid-1973 and December 1976.

Annual mean concentration of phaeo-pigments was considerably less in 1976 (8.8 mg/m^3) than in 1974 and 1975 (14.9 and 13.3, respectively). However, the annual pattern of seasonal change was reasonably similar each year (Fig. 25). Mean concentrations were typically high between April and July; peak values ranged to about 30 mg/m^3 in 1974 and 1975 and 16 mg/m^3 in 1976. Mean level from January through March and from August through December fluctuated each year but was usually less than peak values. In 1976 a secondary peak occurred in September; in 1973 high levels were present in December.

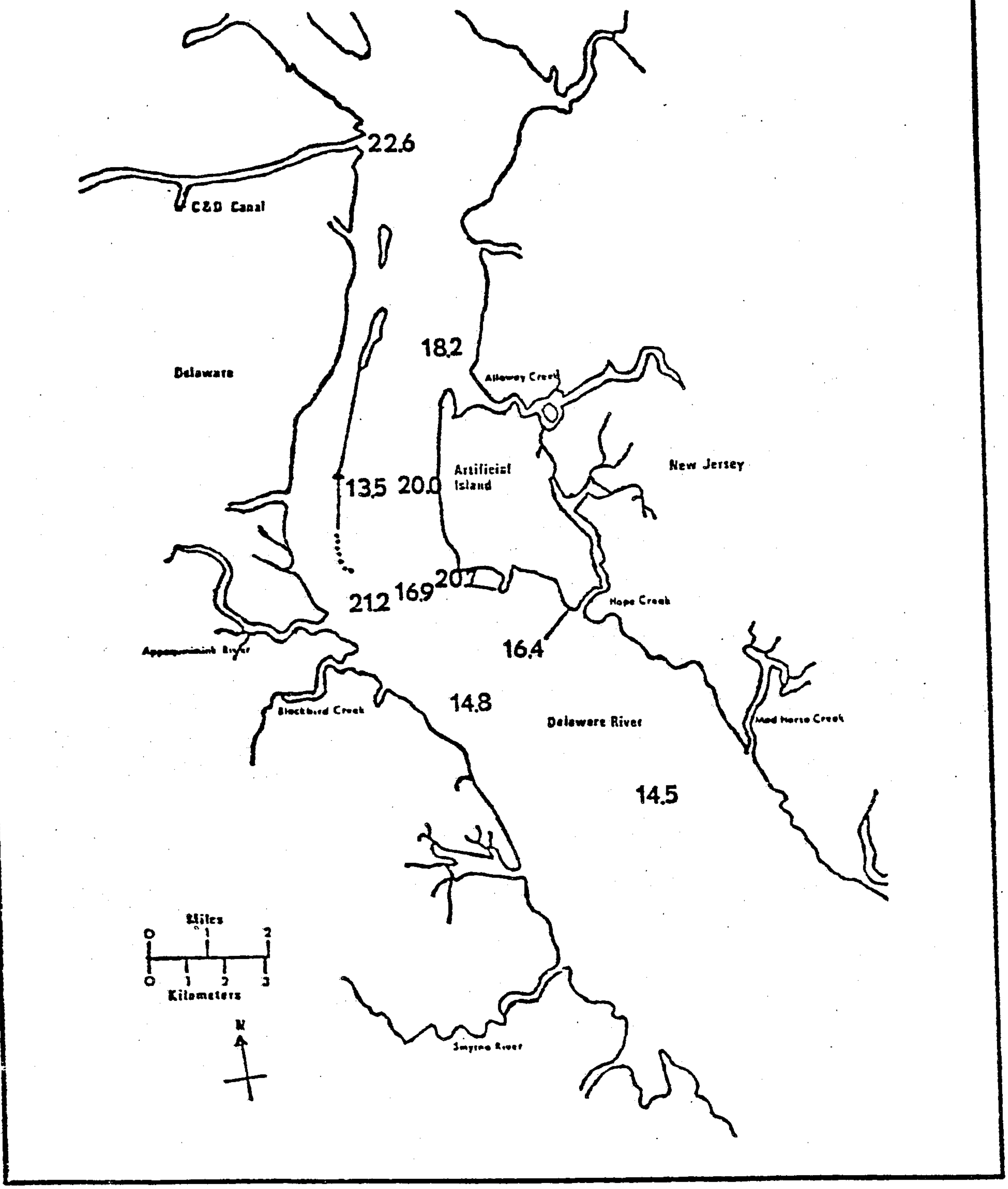
The distribution of phaeo-pigments among stations is shown in Figures 26-29 (1974-1976 data combined quarterly). Mean levels generally decreased from north to south regardless of season. From July through September, 1974, mean



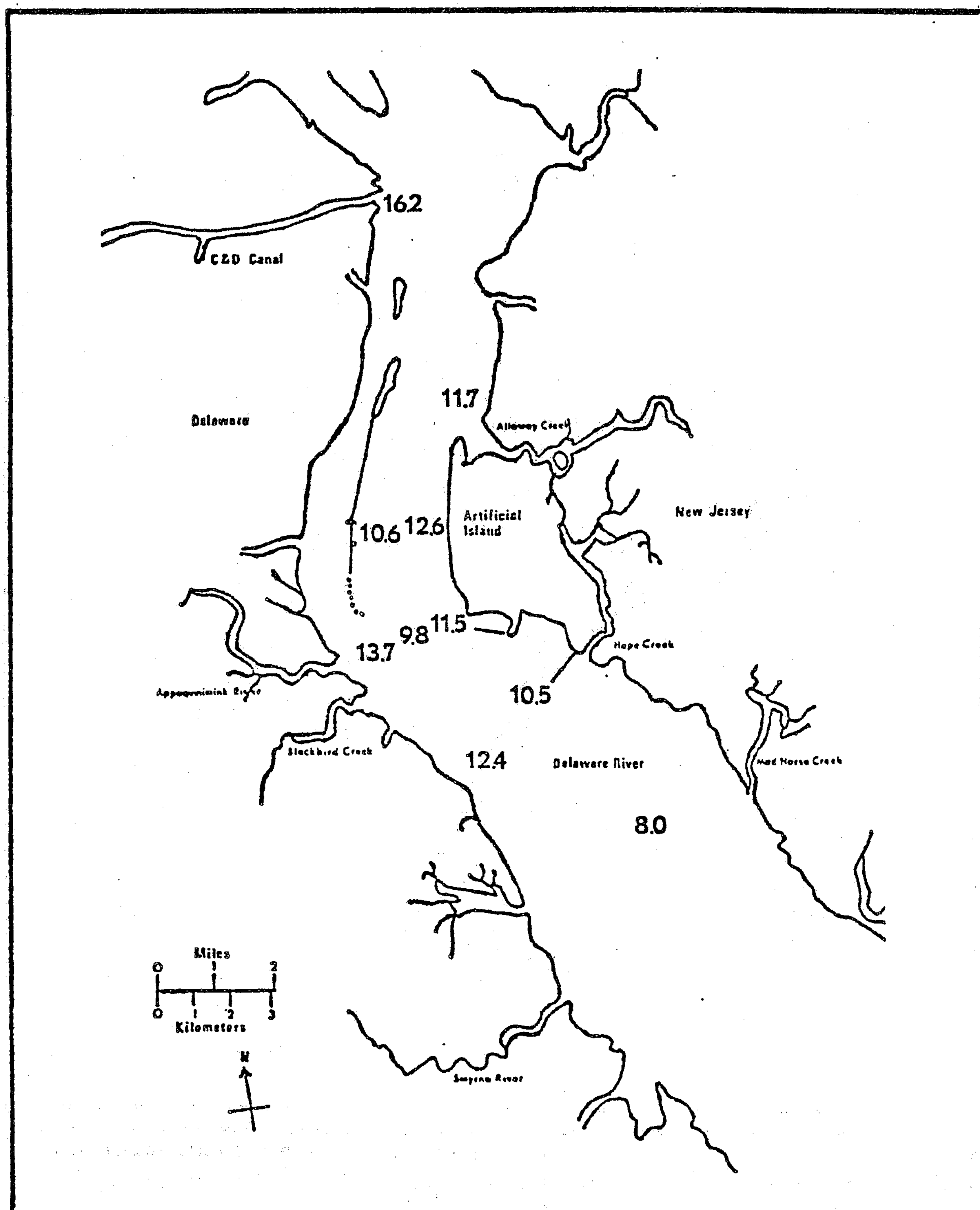
PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Semimonthly mean levels, and standard deviation, of phaeo-pigment concentration.
	Figure 25



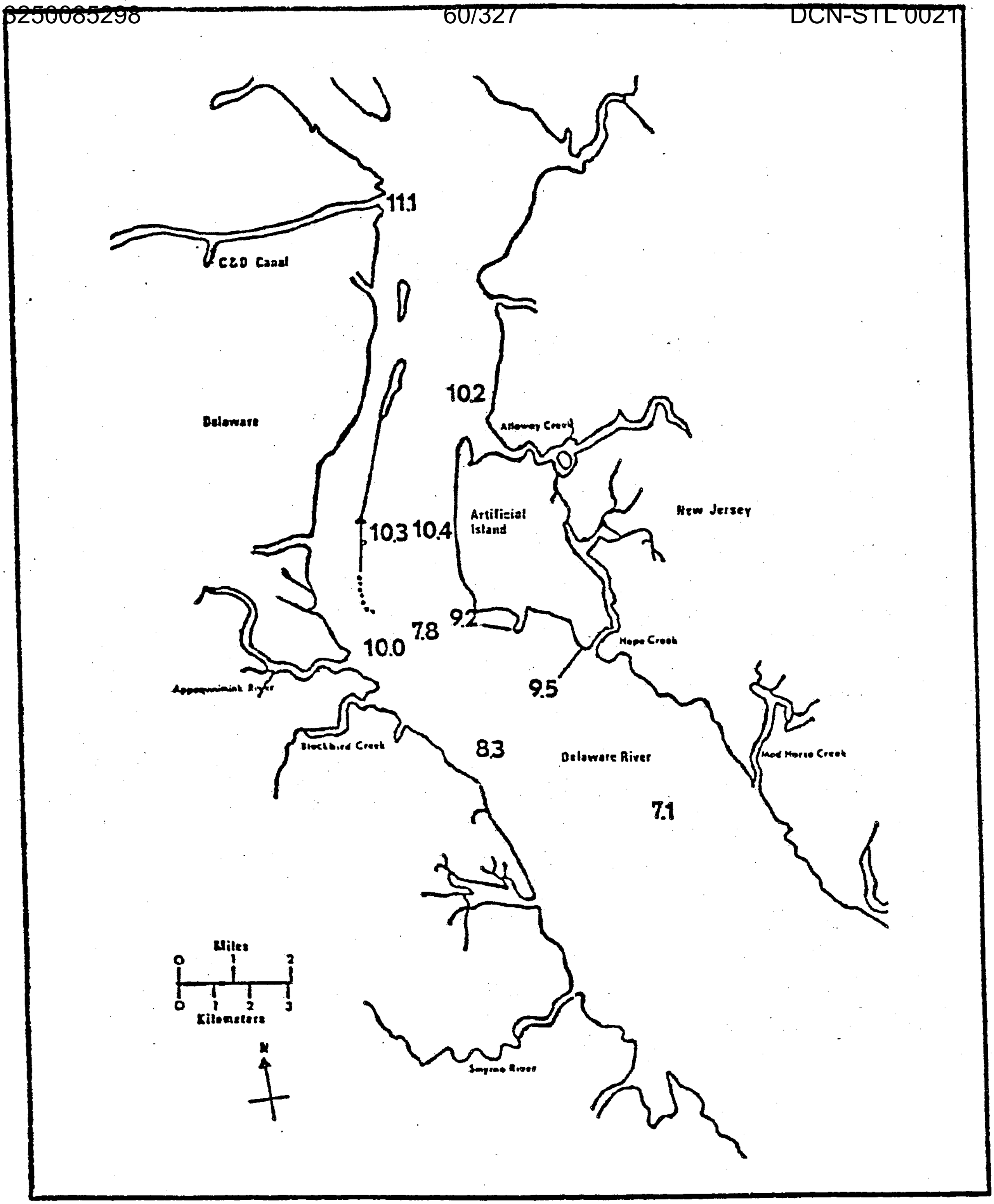
PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Mean phaeo-pigment concentration (mg/m^3) by station, January-March 1974-1976.
	Figure 26



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Mean phaeo-pigment concentration (mg/m^3) by station, April-June 1974-1976.
	Figure 27



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Mean phaeo-pigment concentration (mg/m^3) by station, July-September 1974-1976.
	Figure 28



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Mean phaeo-pigment concentration (mg/m^3) by station, October-December 1974-1976. Figure 29

concentration in the mesohaline reach near Ship John Shoal was less (6.4 mg/m^3) than near Artificial Island (13.7). These north-south trends of progressively lower pigment concentration reflect at least in part dilution of river water as the detrital material is flushed up to down river.

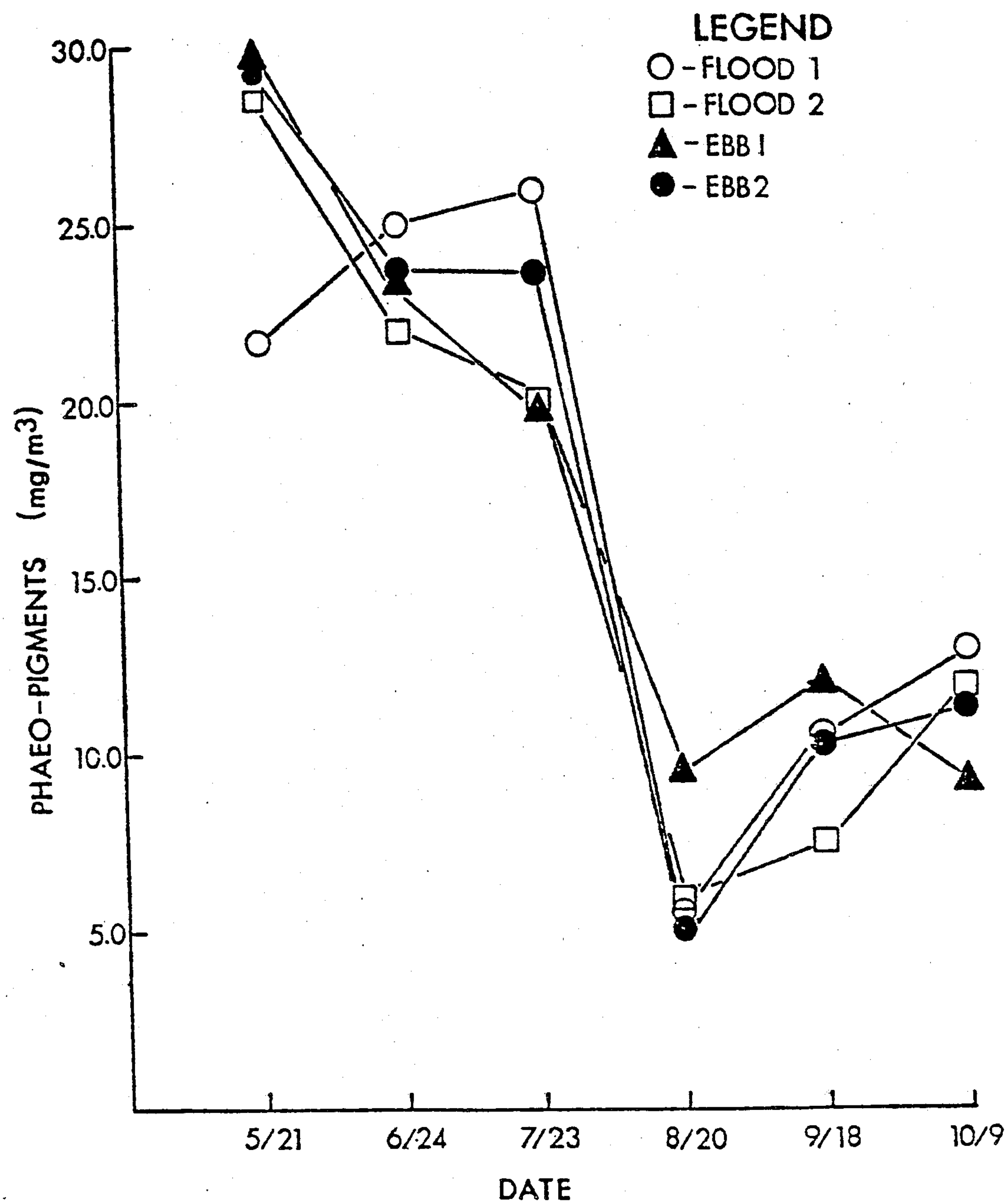
No consistent pattern of variation in mean phaeo-pigment level with tidal stage was evident (Fig. 30). Although mean concentration fluctuated, the monthly range in values over each 12-hr period did not vary greatly.

The vertical distribution of local phaeo-pigment concentrations was consistent. Annual mean phaeo-pigment levels in 1974, 1975, and 1976 were less near surface (12.8, 11.3 and 7.2 mg/m^3, respectively) than near bottom (16.9, 15.4, and 10.4, respectively). Since detrital materials are generally not as buoyant as living plankton they tend to accumulate near bottom during slack tides and in localized areas of low turbulence.

Plant detritus, which consists mostly of fragments of grass (family Gramineae) including roots, stems, and rhizomes in various stages of decay, generally occurs in the Delaware River near Artificial Island. Larger stems and green leaves of Phragmites communis and Spartina spp. and smaller fragments (length < 5 cm) of these and other grasses (Ichthyological Associates, 1976; unpublished observations) have as their most immediate source the extensive local low marsh stands which are regularly flooded and drained by the tides.

The tides alternately transport detrital materials back and forth on the surface and in the water column. Krout et al. (1978) reported that density was usually greatest on the late stage of the ebbing tide and the early stage of the flooding tide near Artificial Island in May 1978. Additionally, the density of detritus generally increased from near surface to near bottom and from offshore to near shore. However, these patterns may change with weather and tidal conditions.

Plant detritus is utilized by numerous primary consumers. Some particles are stripped only of associated micro-organsisms, re-colonized, and utilized over and over again until completely broken down (Daiber et al., 1976). During this process dissolved organic materials are also released into the water column where they may function as nutrient sources.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Mean phaeo-pigment concentration by tidal stage, May-October 1975.
	Figure 30

AQUATIC INVERTEBRATE FAUNA

INTRODUCTION

Invertebrates have a crucial role in the transfer of energy between the primary producers (phytoplankton and marsh vegetation) and the higher level consumers such as fish. They are a diverse assemblage which, depending on species and life stage, occupy a variety of habitat types including the water column, bottom sediments and intertidal zone.

The present Study has included the invertebrate fauna near Artificial Island through investigations of the macroinvertebrate plankton, microzooplankton, benthos, and blue crab. Annual species composition and seasonal and spatial distribution were presented in Progress Reports. This discussion integrates and collates these annual data, describes general trends, and presents life history information on selected species. Field and laboratory techniques are only briefly discussed. For details on techniques, gear, etc., see annual Progress Reports.

MATERIALS AND METHODS

Study during the early years of each invertebrate program was of a range-finding nature. Sampling frequency, location, gear type and, in some cases, objectives were modified in the development of final program specifications.

Zooplankton

Sampling Techniques and Schedule

From 1968 through 1970, 1/2-m nets (0.5 mm mesh) were deployed biweekly to collect macroinvertebrate plankton samples in eight river zones near Artificial Island. During 1971 and 1972 the 1/2-m net was replaced with a Clarke-Bumpus plankton sampler fitted with a 0.08-mm mesh net in an effort to also collect the microzooplankton (<0.5 mm). Samples were collected biweekly to monthly at 8 to 19 stations. Although the Clarke-Bumpus was successful in filtering the microzooplankton, net clogging (by detritus) proved a serious problem and necessitated a gear change. In 1973 a pump filter system (fitted with a 0.08-mm mesh net), modified after Icanberry and Richardson (1972), was employed because it allowed quantitative sampling and constant monitoring of detritus levels; sample duration could be shortened accordingly. Macroinvertebrates were collected coincident with ichthyoplankton using a 1/2-m net.

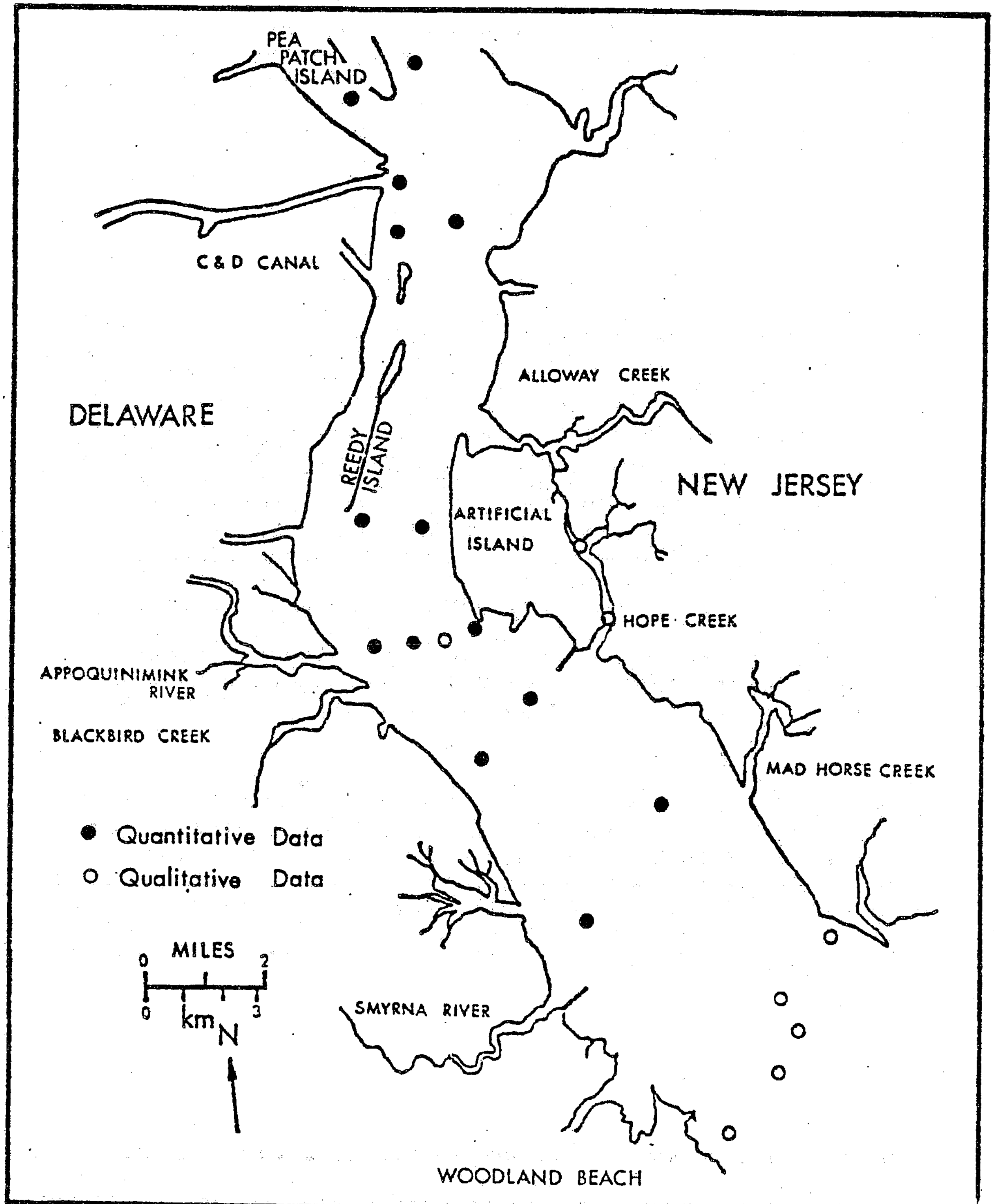
The standardized quantitative phase of the zooplankton program was initiated in 1973 and continued through 1976. This consisted of three discrete studies including area wide microzooplankton and macroinvertebrate studies, and a station-specific time-duration microzooplankton study. These provided spatial and temporal data on the abundance and distribution of both micro- and macroinvertebrate plankton within a region of the Delaware River from 12 km north to 8 km south of Artificial Island.

In the area wide microzooplankton study samples were collected at a total of 22 locations (Fig. 31). However, not all locations were sampled in each year; from 11 to 16 stations were sampled. Quantitative discussion is based on data from those stations which are most representative of the area between Pea Patch Island and Mad Horse Creek. The monthly station-specific time-duration study provided data on the vertical (surface, mid, and bottom) distribution of microzooplankton at three stations (located on a transect opposite Appoquinimink River) during four consecutive tidal stages over a 12 hr period. All data collected were used in the quantitative discussion. In the macroinvertebrate plankton study samples were collected at a total of 10 stations (Fig. 32). However, not all locations were sampled in each year; from 5 to 7 stations were sampled. Surface and bottom data were collected during daylight and darkness on a biweekly to monthly schedule. Quantitative discussion of macroinvertebrate plankton is based on data from 1974 through 1976.

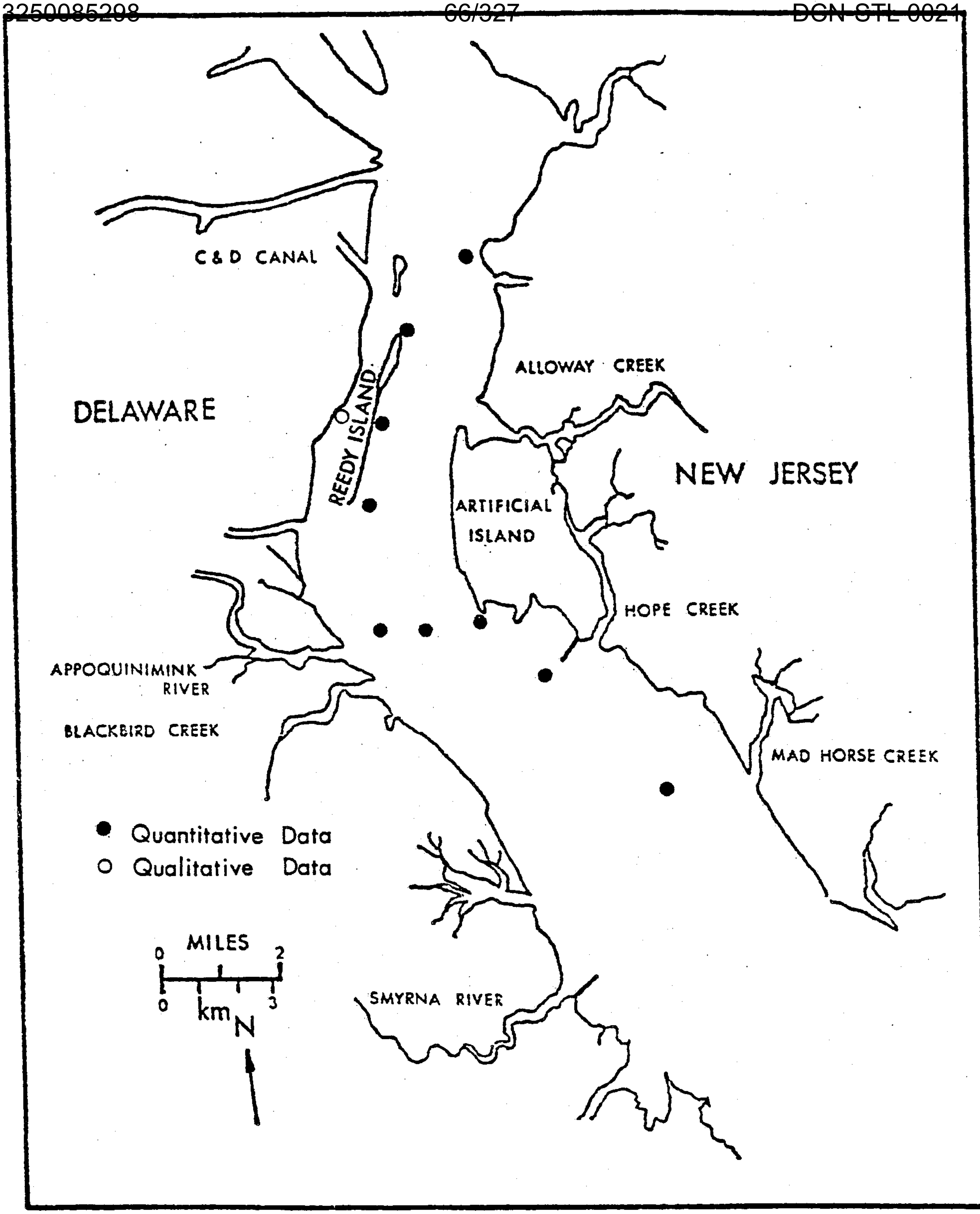
From 1971-1973 larval crab were collected at 9 to 11 stations from ca. 8 km north to 8 km south of the southern tip of Artificial Island. Surface, mid and bottom samples were collected during daylight and darkness biweekly to monthly from June through October (daylight sampling through December in 1971). In 1971 all samples were collected with a 1/2-m (0.5-mm mesh) plankton net. In 1972 and 1973 the 1/2-m net and a 9-ft bottom trawl fitted with a 0.5-mm mesh liner were used.

Laboratory Techniques

From each microzooplankton sample two to five subsamples were examined in a Sedgewick Rafter counting cell under a compound microscope. Densities were expressed as number per cubic meter of water filtered (n/m^3).



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Stations at which microzooplankton was sampled, 1974-1976 (not all stations sampled in each year).
	Figure 31



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Stations at which macroinvertebrate plankton was sampled, 1973-1976 (not all stations sampled in each year).
	Figure 32

Macroinvertebrate plankton samples were sorted completely or subsampled with a Folsom Plankton Splitter and/or Hensen-Stempel pipette depending on sample density and amount of detritus present. Specimens were enumerated under a dissection microscope with density expressed as number per 100 cubic meters of water filtered ($n/100m^3$). Length-frequency data for selected macroinvertebrates were generated.

Benthos

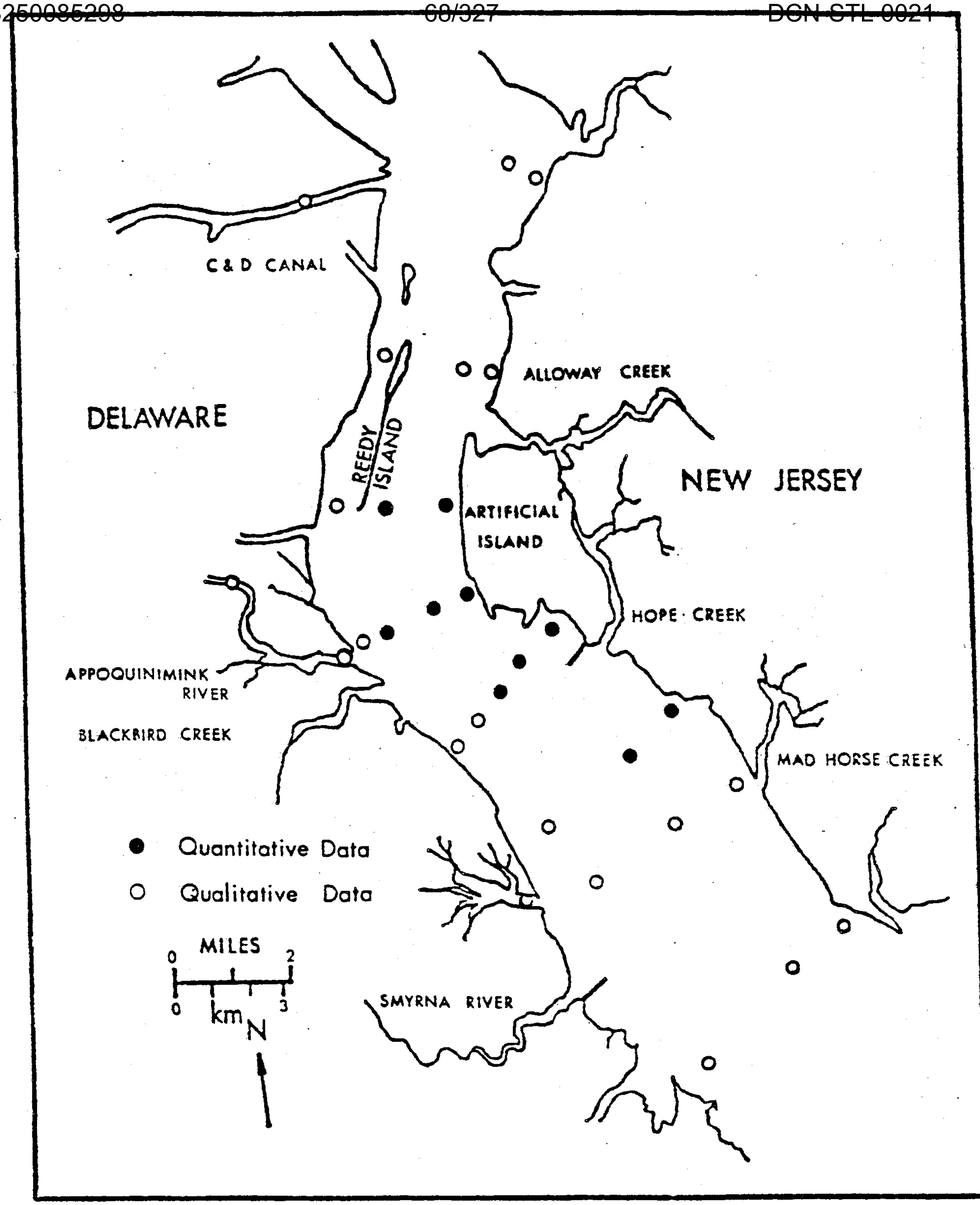
Sampling Techniques and Schedule

The benthos was studied from June 1969 through 1976. Several exploratory gear types (Ekman, Peterson, and Ponar grab samplers and KB core sampler) were employed through 1970 to inventory fauna and sediment type near Artificial Island. Based on sampling efficiency, the Ponar grab, which samples an area of $0.05m^2$ to a depth of approximately 15 cm, was selected as the most suitable sampling device for the region.

The standardized quantitative phase of benthos study was initiated in June, 1971. From 1971 through 1974, from 20 to 30 stations were sampled during daylight on a monthly to bimonthly basis (Fig. 33). At each station three replicate grabs were taken. Analysis showed that data from 14 stations, 10 of which were sampled monthly, adequately described local distribution and abundance. Of these 14, 10 stations were sampled most intensively from 1974 through 1976 and these data are the basis for the quantitative discussion of abundance. Data from the other four are used for qualitative reference.

Laboratory Techniques

Each grab sample was washed in a No. 35 U.S. Standard Sieve with 0.5-mm mesh. Rose bengal was added to facilitate recovery of organisms which were separated from extraneous material (sand, gravel, detritus, etc.) in enamel pans and preserved in 40 percent isopropyl alcohol. Specimens in each sample were sorted to the lowest taxon practicable and tallied accordingly. Densities were expressed as number per square meter (n/m^2).



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Stations at which benthos was sampled, 1971-1976 (not all stations sampled each year).
	Figure 33

Blue Crab

Sampling Techniques and Schedule

From 1968 through 1970 juvenile and adult blue crab were collected and the carapace width of random subsamples measured as part of the fisheries trawl program. Trawls were hauled on the bottom in river and creek zones on an approximately semi-monthly schedule.

In 1971 the program was expanded to include all crab collected in the fisheries trawl program. These were counted, measured, sexed, and categorized to maturity and stage of growth. Additionally, the local commercial crab fishery was annually surveyed for information on daily landings (numbers of bushels) and effort expended (number of pots tended), location of effort, and the number of "peelers" (molting crab) taken. These commercial data are presented in annual reports, but are not discussed in this summary. Data were collected on a weekly to monthly schedule from an area extending from approximately 16 km north to 16 km south of Artificial Island.

RESULTS AND DISCUSSION

General Sample Composition

A total of 203 invertebrate taxa ("taxa" used here to denote the lowest practicable level of specimen identification) were identified in 6,931 samples taken from 1971 through 1976. Crustaceans comprised 43 percent, rotifers 22 percent, molluscs 7 percent and polychaetes 6 percent. Specific physicochemical and distributional data for each of the 203 taxa are included in Appendix A.

Species discussion is presented after program specific results since it draws upon data from all three programs.

Microzooplankton

From January 1973 through December 1976 a total of 110 microzooplankton taxa was identified in 2,332 collections. These include 57 taxa of Phylum Arthropoda, 45 of Aschelminthes, 2 of Annelida, 2 of Mollusca and 1 each of Platyhelminthes, Gastrotricha, Nematoda and Tardigrada. Annual mean density ranged from ca. 32,000/m^3 in 1975 to 46,000/m^3 in 1973.

Monthly mean density within the four years varied considerably (Fig. 34). It was lowest in November 1973 (ca. 3,000/m^3); common taxa included copepod nauplii (31 percent), Halicyclops fosteri (19), Polychaeta (8) and Cirripedia nauplii (2). It was greatest in February 1973 (ca. 154,000/m^3); common taxa included "rotifer" spp. (96 percent) and copepod nauplii (2). More typically, monthly densities ranged from ca. 10,000/m^3 to 100,000/m^3 and reflected the great variation typical of estuarine microzooplankton.

Annual patterns of seasonal composition and abundance were generally similar (Fig. 35). During January through March density levels were generally moderate (ca. 17,000-35,000/m^3) except during February 1973 when mean density (mainly rotifers) was ca. 154,000/m^3. Density peaked during April through June (ca. 75,000-105,000/m^3) and then decreased to again moderate levels. From July through October it decreased to low levels (ca. 5,000-15,000/m^3) but recovered in December to again moderate levels.

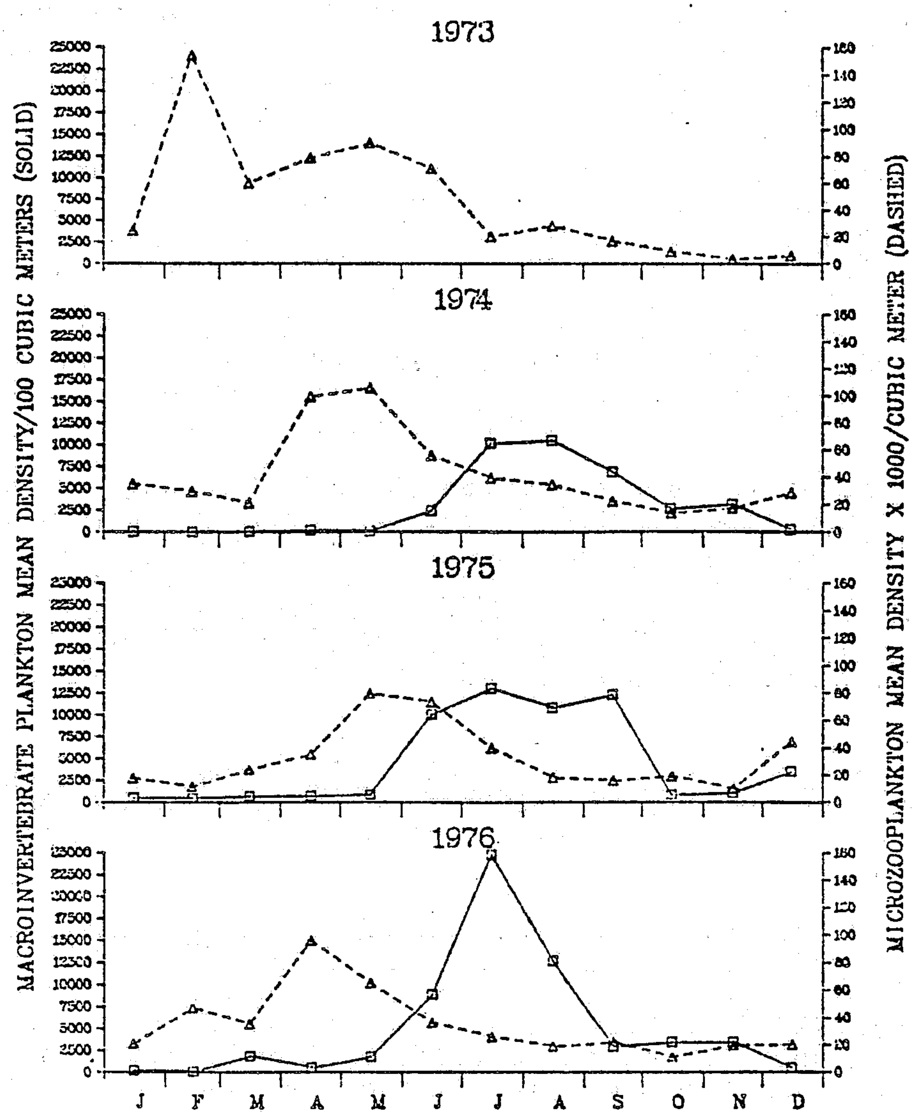
During the winter-spring period (December through mid-June) dominant microzooplankters (based on density and percent composition of the sample) included "rotifer" spp., Brachionus angularis, B. calyciflorus, Keratella spp., copepod nauplii, Eurytemora affinis, Halicyclops fosteri, Cyclops bicuspidatus thomasi, and Oithona colcarva. Of these, only copepod nauplii was abundant throughout the year.

Cyclopoid copepods including Halicyclops fosteri, Cyclops bicuspidatus thomasi and Oithona colcarva were abundant during winter and comprised to 19 percent of monthly samples.

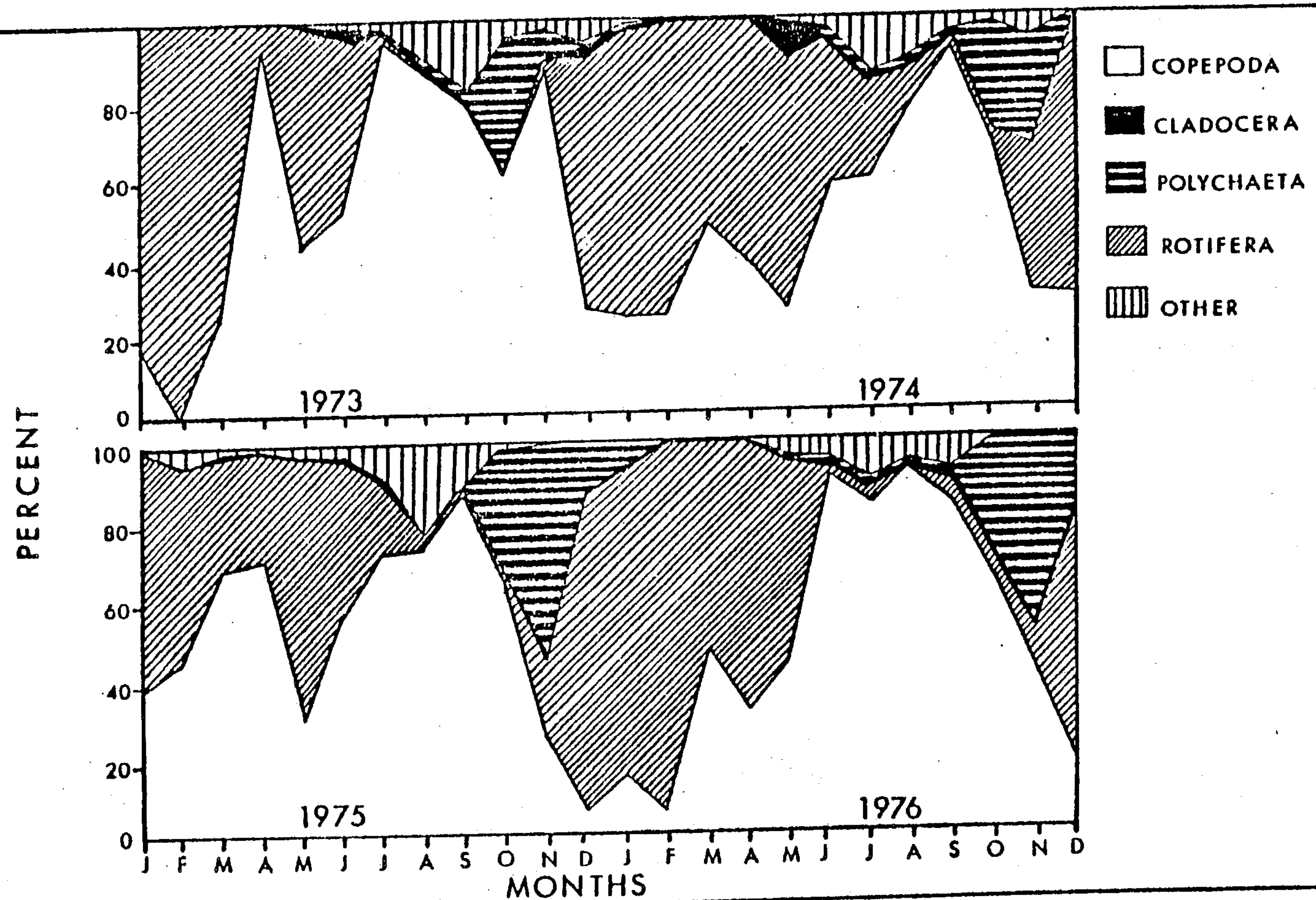
Rotifers, including "rotifer" spp., Brachionus angularis, B. calyciflorus and Keratella spp., were the most abundant microzooplankters collected from December through mid-June, comprising 28 to 97 percent of monthly samples. "Rotifer" spp. was generally dominant and comprised as much as 96 percent of monthly samples. During late spring the genera Brachionus, Notholca and Keratella together comprised from 10 to 60 percent of monthly samples.

The brackish (< 15 ppt) water calanoid copepod, Eurytemora affinis, was abundant during winter-spring, comprising from 5 to 18 percent of monthly samples. Its density peaked during April through June.

Copepod nauplii reached peak abundance during April through mid-June when they comprised from 25 to 85 percent of monthly samples.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density of micro-zooplankton (1973-1976) and macroinvertebrate plankton (1974-1976).
	Figure 34



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Relative temporal abundance of dominant microzooplankton groups. Figure 35

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Cladocerans (mainly Bosmina spp.) were essentially a transition group being most abundant from May through July when they comprised to nine percent of monthly samples. In 1976, they were most abundant in October and November.

The summer-fall (mid-June through November) microzooplankton community was dominated by meroplanktonic larvae of Polychaeta, Gastropoda and Cirripedia and the euryhaline calanoid copepod, Acartia tonsa.

Cirripedia larvae were most abundant from June through September. They typically comprised less than 6, but occasionally to 18 percent of monthly samples.

Gastropod larvae were most abundant during July or August, comprising some 10 percent of monthly samples.

Polychaete eggs and larvae were most abundant during October-November, comprising from 30 to 54 percent of monthly samples.

The most abundant copepod collected during the summer-fall period was Acartia tonsa which generally comprised from 15 to 38 percent of monthly samples. Its density typically increased with salinity. The epibenthic harpacticoid copepod Ectinosoma spp. comprised from one to three percent of monthly samples during summer-fall.

Macroinvertebrate Plankton

From January 1974 through December 1976 a total of 46 macroinvertebrate taxa was identified in 492 collections. These included 32 taxa of the phylum Arthropoda, 5 of Cnidaria, 4 of Annelida, 2 each of Ctenophora and Mollusca, and 1 of Rhynchocoela. Annual mean density ranged from ca. $3,000/100m^3$ in 1974 to $5,100/100m^3$ in 1976.

Monthly mean density of macroinvertebrates during 1974 through 1976 was extremely variable. It was lowest in February 1974 (ca. $10/100m^3$); common taxa included Gammarus spp. (40 percent), Neomysis americana, (22) and Chiridotea almyra (14). It was greatest in July 1976 (ca. $25,000/100m^3$); common taxa included Uca minax (43 percent), Rhithropanopeus harrisii (29) and N. americana (26). Monthly mean density more typically ranged from ca. $100/100m^3$ to ca. $10,000/100m^3$.

Based on percent composition of monthly samples, Mysidacea (mysid shrimp) and Amphipoda (scuds) were the dominant organisms throughout each year. The only mysid observed was

N. americana, but Mysidopsis bigelowi may have occurred rarely during periods of high salinity. The category Gammarus spp. was the dominant amphipod although Corophium lacustre was occasionally abundant.

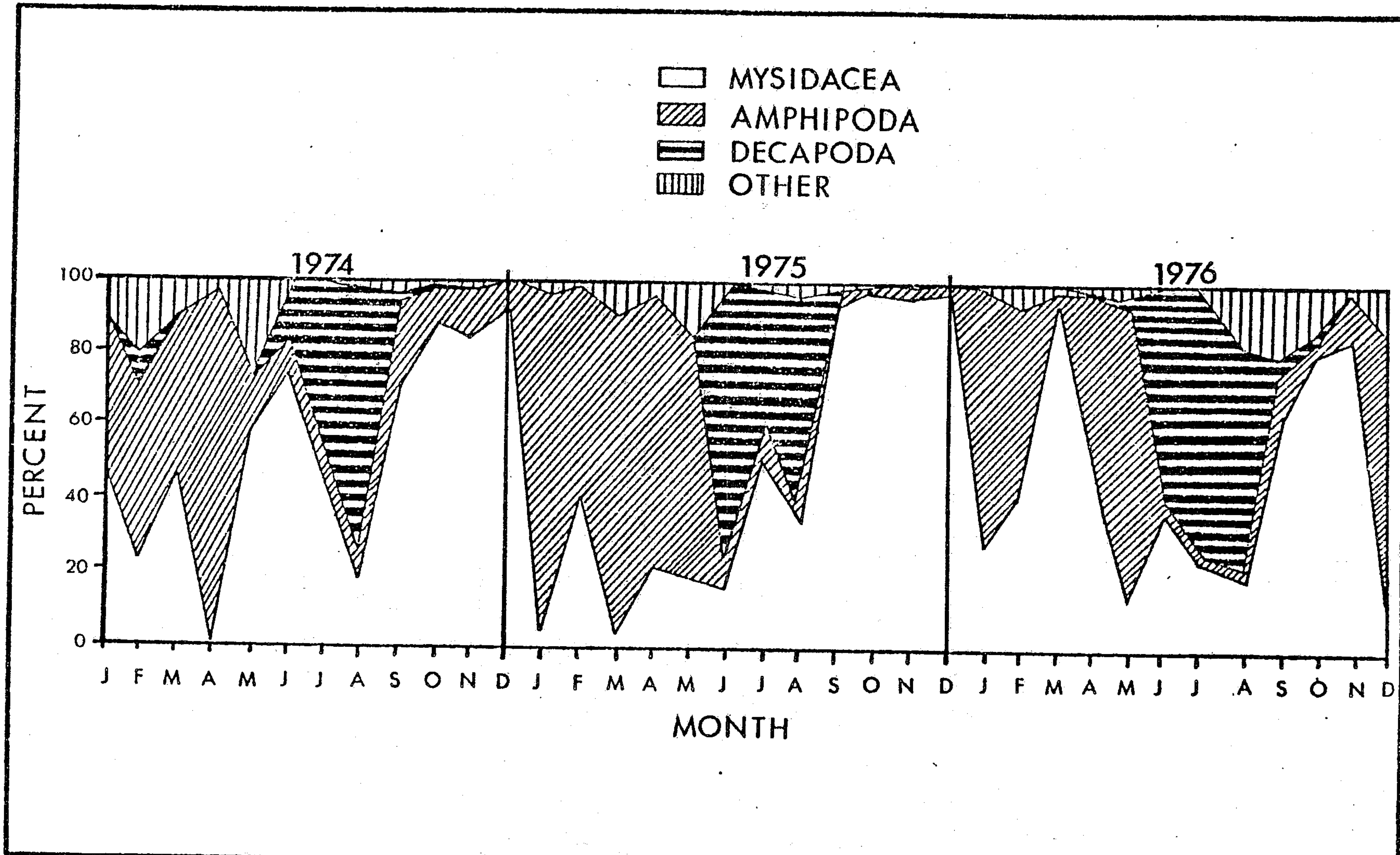
Annual similarity of monthly (Fig. 36) and seasonal mean density is evident. During January through May density was typically low, occasionally to ca. 2,000/100m^3 and often under 1,000/100m^3. Density peaked (at typically >6,000/100m^3) during June through August-September, declined sharply in September or October and then increased to moderate levels (ca. 3,000-3,500/100m^3) during November-December.

Seasonal change in macroinvertebrate plankton abundance was generally related to abundance of a few dominant taxa including Gammarus spp., Neomysis americana, Uca minax and Rhithropanopeus harrisii.

During January through May Gammarus spp. and Neomysis americana typically comprised at least 80, and occasionally more than 95 percent, of monthly density.

During June through August-September N. americana, U. minax, R. harrisii and Gammarus spp., typically comprised over 95 percent of monthly density. Rising temperature resulted in reproductive peaks for many taxa, particularly the brachyurans U. minax and R. harrisii which were typically collected only during this period, comprising to 75 percent of monthly samples. Density of U. minax larvae typically increased rapidly from zero in May to a peak (ca. 7,000-10,000/100m^3) in June or July and then declined sharply in July or August. This was most evident in 1975. Why its density in 1974 was so low is not known. Density of R. harrisii larvae typically increased from June through July, peaked in August, and declined in September. During this period Neomysis americana and Gammarus spp. comprised from 17 to 95 and 2 to 22 percent, respectively, of monthly samples. Other taxa seasonally abundant during August-September included Blackfordia virginica, Corophium lacustre and Edotea triloba.

The sharp decline in monthly macroinvertebrate density during September-October reflected the seasonal decrease in brachyuran larvae. From September-October through December N. americana and Gammarus spp. were dominant and comprised 66 to 99 percent and 1 to 12 percent, respectively, of monthly samples.



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ARTIFICIAL ISLAND STUDIES

Relative temporal abundance of dominant macroinvertebrate plankton groups.

Figure 36

From January 1974 through December 1976 a total of 57 taxa representing eight phyla was identified in 1,044 samples. These included 20 taxa of the phylum Arthropoda, 12 of Annelida, 12 of Mollusca, 5 of Cnidaria, 3 each of Platyhelminthes and Ectoprocta, and 1 each of Porifera and Rhynchocoela.

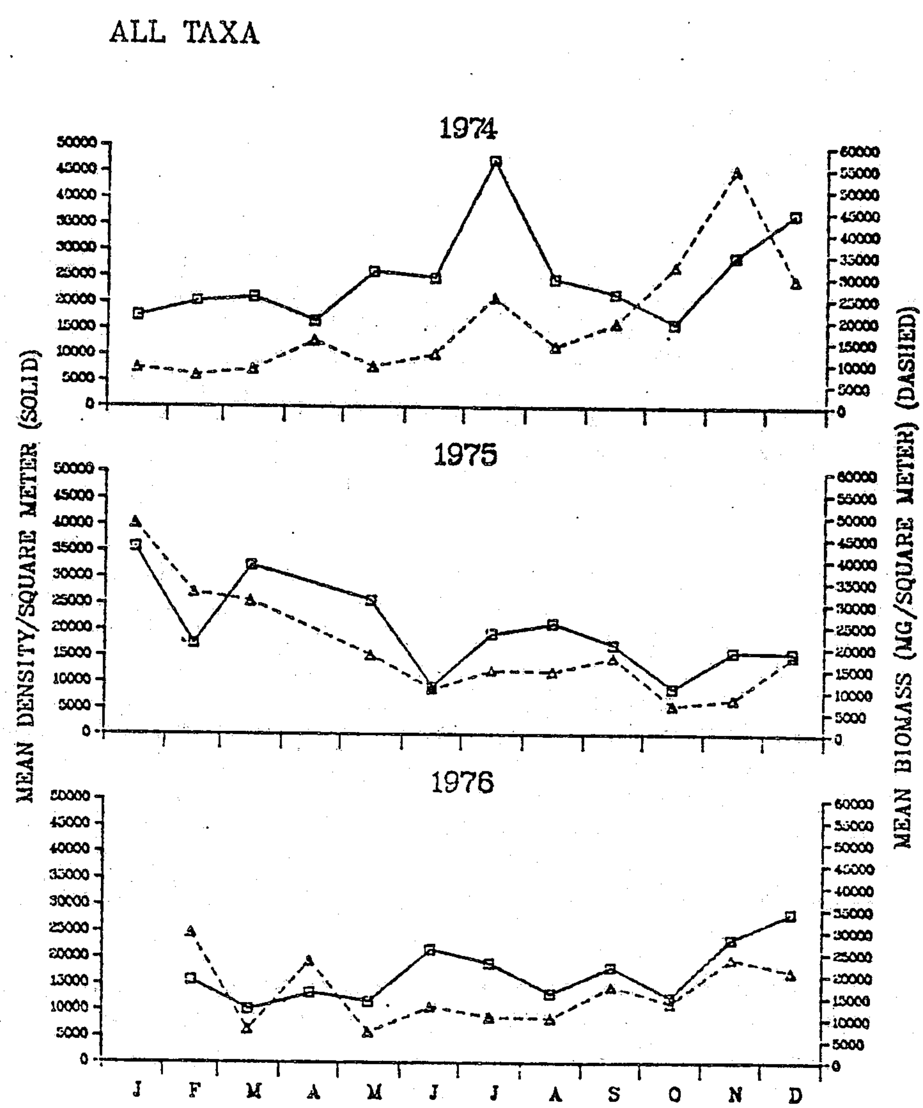
Mean density was greater in 1974 (ca. 25,100/m^2) than in 1975 and 1976 (ca. 19,100/m^2 and 17,000/m^2, respectively); mean biomass was greater in 1975 (ca. 21,400 mg/m^2) than in 1974 and 1976 (ca. 19,600 mg/m^2 and 15,800 mg/m^2, respectively).

Scolecolepides viridis, Polydora sp., Paranais litoralis, Balanus improvisus, and Cyathura polita annually ranked among the top six species during 1974 through 1976. Together they comprised 78 to 80 percent of annual mean density. In terms of biomass, S. viridis and B. improvisus were most important and comprised 59 to 67 percent of annual samples. These five resident species occurred throughout the study area but were abundant only in specific substrate types.

Monthly benthos density varied greatly. It was lowest in October 1975 (ca. 8,700/m^2); common taxa included Polydora sp. (47 percent), Scolecolepides viridis (16), and Paranais litoralis (9). It was greatest in July 1974 (ca. 47,200/m^2); common taxa included Balanus improvisus (53 percent), P. litoralis (15), and Polydora sp. (9). Monthly mean biomass was lowest in October 1975 (6,500 mg/m^2); common taxa included S. viridis (56 percent), Macoma balthica (12), and Cyathura polita (8). It was greatest in November 1974 (54,600 mg/m^2); common taxa included B. improvisus (68 percent), S. viridis (8), and M. balthica (7).

A similar seasonal pattern of species composition and abundance was annually evident. Mean density was highest during June through September (ca. 9,100-47,200/m^2), reflecting reproduction of B. improvisus, and was also high during November through March (ca. 10,100-37,100/m^2) due to an increase of the polychaetes S. viridis and Polydora sp. (Fig. 37). Density was typically low in April and October (ca. 8,700-16,500/m^2). The seasonal pattern of mean biomass varied between years but it closely paralleled the abundance of B. improvisus which comprised most of the biomass.

On a density basis Polychaeta, Oligochaeta, and Cirripedia together comprised 62 to 89 percent of monthly samples (Fig. 38). Polychaeta, represented by nine taxa, was the



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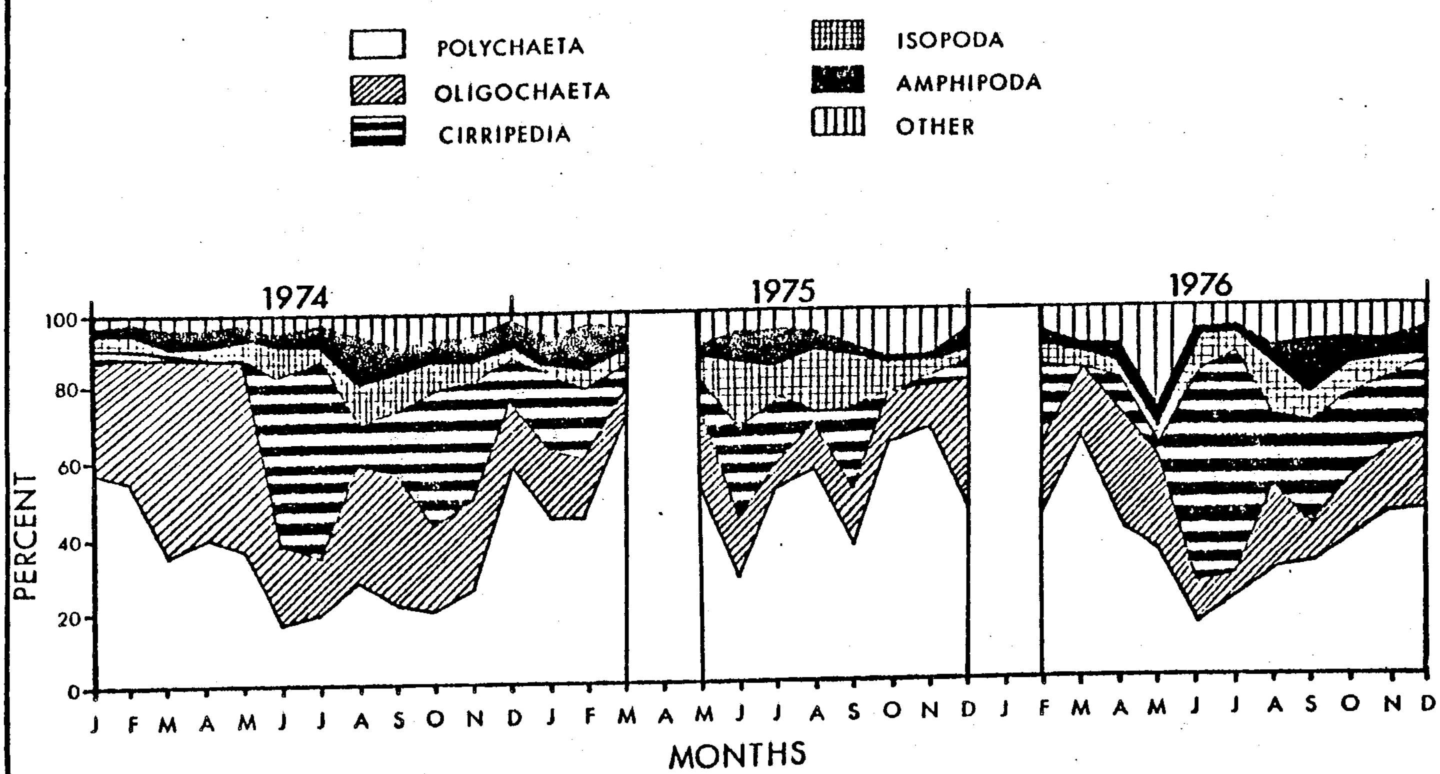
ARTIFICIAL ISLAND STUDIES

Monthly mean density and biomass of benthic invertebrates.

Figure 37



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ARTIFICIAL ISLAND STUDIES

Relative temporal abundance of dominant benthic invertebrate groups.

Figure 38

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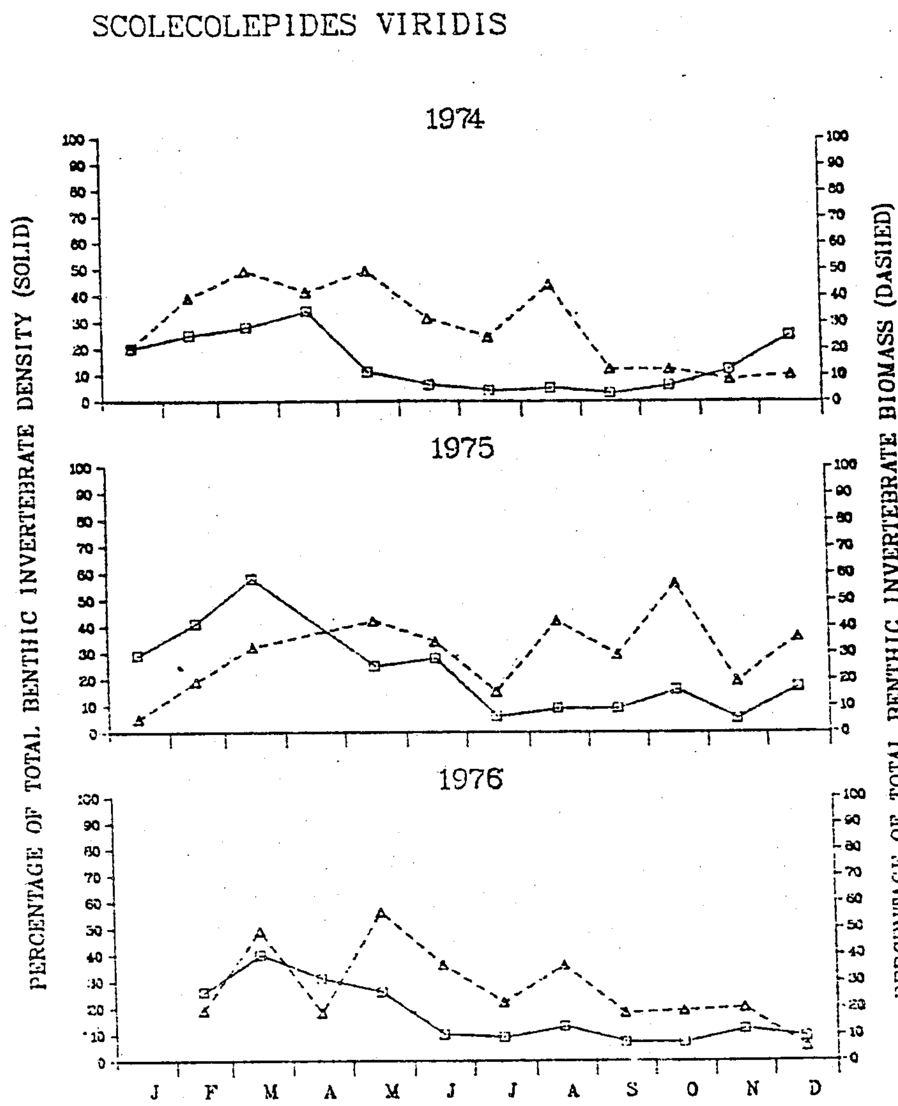
most diverse and dominant group. It was most abundant during October through April when it comprised 20 to 69 percent of monthly samples (Fig. 38). Scolecolepides viridis and Polydora sp., both estuarine deposit feeding polychaetes, were among the most abundant benthic taxa near Artificial Island. S. viridis had a high annual percent occurrence (55-100 percent) at all stations. It was most abundant during November through April, comprising 5 to 58 percent of the monthly density (Fig. 39), reflecting reproduction during September through December. It comprised 4 to 56 percent of the monthly biomass, but no seasonal pattern was discernible. Polydora sp. was taken at 8 of the 10 stations and had a high annual percent occurrence (50-91 percent) at only three stations. It comprised 0 to 62 percent of monthly density (Fig. 40) although no annual pattern of seasonal abundance was evident. In terms of biomass it comprised to 10 percent of monthly samples. Other numerically important polychaetes were Nereis succinea and Streblospio benedicti. N. succinea was taken during all months but in terms of density was only sporadically abundant, comprising to 10 percent of monthly samples. S. benedicti was common only during high salinity periods from August through December when it comprised to 6 percent of monthly density.

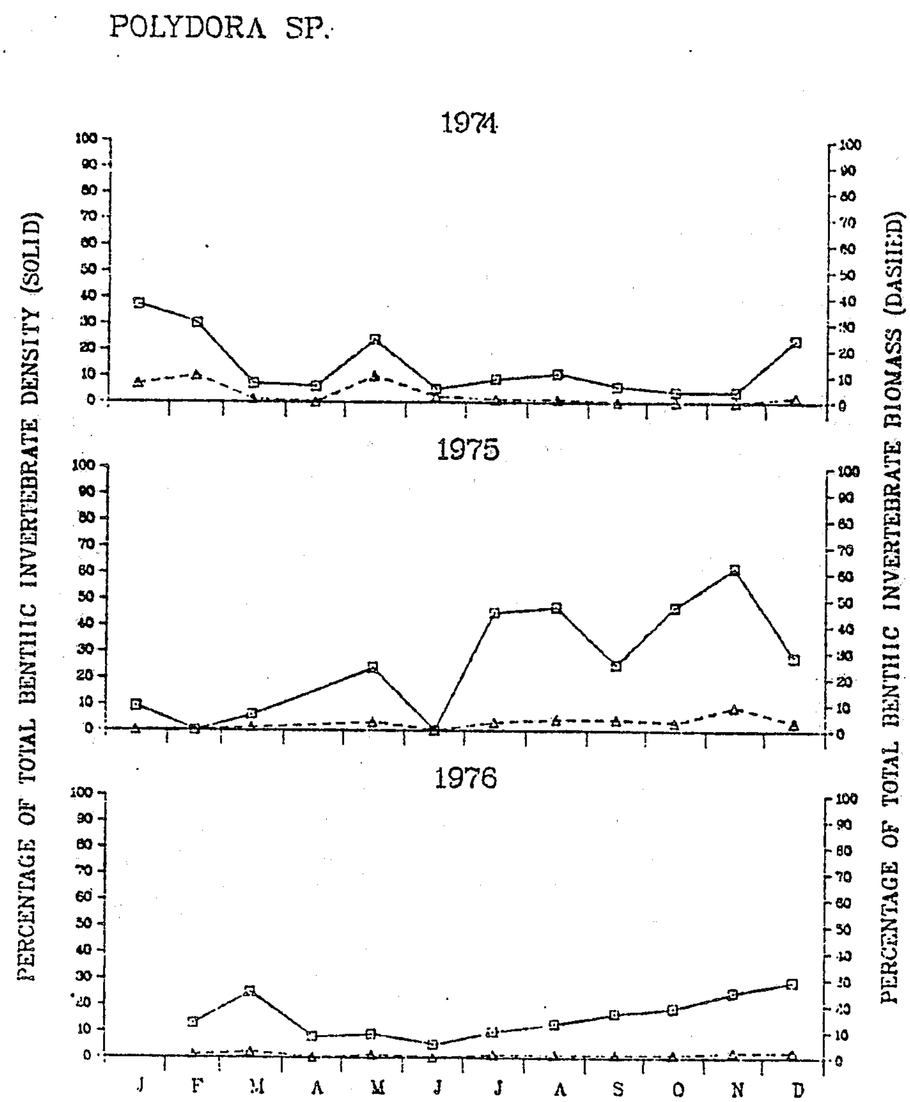
Oligochaeta, represented by three taxa, generally was most abundant during spring and late fall, comprising 8 to 54 percent of monthly density (Fig. 38). Paranais litoralis, the only common oligochaete, was one of the most abundant benthic taxa in terms of density. It was taken at all stations and had a high annual percent occurrence (61-100 percent) at six stations. Density was generally high during spring and late fall (6-54 percent of monthly samples) (Fig. 41). P. litoralis comprised 5 percent or less of monthly biomass.

Cirripedia, represented only by Balanus improvisus, was important in terms of both density and biomass. It was taken at nine stations but had a high annual percent occurrence (67-89 percent) at only the one station with gravel-shell substrate. Generally it was most abundant during June and July when it comprised 18 to 61 percent of monthly density (Fig. 42). This abundance followed the period of maximum reproductive activity in May. Biomass generally was high in spring and late fall when larger individuals predominated. During these periods it comprised to 75 percent of monthly samples.

Isopoda and Amphipoda were also important groups in the benthos in terms of both density and biomass. Isopoda, represented by four taxa, was most abundant during summer and fall when it comprised 4 to 19 percent of monthly density (Fig. 38). Cyathura polita, the most common isopod, was taken at all stations and had a high annual percent



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Percent of total monthly benthic invertebrate density and biomass - <u>S. viridis</u>.
	Figure 39



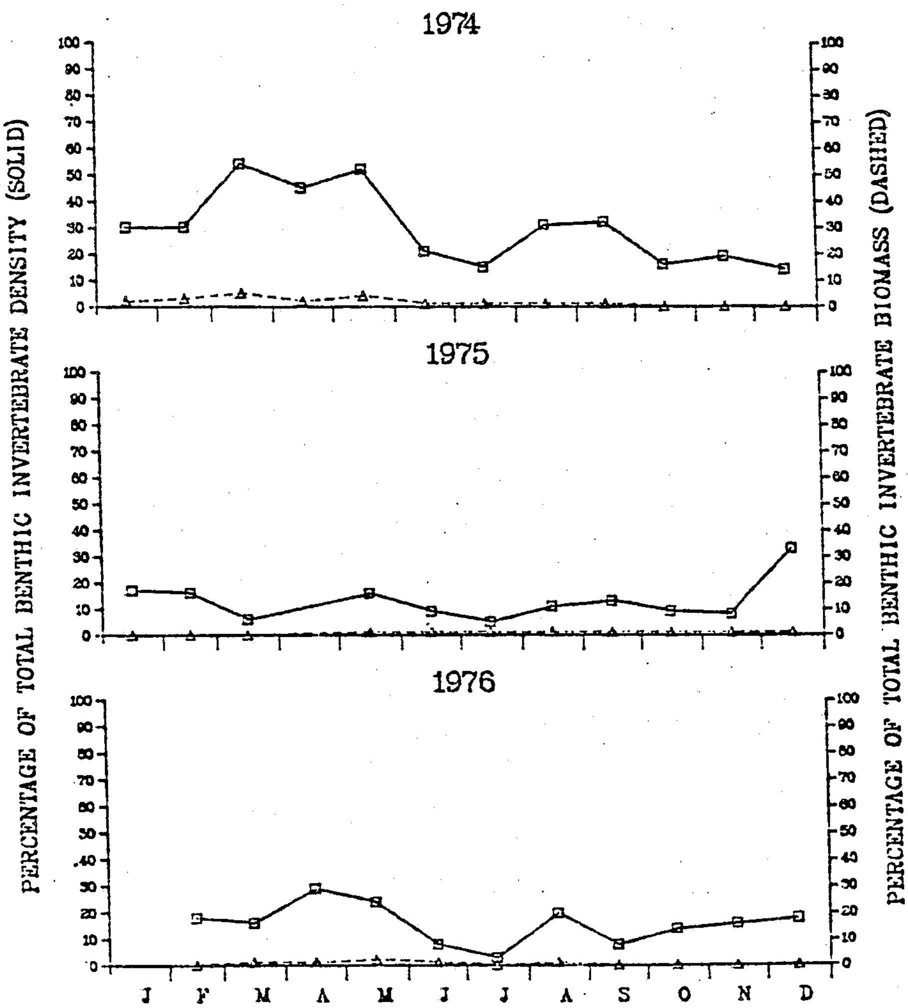
PUBLIC SERVICE ELECTRIC AND GAS COMPANY

ARTIFICIAL ISLAND STUDIES

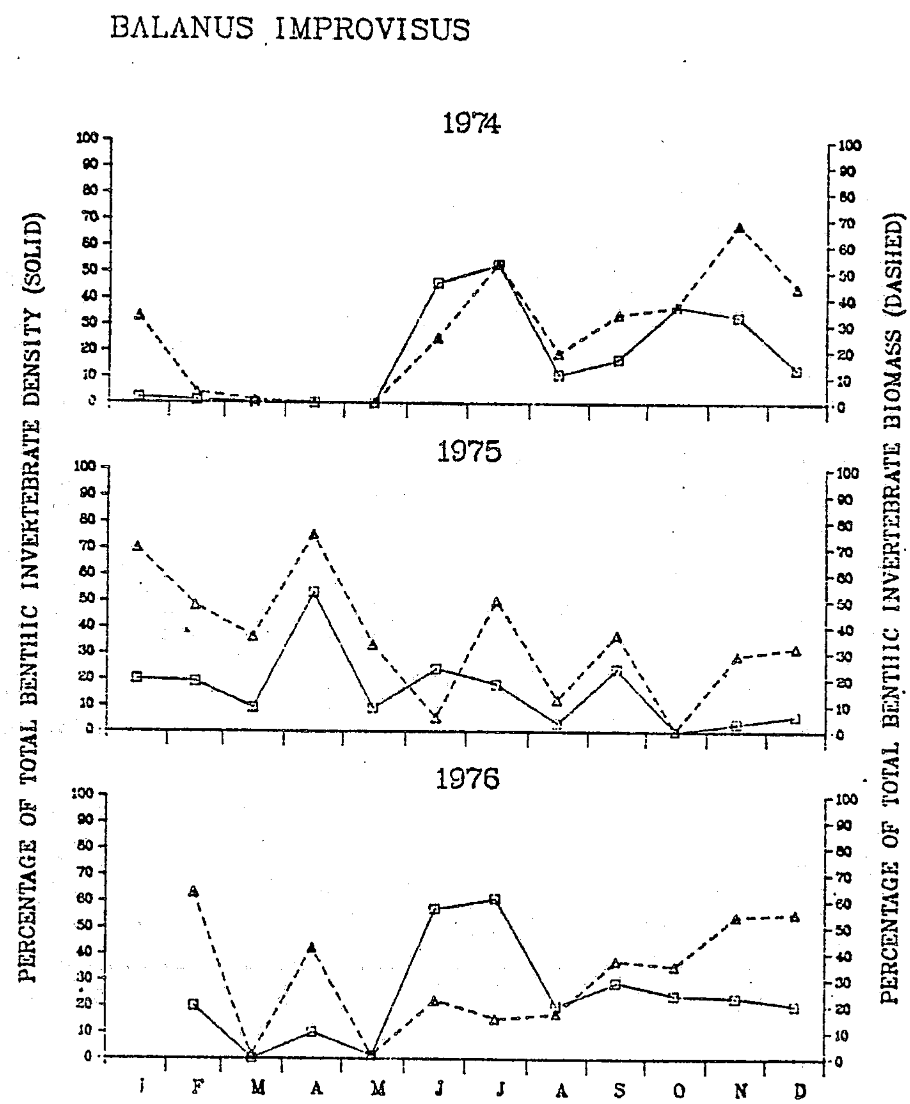
Percent of total monthly benthic invertebrate density and biomass - Polydora sp.

Figure 40

PARANAIS LITORALIS



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Percent of total monthly benthic invertebrate density and biomass - P. litoralis.
	Figure 41



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Percent of total monthly benthic invertebrate density and biomass - B. improvisus.
	Figure 42

occurrence (61-100 percent) at seven stations. Density was variable, but was greatest (3 to 10 percent of monthly samples) in August and September (Fig. 43). It comprised from 1 to 9 percent of monthly biomass and no seasonal pattern was evident.

Amphipoda, represented by six taxa, demonstrated no seasonal density pattern and comprised 1 to 15 percent of monthly samples (Fig. 38). Gammarus spp. and Corophium lacustre were the most abundant amphipods. They occurred, but in low numbers, at most stations. Gammarus spp. comprised to 12 percent of monthly density and biomass. C. lacustre comprised to 14 percent of monthly density and 1 percent or less of monthly biomass.

The remainder of the sample consisted of 34 taxa and comprised 2 to 26 percent of the monthly density (Fig. 38). In terms of biomass they comprised 5 to 46 percent, with Hydrozoa, Pelecypoda, and Decapoda being most abundant.

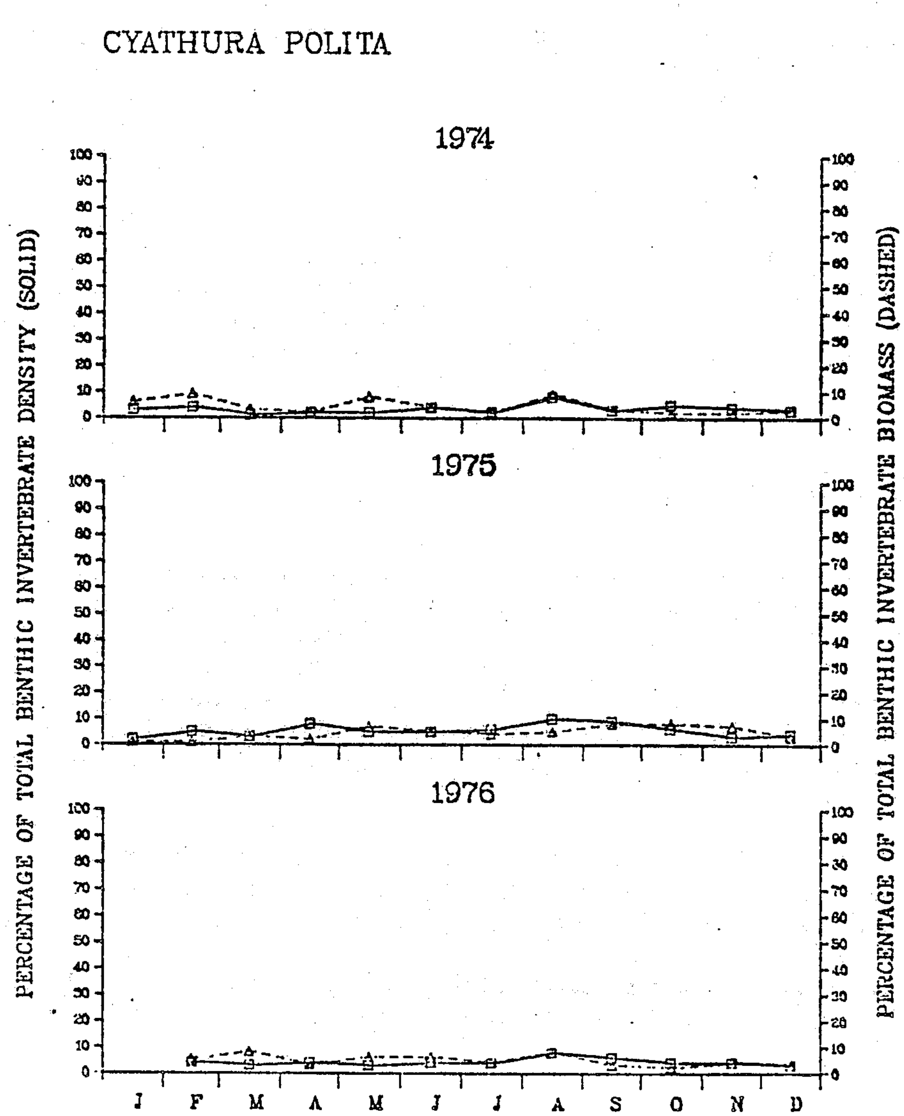
Species Discussion

This section discusses life history, temporal and spatial distribution, and abundance of important aquatic invertebrates that utilize the Delaware River near Artificial Island. Information on some 20 taxa, selected on the basis of annual abundance and ecological importance, is presented in phylogenetic order. Where available, information on the ecology and taxonomy of the major groups is also presented.

Quantitative statements are based primarily on data obtained in the sampling program (i.e., Microzooplankton, Macroinvertebrate plankton, Benthos or Blue Crab) in which the organism was most commonly taken. Several organisms occupy a variety of habitats during their life stages and abundance data from more than one program may be referenced.

Class Rotifera

Rotifers, or microscopic wheel animals, were numerically dominant members of the zooplankton community near Artificial Island. Due to their size (200-500), and numerical abundance they are an important link in the food web between primary producers and carnivores, serving as food for larval and juvenile fishes. Rotifers occurred throughout the year but were most abundant from January



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Percent of total monthly benthic invertebrate density and biomass - C. polita.
	Figure 43

through May or June. When abundant they comprised from 28 to 97 percent of the total microzooplankton sample.

Rotifer reproduction is usually asexual (parthenogenesis). However, during periods of adverse environmental conditions males develop and fertilize females. When this occurs, haploid "winter resting" eggs are deposited and hatch after conditions improve. Otherwise, most species carry their eggs until hatching. The life cycle may occur in from 5 to 15 days (Hyman, 1951).

Near Artificial Island, the predominant rotifers were "rotifer" spp, *Notholca* spp., *Brachionus angularis* and *B. calyciflorus*. Only the category "rotifer" spp., which annually ranked among the top two microzooplankton taxa, is discussed.

"Rotifer" spp.

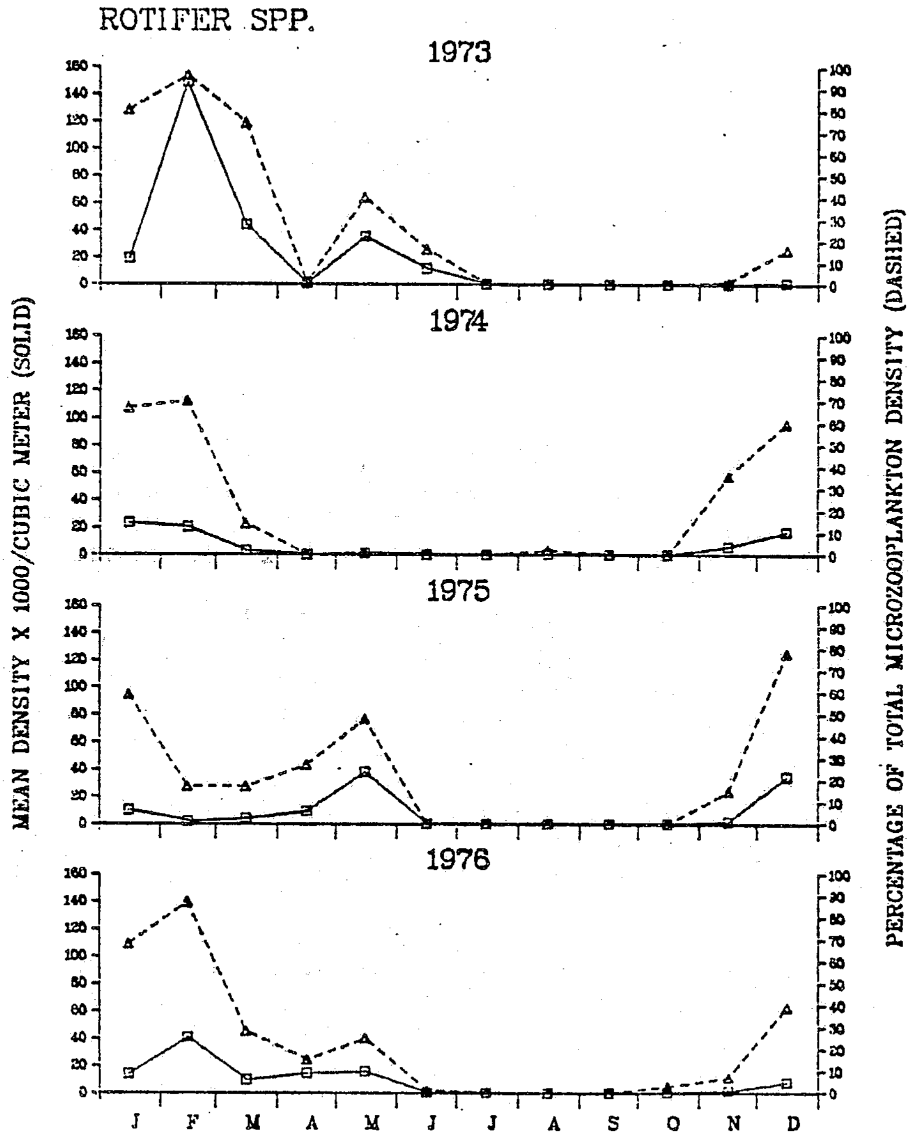
This is an artificial taxon used to describe, as a group, soft-bodied rotifers that contract upon preservation making specific identification difficult. It includes several species of *Synchaeta* and possibly other illoricate rotifers.

"Rotifer" spp. was annually collected at all stations and during all months at temperature of 0.1 to 29.5 C and salinity of 0.0 to 14.0 ppt. Generally, density was greatest from December through February, declined through March or April, increased to moderate levels through May, and then decreased from June through October or November (Fig. 44). During the period of maximum abundance "rotifer" spp., with mean monthly density of from 2,000 to 148,000/m^3, comprised from 17 to 96 percent of monthly microzooplankton samples.

Abundance seems inversely related to salinity and was typically greatest at less than 7.5 ppt. Density was greatest at the northernmost (low salinity) sampling stations near the Chesapeake and Delaware Canal. No vertical distributional trends were apparent.

Class Polychaeta

Polychaeta, commonly known as bristleworms, range in size from five to several hundred millimeters. Body shape is extremely diverse and ranges from conventional wormlike to forms that are stout, conical or ovoid. Most species are



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density, and percent of total monthly microzooplankton - "Rotifer" spp.
	Figure 44

marine or estuarine but there are freshwater forms. Near Artificial Island, polychaetes are ecologically important in both the plankton and benthos communities. Microscopic planktonic eggs and larvae, due to their size and availability, are probably utilized as food by fishes. Adults function in the benthos as deposit feeders, predators, and as prey for demersal fishes. They occurred throughout the year but were most abundant from November through March when they comprised from 25 to 69 percent of monthly benthos samples.

The sexes are separate but some species reproduce asexually. Gametes are usually shed into the water, and offspring pass through developmental stages including the egg (usually encapsulated), a swimming trochophore larva, and segmented larval stages (Gosner, 1979).

Eggs and larvae, although unspeciated, are considered representative of the 7 to 8 polychaete species collected annually. These life stages, and adults of the predominant species, *Scolecolepides viridis* and *Polydora* sp., are discussed.

Polychaeta Eggs and Larvae

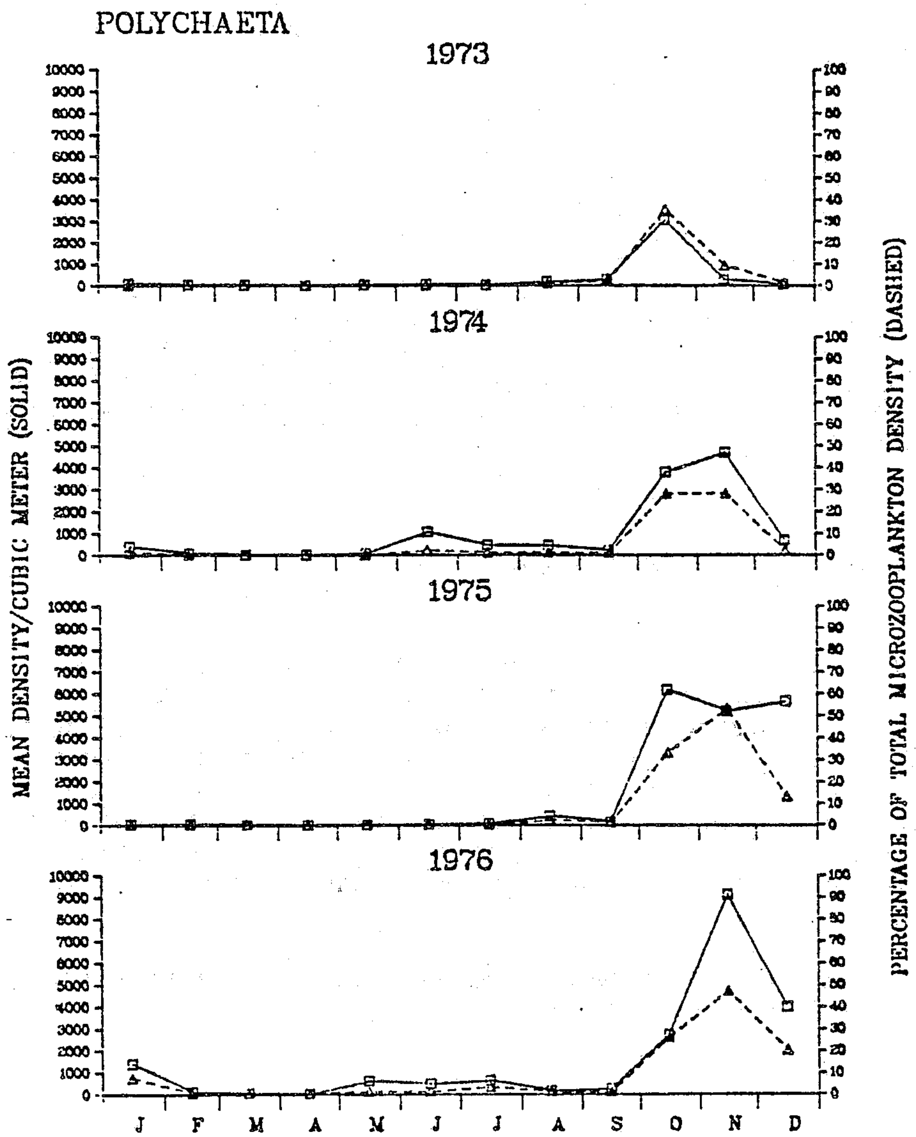
Near Artificial Island, eggs and larvae were seasonally abundant in the microzooplankton. They occurred throughout the year at temperature of 0.0 to 31.0 C and salinity of 0.0 to 17.2 ppt, but were most abundant from September through December, when they comprised to 51 percent of monthly microzooplankton samples (Fig. 45). In a recent study of the lower Delaware Bay, Lambert and Pembroke (1976) reported a similar period of maximum abundance (September through November).

Neither eggs nor larvae demonstrated horizontal or vertical distribution patterns.

Scolecolepides viridis

This oligo-mesohaline, sedentary polychaete is found on the east coast of North America from Newfoundland to South Carolina (George, 1966).

In the Delaware River estuary it ranges north to New Castle, Delaware (RK 108; RM 67) (Taylor et al., 1973) and south to the mouth of the Bay (Kinner et al., 1975).



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density, and percent of total monthly microzooplankton - Polychaeta (eggs and larvae).
	Figure 45

Near Artificial Island *S. viridis* annually ranked among the top four benthic taxa in density and was second in biomass. Although it was taken in all substrate types, density was greatest in clay and only slightly less on sand or sandy-mud substrates. Its abundance in the estuary is greatest in the study area.

Density increased in November or December and peaked during January through April (Fig. 46). During the peak period, *S. viridis*, with monthly mean density of ca. 3,400 to $18{,}600/m^2$, comprised from 20 to 58 percent of monthly benthos samples (Fig. 39). The period of greatest reproductive activity, as indicated by abundance of juveniles (1.5-3.0 mm), was from October through December.

Its great density and biomass demonstrate its importance in the benthos and to the local food chain.

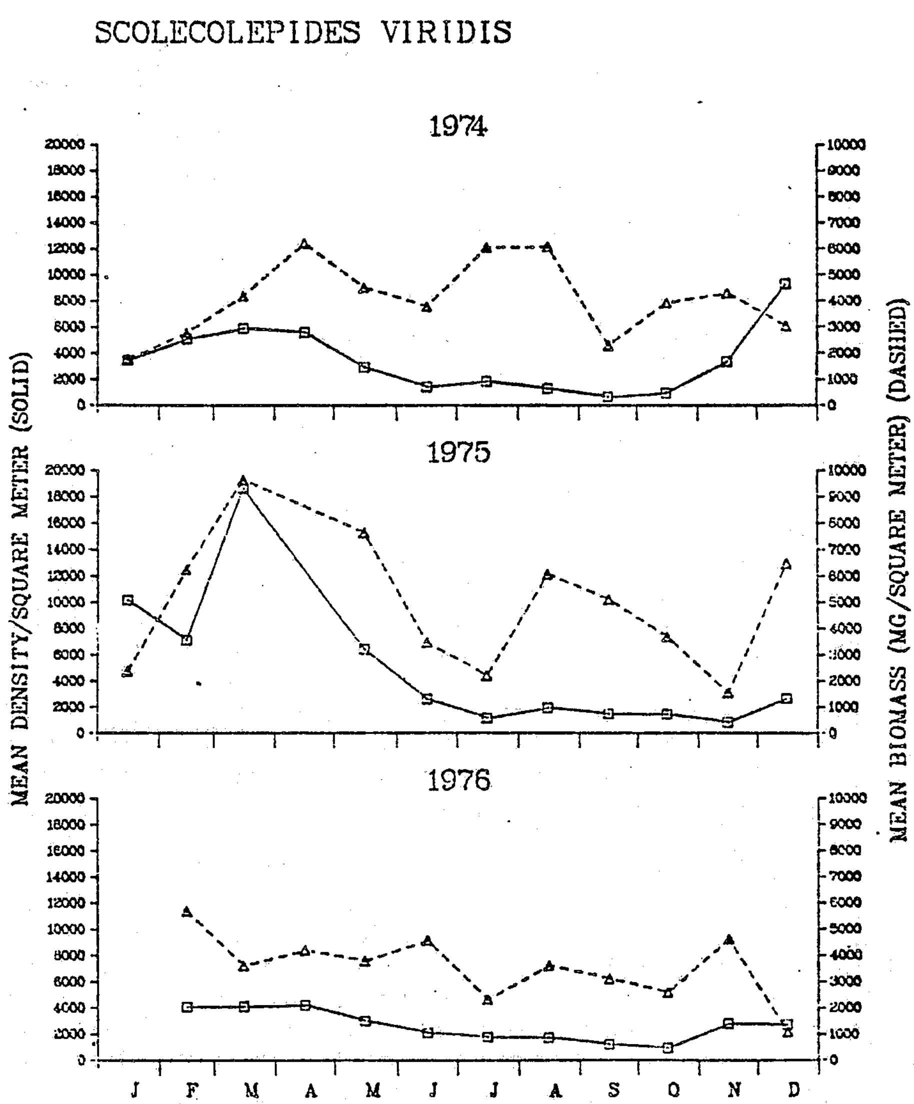
Polydora sp.

This polychaete is found along the entire Atlantic coast. Most specimens taken near Artificial Island are probably *P. ligni*, an oligo-euhaline polychaete (Wass et al., 1972) which prefers a mud-clay substrate (Gosner, 1979).

In the Delaware River Estuary, species of *Polydora* range from the Bay mouth to the Chesapeake and Delaware Canal. Although five species of *Polydora* were taken by Kinner and Maurer (1978) in Delaware Bay, *P. ligni* was the most common. *P. ligni* was the only species of *Polydora* taken in the Chesapeake and Delaware Canal (Raytheon, 1975).

Near Artificial Island, *Polydora* sp. was collected at 23 of 30 stations and annually ranked among the top four benthic taxa in density. It was most abundant at stations with mud-clay substrate. Greatest density (ca. $8{,}200$-$9{,}900/m^2$) occurred during August, November, and December, but it was sporadically abundant during other months (Fig. 47). No distinct reproductive period was apparent. Blake (1969) stated that *P. ligni* produces two or more broods in a season. Since this taxon is at its upriver limit in the estuary, recruitment from downbay may supplement local reproduction.

Ecological importance is indicated by its numerical abundance in the benthic community, and a negative economic importance has been documented in nearby areas. In Delaware Bay, Galtsoff (1964) reported that the reproduction of *P. ligni* on oyster grounds was so rapid that almost every live



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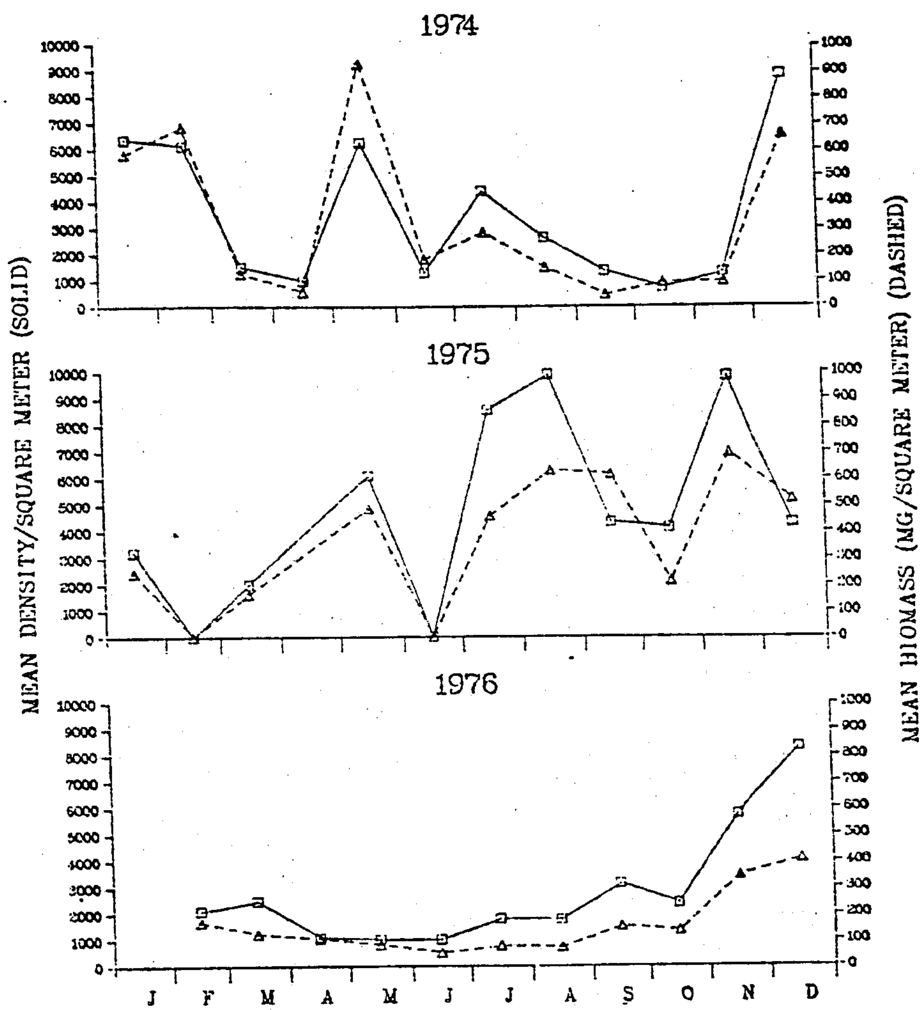
ARTIFICIAL ISLAND STUDIES

Monthly mean density and biomass - S. viridis.

Figure 46

POLYDORA SP.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density and biomass - *Polydora* sp.
	Figure 47

oyster in the affected area was killed by the accumulation of "mud" consisting of hordes of live worms and their tubes.

Class Oligochaeta

Oligochaeta, aquatic earthworms, are small, slender hermaphroditic annelids. They are essentially benthic organisms which live within and feed on bottom deposits (Cook and Brinkhurst, 1973). They are ecologically important as detritivores. Near Artificial Island oligochaetes were numerically dominant members of the benthos community. They occurred throughout the year and comprised to 54 percent of monthly benthos samples.

Some genera are capable of self-fertilization, but the common reproductive technique is simultaneous cross-fertilization (Gosner, 1971). The eggs are deposited in a cocoon, and development after hatching is direct with no distinct larval forms.

Paranais litoralis was annually the most abundant oligochaete in the benthos and is discussed.

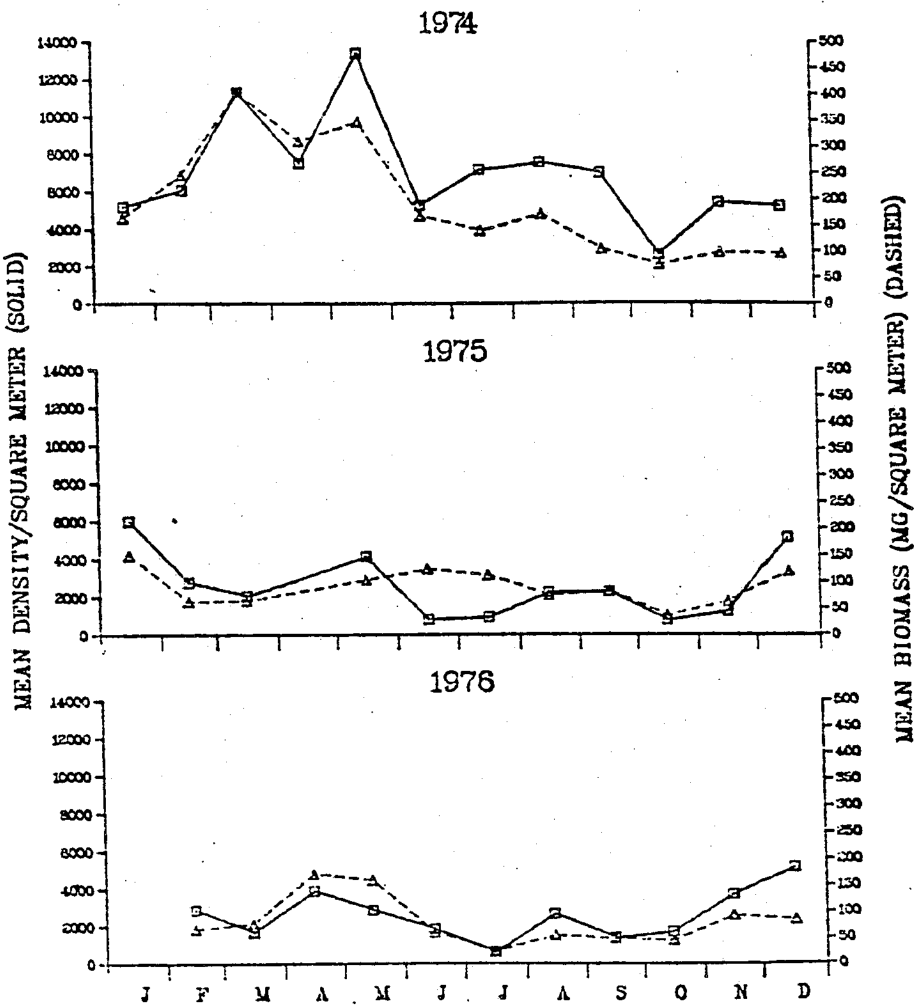
Paranais litoralis

This brackish marine species ranges from Nova Scotia to Delaware and occurs inter- and subtidally to 7 m depth (Cook and Brinkhurst, 1973). Distributional data are limited and although no record in Delaware Bay was found it probably occurs. Watling (1975) took high densities of *P. litoralis* in Rehobeth Bay, Delaware at salinity of 25 to 29 ppt.

Near Artificial Island it annually ranked among the top three benthic taxa in density and was collected in all substrate types. Lowest density (ca. 1-280/m^2) occurred in sand and clay; greatest (ca. 320-2,000/m^2) occurred in mud. Density was generally high during spring, decreased during summer, and increased again during late fall (Fig. 48). Watling (1975) found that in Rehobeth Bay density of *P. litoralis* increased in March, reached a peak in May, and then sharply declined during summer.

P. litoralis probably functions as a major competitor with other deposit feeding organisms.

PARANAIS LITORALIS



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density and biomass - P. litoralis.
	Figure 48

Class Gastropoda

Gastropods, or snails, are characterized by a univalve shell and comprise the largest and most diverse group of molluscs (Leatham and Maurer, 1976). They occur in fresh, brackish, and marine waters and terrestrial environments throughout the world. Near Artificial Island adults were rare in the benthos. However, veliger larvae were seasonally abundant and comprised to 10 percent of monthly microzooplankton samples. They are ecologically important as detritivores and as a food source for fish and invertebrates.

Several families, including Hydrobiidae, Nassariidae, Pyramidelliidae and Melampidae, are common to the mudflats, tidal creeks and marshes surrounding Delaware River and Bay (Maurer and Watling, 1973). Veligers taken in our samples are believed to originate in these local areas.

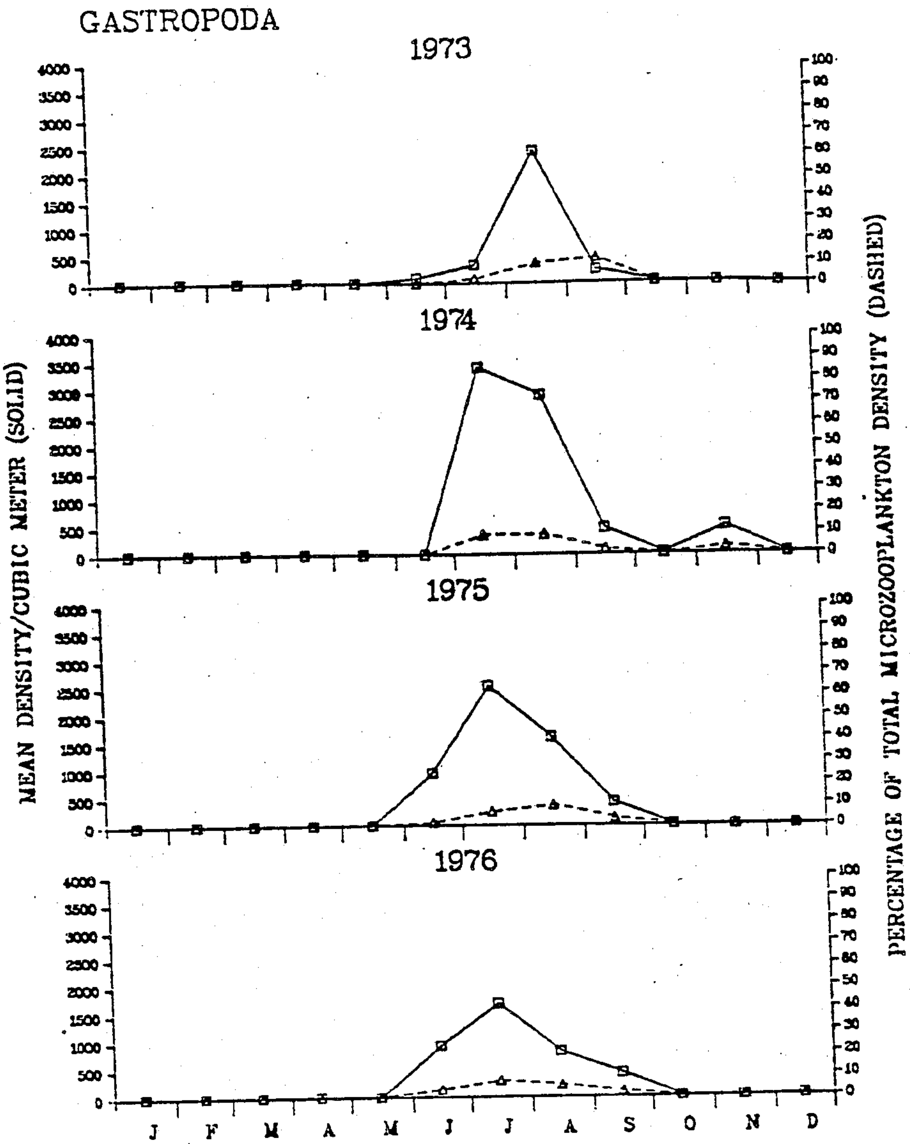
Reproduction is sexual. Sexes are usually separate although some orders may be hermaphroditic. Fertilization may be internal or external. Developmental stages include egg, ciliated trocophore larvae, veliger larvae, and adult. Veliger larvae were abundant in the microzooplankton and are discussed.

Gastropod Veligers

Veliger larvae were collected in microzooplankton samples as far upriver as Pea Patch Island (RK 97; RM 60) but were most abundant downriver of Artificial Island. Density in Hope Creek during 1974 and 1975 was greater than in the river, suggesting that most larvae originate in local tidal marshes.

Although veliger larvae were annually abundant, seasonal occurrence was generally restricted to May through December at temperature of 8.2 to 31.0 C and salinity of 0.0 to 12.5 ppt. Greatest abundance was in July-August when density ranged from 1,800 to 3,400/m^3 and the larvae comprised to 10 percent of monthly samples (Fig. 49).

Veliger larvae were generally distributed near the river bottom; ca. 82 percent were collected in bottom samples.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density, and percent of total monthly microzooplankton - Gastropoda (veligers).
	Figure 49

Subclass Copepoda

Copepods are small (1-10 mm) crustaceans of which free-living, benthic, commensal, and parasitic forms occur universally in fresh, brackish and marine waters. They are ecologically important as primary consumers and detritivores, and are important in the diet of many fishes and invertebrates. Near Artificial Island, copepods are the most abundant component of the microzooplankton. They occur throughout the year but were most abundant from March through October or November when they comprised from 25 to 96 percent of monthly samples.

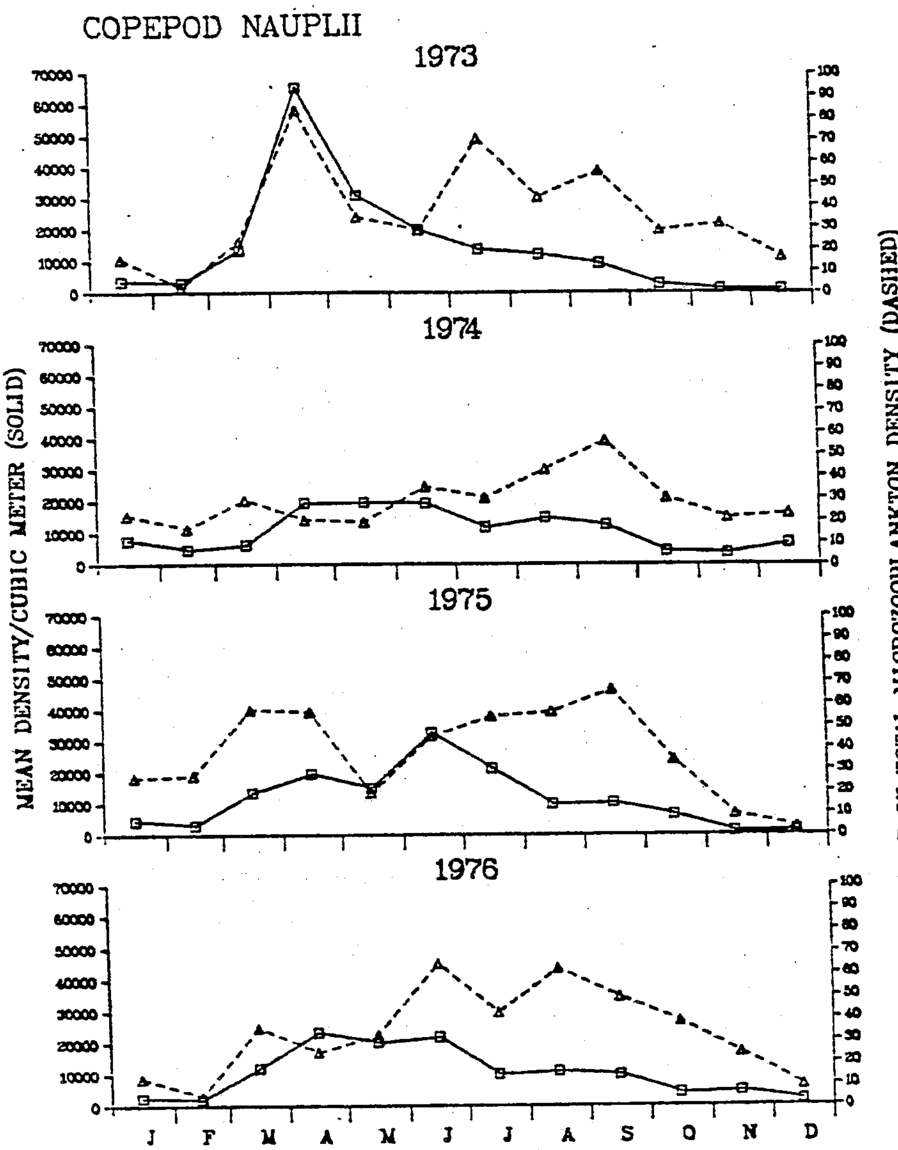
The free-living copepods are divided into the orders Calanoida, Cyclopoida and Harpacticoida. Calanoids are characterized by a fusiform shape and a filter feeding habit. Cyclopoids are tear shaped and have mouthparts adapted to seizing and biting. Harpacticoids are slender and elongate and feed by raking, seizing and scraping food from the bottom (Pennak, 1953).

Reproduction is sexual. Sperm is deposited in a spermatophore on the female genital segment and the eggs are fertilized and, with some exceptions, carried in external cases located on the genital segment (Wilson, 1932). A local exceptions is Acartia tonsa, which releases its eggs into the water column (Heinle, 1970). Incubation time varies with species and environmental conditions. Copepod development includes the egg, 6 nauplius, and five or six copepodid stages prior to adulthood.

Nauplii, although unspeciated, are considered representative of the 15 to 25 copepod species collected annually. This life stage, and copepodids and adults (collectively) of the predominant species Acartia tonsa and Eurytemora affinis are discussed.

Nauplii

Near Artificial Island nauplii were the most abundant copepod component and were collected at temperature of 0.1 to 28.7 C and salinity of 0.0 to 14.0 ppt. Their occurrence reflects the combined seasonal occurrences and reproductive periods of all local copepods. Greatest density was from March through September (ca. 5,000 to 65,000/m^3) when they comprised from 20 to 83 percent of monthly samples (Fig. 50). Due to their size and prolonged abundance they are an important fish and invertebrate food. They were collected at all stations with no apparent pattern of



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density, and percent of total monthly microzooplankton - copepod nauplii.
	Figure 50

horizontal or vertical distribution.

Eurytemora affinis

This true estuarine calanoid occurs in fresh and brackish waters from Cape Cod to the Gulf of Mexico (Edmondson, 1959).

In the Delaware River Estuary E. affinis ranges from the Christina River (RK 114; RM 71) to Bombay Hook Island (RK 63; RM 39) during summer and from the Chesapeake and Delaware Canal area (RK 98; RM 61) to Slaughter Beach (RK 18; RM 11) during winter (Daiber et al., 1976).

Near Artificial Island it was generally collected during spring and fall at temperature of 0.1 to 31.0 C and salinity of 0.0 to 14.0 ppt (Fig. 51). It ranked among the five most abundant microzooplankters during 1975 and 1976, with greatest density during March through June. It annually ranked among the top two copepods, alternating with Acartia tonsa. During the period of maximum abundance, E. affinis, with monthly mean density of ca. 1,000 to 17,000/m^3, comprised from 5 to 15 percent of monthly samples.

Adults and copepodids were generally most abundant near bottom.

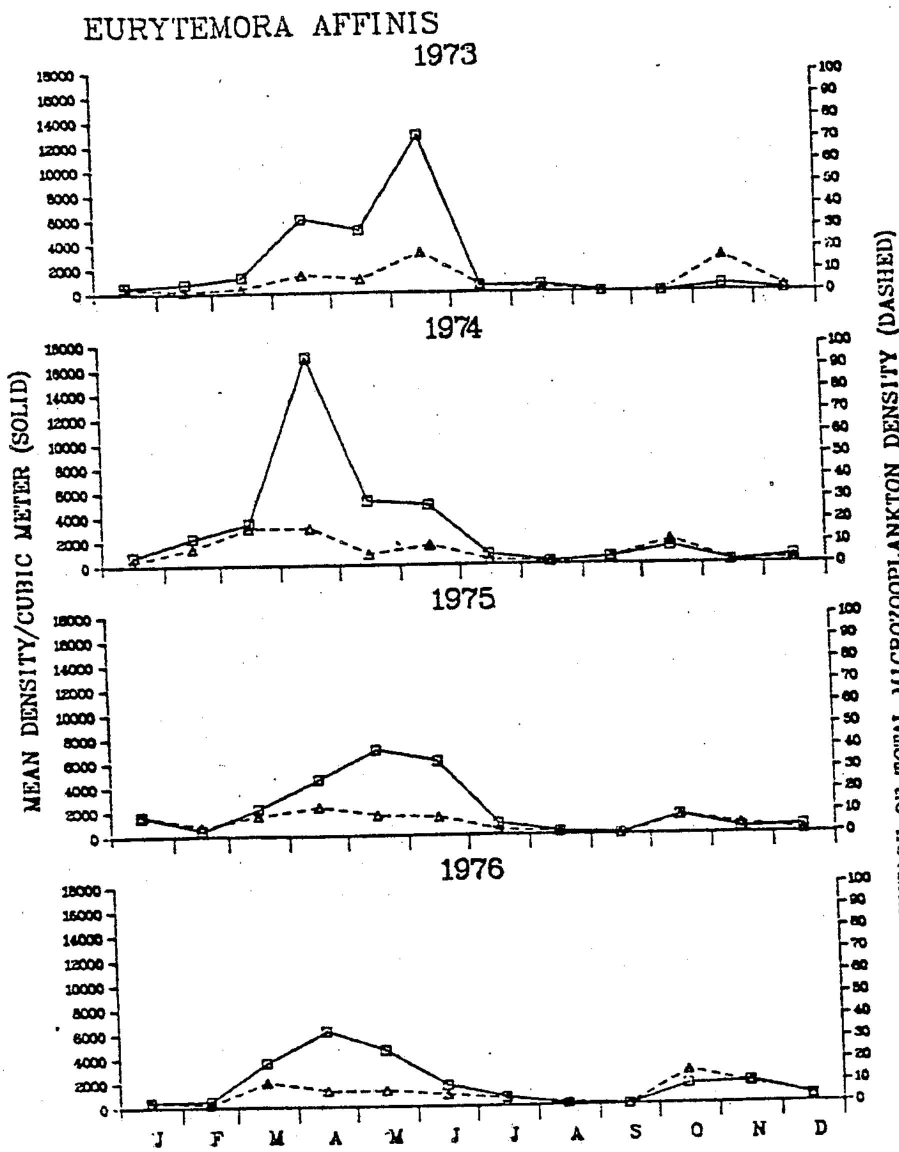
The sexes are separate and reproduction is sexual. Males are characterized by a geniculate (bent abruptly) left antennae and large fifth legs which are used to hold the female during copulation. Eggs are carried in egg sacs on the female genital segment until hatching. Developmental time ranges from 24 hrs at 25 C to 12.5 days at 5 C (Heinle, 1970).

It filter feeds on phytoplankton and detritus of from ca. 2-60 m (Heinle and Flemer, 1975), but demonstrates a selection for the larger sized particles (Richman et al., 1977).

In the present study it was found in the diet of the bay anchovy, white perch, and juvenile weakfish (Meadows, 1976).

Acartia tonsa

This calanoid copepod is found in all subtropical, tropical and temperate waters of the Atlantic and Pacific Oceans and



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density, and percent of monthly total microzooplankton - E. affinis.
	Figure 51

in estuaries to the limits of salt intrusion (Heinle, 1972). It is the most abundant and persistent copepod in the Delaware River Estuary (Cronin et al., 1962; Deevy, 1960; Annual Progress Report, 1977), Raritan Bay (Jeffries, 1962), Navesink River Estuary (Knatz, 1978), Patuxent River Estuary (Heinle, 1966), and Chesapeake Bay (Wilson, 1932).

In the Delaware River Estuary, Daiber et al. (1976) reported that it ranged from the Bay mouth to Pigeon Point (RK 112; RM 70) during summer and as far upriver as the Chesapeake and Delaware Canal (RK 95; RM 59) in winter.

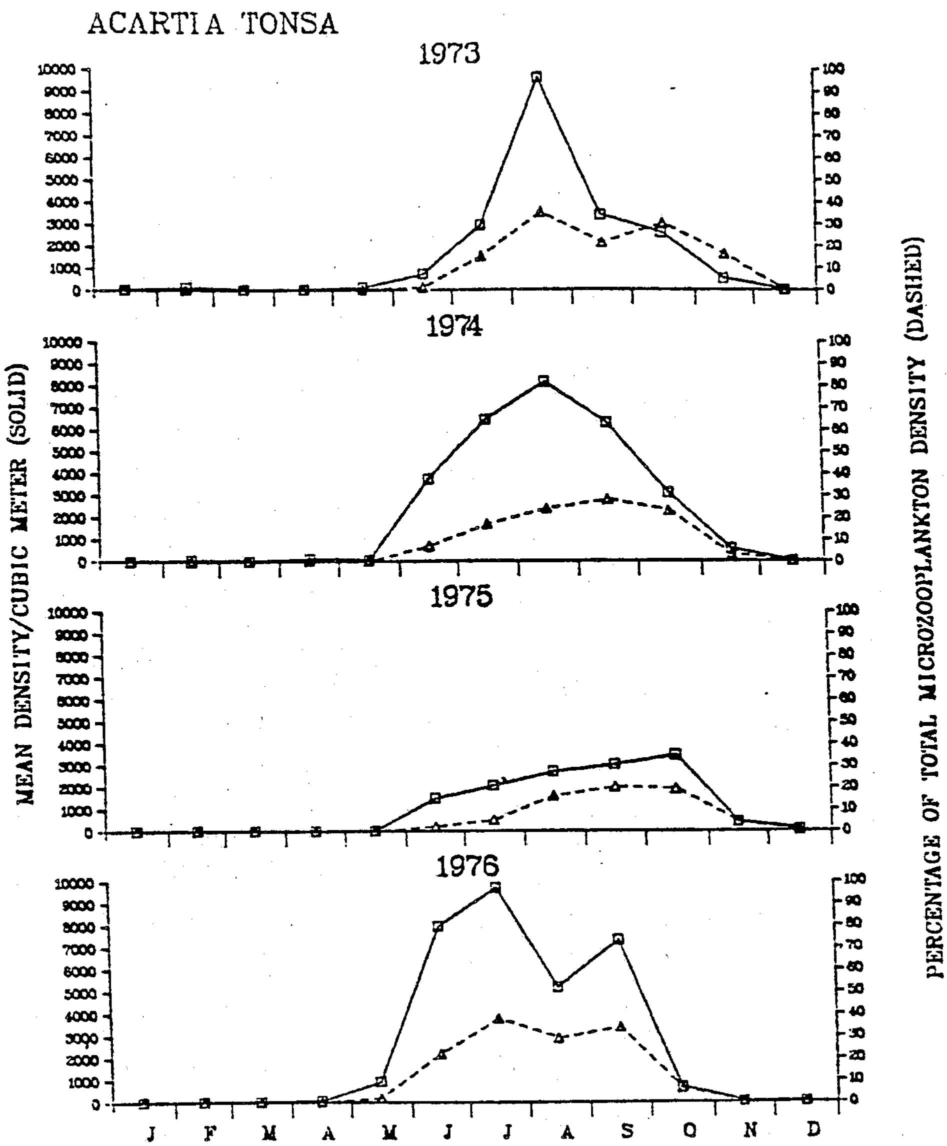
Near Artificial Island it was annually collected at all microzooplankton stations and during all months at temperature of 0.2 to 30.0 C and salinity of 0.0 to 14.0 ppt. Deevey (1960) reported a similar temperature range, 0.6 to 28.0 C, in the lower Delaware Bay. During 1974 and 1976 it was the most abundant copepod collected; in 1972, 1973, and 1975 it ranked second in abundance to Eurytemora affinis. Generally, density was lowest during winter and early spring and increased during late spring (Fig. 52). Greatest density was from June through September (ca. 1,500 to 10,000/m^3) when it comprised from 2 to 38 percent of monthly microzooplankton samples.

Adults of A. tonsa were generally most abundant near bottom.

In Delaware Bay there are at least five generations per year (Deevey, 1960), with developmental rates varying with temperature. The three or four summer generations develop quickly in contrast to the longer lived winter generation. Heinle (1972) reported population turnover time of 1.5 to 2.0 days during summer and as long as one month during winter. During summer months, developmental time from egg to egg-bearing adult may be as short as five to ten days; during winter it may be as long as three months (Heinle, 1966).

Mating consists of brief physical contact during which the male deposits sperm in the female's sperm sac organ. A single sperm deposit is sufficient for up to a week of egg-laying. Eggs are produced continuously until sperm supply is exhausted. A female may lay from a few to one hundred eggs per day throughout its adult life (Heinle, 1966, 1970).

Sex ratio is usually 1:1 during periods of high density but may become predominantly female if population densities become low; then, genetic males may become phenotypic females capable of producing fertile eggs (Heinle, 1970). In the present study, this density-sex relationship was indicated by seasonal change in population structure. During late fall through early spring, a period of low density, the A. tonsa population was predominately female



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density, and percent of total monthly microzooplankton - A. tonsa.
	Figure 52

but as density increased to high levels during late spring the proportion of males increased. The sex ratio was typically 1:1 from late spring through late fall.

A. tonsa is an omnivore adapted to filter and raptorial feeding on small and large phytoplankton and detritus particles (Richman et al., 1977; Heinle, 1966).

It is important in the diet of several fishes and invertebrates. It is a major food of the bay anchovy (Meadows, 1976) and is utilized by silverside (Moore, 1968), young weakfish, silver perch, and spot (Thomas, 1971). It is also preyed up extensively by ctenophores and hydromedusae.

Subclass Cirripedia

Cirripedia, commonly known as barnacles, are sessile, filter feeding crustaceans enclosed in a shell consisting of calcareous plates and are typically considered a nuisance organism. They are economically significant as fouling organisms on man-made structures and are numerically dominant in some communities. Near Artificial Island adults were numerically dominant in the benthos. They occurred throughout the year but were most abundant from June through July when they comprised from 18 to 61 percent of monthly benthos samples. Cirripedia larvae occurred in the microzooplankton throughout the year but were most abundant during May through September when they comprised to 18 percent of monthly microzooplankton samples.

Barnacles are hermaphroditic, but do cross fertilize (Gosner, 1979). They typically have a bimodal spawning pattern. The eggs are brooded in the mantle cavity and hatch as nauplii (Gosner, 1979) which exist in the plankton for approximately 18 days (Bousfield, 1955). These metamorphose into cypris larvae which settle to the bottom seeking firm substrate on which to attach for their final transformation to the sessile adult stage.

Balanus improvisus was the only barnacle collected near Artificial Island. It annually ranked among the top three benthic taxa in density and first in biomass, and is discussed.

Balanus improvisus

This euryhaline species, commonly known as the bay barnacle, ranges from Nova Scotia to South America (Gosner, 1979). It was one of the most characteristic oyster associates found in Delaware Bay (Maurer and Watling, 1973).

In the Delaware River Estuary the reported range of B. improvisus is from the Bay mouth (Watling et al., 1976) to New Castle, Delaware (RK 105; RM 65) (Taylor et al., 1973).

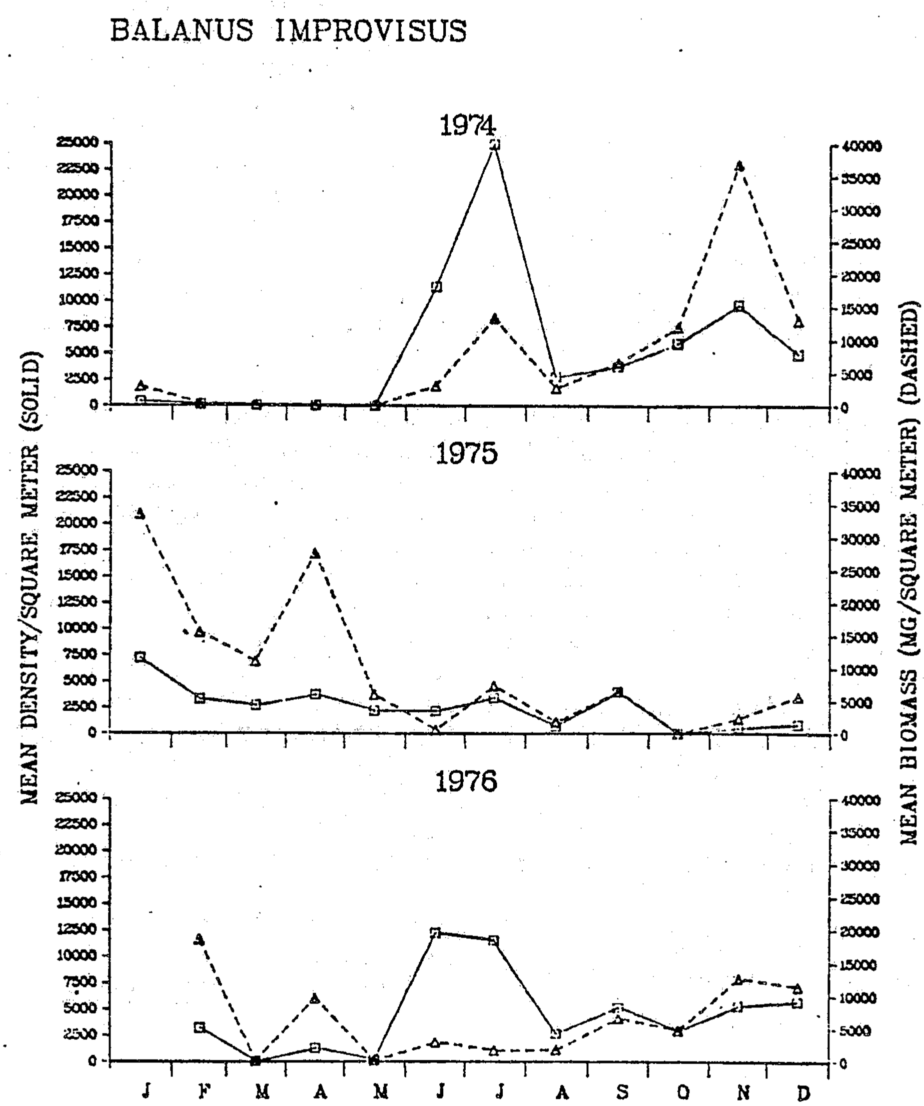
Near Artificial Island larvae were taken in microzooplankton samples throughout the study area. Abundance of barnacle larvae is correlated mainly with temperature (Weiss, 1948). Great density of Cirripedia nauplii first occurred in the microzooplankton in early May at mean temperature of 11.8 to 14.8 C. Peak density occurred in late May to early June at mean temperature of 18.3 to 19.0 C with a later peak occurring from early July to early September at mean temperature of 21.7 to 27.3 C. Timing of peak abundance of larvae near Artificial Island corresponds to the temperature range of optimum reproduction, 18 to 27 C, reported by Weiss (1948).

Adult barnacles were most abundant in the benthos at stations with gravel-shell substrates. Recently set B. improvisus were first taken in the benthos in June. The first appearance of barnacle juveniles in upper Chesapeake Bay was also in June (Branscomb, 1976). Near Artificial Island small individuals were taken through October and adults were collected every month. Because of the patchy distribution of barnacle populations in the benthos, density estimates were extremely variable. Peak density generally occured during June through July after the initial period of reproduction (Fig. 53). During this period, B. improvisus, with a mean density of ca. 2,200 to 25,000/m^2, comprised from 18 to 61 percent of monthly benthos samples (Fig. 49). Great density was also observed during September through November as the result of further reproductive activity.

B. improvisus competes for space with other epifauna. The flatworm, Stylochus ellipticus, is a predator of barnacles (Branscomb, 1976) and was observed in B. improvisus shells near Artificial Island.

Order Mysidacea

Mysids are shrimplike crustaceans which may attain a length of 30 mm (Gosner, 1979). Development is similar to amphipods and isopods, with juveniles hatching directly from eggs carried in a brood pouch (Gosner, 1971). They are ecologically important both as omnivores and as prey for a variety of fishes. Near Artificial Island, mysids were numerically dominant members of the macroinvertebrate



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density and biomass - B. improvisus. Figure 53.

plankton. They occurred throughout the year but were most abundant from June through November or December when they comprised from 17 to 99 percent of monthly macroinvertebrate plankton samples.

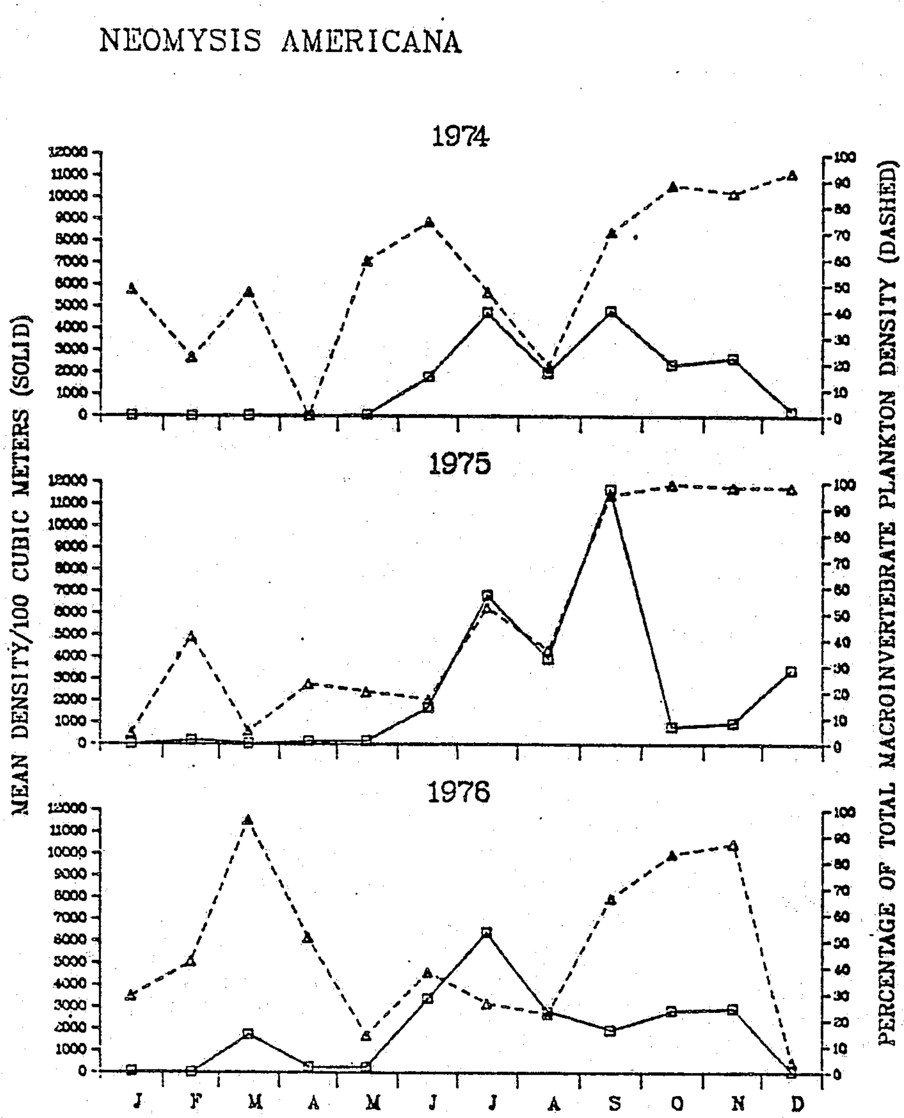
Mysids in the study area included Neomysis americana and possibly Mysidopsis bigelowi; however, N. americana probably comprised greater than 99 percent of the mysid population and is discussed.

Neomysis americana

This species, commonly known as the opossum shrimp, is the most widespread and abundant mysid along the northeastern coast of the United States. It is found from the Gulf of St. Lawrence to Virginia, with greatest abundance occurring south of New England. Although common from the intertidal zone to a depth of 90 meters, abundance is greatest at 30 to 60 meters (Wigley and Burns, 1971).

Horizontal and vertical distribution of N. americana within the Delaware River Estuary is related to two-layered estuarine circulation and to the animal's negative phototropic behavior (Hulburt, 1957; Fikslin, 1973). Its preference for the deeper estuarine waters insures its position in the more saline, net upstream moving bottom currents. Fikslin (1973) stated that increased activity in the water column during flood tide may also contribute to upriver transport. Hulburt (1957) observed that upstream movement from stocks outside the Bay, supplemented by reproduction within the Bay, was responsible for maintenance of the estuarine population. The population center shifts seasonally within the estuary, corresponding to seasonal change in the salinity gradient. Greatest density occurs at 15 to 20 ppt salinity (Cronin et al., 1962). Its upstream limit is associated with the 4 ppt isohaline (Hulburt, 1957) which ranges seasonally from Ship John Shoal to the Delaware Memorial Bridge. Other studies indicate the Delaware Memorial Bridge area (RK 111-122; RM 69-76) as its upstream limit (Morrisson, 1975, 1976a).

Near Artificial Island it was annually the most abundant macroinvertebrate plankter collected. It occurred throughout the year with greatest monthly density (ca. 800-11,700/m^3) from June through November or December (Fig. 54). During this period it comprised from 17 to 99 percent of monthly macroinvertebrate plankton samples. Hulburt (1957) reported similar density near Artificial Island.



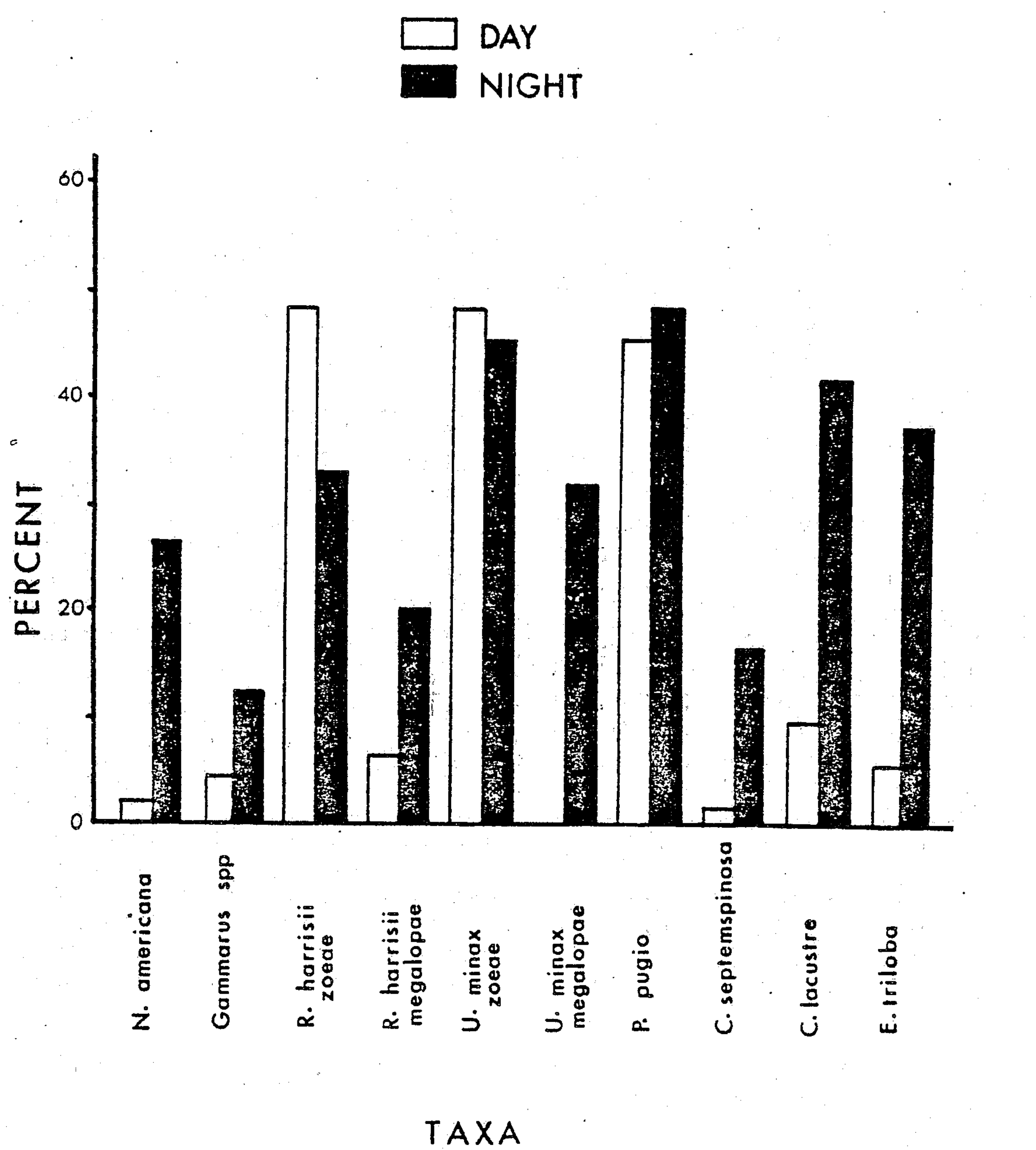
PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density, and percent of total monthly macroinvertebrate plankton - N. americana.
	Figure 54

Constant reproductive activity was indicated by the presence of juveniles throughout the year. Reproductive levels were typically low from December through March. Length-frequency data indicated a bimodal (spring and late summer-fall) reproductive pattern near Artificial Island. This was particularly evident in 1973 and 1974 data. A multiple generation hypothesis agrees with the findings of Hopkins (1965), Wigley and Burns (1971), Williams (1972), and Pezzack and Corey (1979).

Near Artificial Island N. americana apparently congregates on or near the bottom during daylight and migrates upward into the water column during darkness. Its negative response to light may explain its diurnal migration pattern, although this pattern may also be related to reproductive activity (Herman, 1963a). Mean surface density increased from 2 percent of the surface-bottom total during daylight to 26 percent of the total during darkness (Fig. 55). Other studies have demonstrated a similar pattern (Hulburt, 1957; Herman, 1963a; Hopkins, 1965).

N. americana is important in the transfer of energy between trophic levels in estuarine food webs. It feeds on phytoplankton and detritus (Pezzack and Corey, 1979) and probably copepods (Heinle and Flemer, 1975). It in turn is fed upon by other invertebrates and fishes. Herman (1963a) observed that Crangon septemspinosa, the sand shrimp, feeds heavily upon N. americana at night, possibly influencing vertical migration. A great variety of fishes prey on the opossum shrimp. Weakfish and other sciaenids, including the silver perch and Atlantic croaker, utilize it as an important food source (Shuster, 1959; de Sylva et al., 1962; Thomas, 1971; Bason et al., 1975, 1976; Keirsey et al., 1977; Shirey et al., 1978). Its appearance in the diet of the bay anchovy (Stevenson, 1958; Meadows, 1976), an important local forage fish, is another indication of its role in estuarine energy transfer. It is also included in the diet of striped bass (Bason, 1971; Bason et al., 1975, 1976), white perch (de Sylva et al., 1962; Meadows, 1976), crevalle jack (Bason et al., 1975), spotted and southern hake (Sikora et al., 1972), clearnose skate (Fitz, 1956), bluefish, northern kingfish, winter flounder, and windowpane (de Sylva et al., 1962).

Based on its abundance and ecological importance, both within the Bay and near Artificial Island, Neomysis americana was selected as a target species for subsequent study during operation of Salem. The study will attempt to further delineate population movement and their potential involvement with Salem.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Component of the combined surface-bottom sample, per species, taken at the surface, day versus night, 1974-1976 combined.
	Figure 55

Order Isopoda

Isopods are crustaceans typified by a dorso-ventrally compressed body form, i.e., flattened from top to bottom, ranging from 3 to 34 mm in length (Gosner, 1979). Development is similar to amphipods and mysids, with juveniles hatching directly from eggs carried in a brood pouch (Gosner, 1971). They are ecologically important as omnivorous scavengers, accelerating the decay and recycling process (Shultz, 1969). Some species are specialized as fish and crustacean parasites. Near Artificial Island, isopods were numerically important members of the macroinvertebrate plankton and benthos. They occurred throughout the year, but were most abundant from May through October when they comprised to 8 percent of monthly macroinvertebrate plankton samples and to 19 percent of monthly benthos samples.

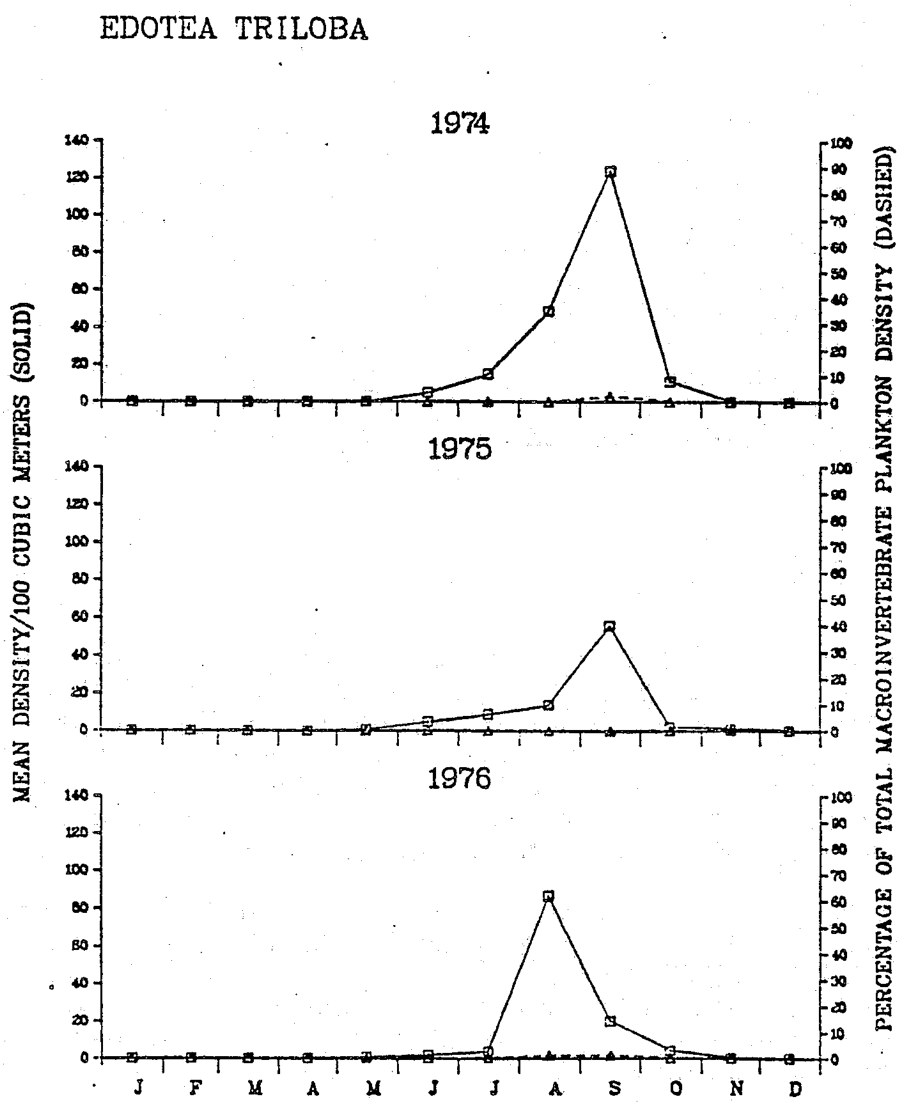
Edotea triloba and Cyathura polita, based on density, were the dominant isopods in the macroinvertebrate plankton and benthos and are discussed below.

Edotea triloba

This euryhaline estuarine species ranges from Nova Scotia south to at least the Chesapeake Bay (Gosner, 1979) and is probably the most widespread estuarine isopod in the Delaware Bay region (Watling et al., 1974). Its habitat includes wharf-piles, eelgrass, decaying vegetation, sediments, hydroids, oyster beds, and algae (Richardson, 1905; Miner, 1950; Watling et al., 1974).

In the Delaware River Estuary, it ranges from approximately the Chesapeake and Delaware Canal (Annual Progress Reports, 1974, 1976; Dommermuth, 1978) to the Bay mouth (Watling et al., 1976). Abundance is related to salinity and habitat availability. Density typically increased with salinity from the Chesapeake and Delaware Canal south to the Mad Horse Creek area. During late summer 1974 densities near Ship John Shoal (RK 51-63; RM 32-39), at a mean salinity of 13.6 ppt, were approximately 1.5 times greater than near Artificial Island, at a mean salinity of 4.6 ppt. E. triloba was especially abundant on oyster beds in the Bay (Watling et al., 1974).

Near Artificial Island it was annually the most abundant isopod in macroinvertebrate plankton samples and was typically collected from spring (April-May) to fall (October-November) (Fig. 56). Peak density (ca. 15-125/100m^3) occurred during August and September. During this period it



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density, and percent of total monthly macroinvertebrate plankton - *E. triloba*.
	Figure 56

comprised from less than 1 to 2 percent of monthly macroinvertebrate plankton samples. Its great abundance near Sunken Ship Cove (RK 86) relative to nearby stations may be related to habitat provided by the wooden barges encircling the cove.

E. triloba demonstrated a diurnal vertical migration pattern. Mean surface density increased from 6 percent of the surface-bottom total during daylight to 37 percent of the total during darkness (Fig. 55).

Reproduction, as indicated by the occurrence of juveniles, probably occurs throughout the year.

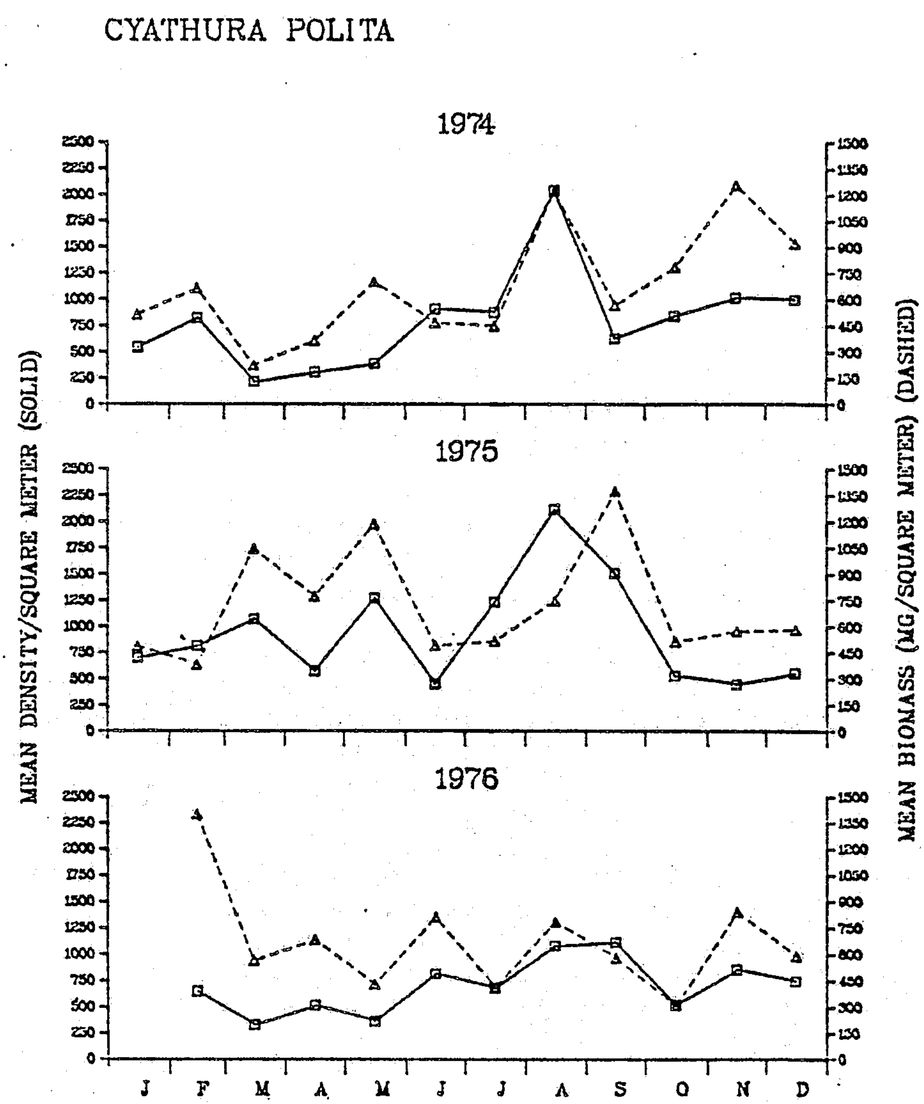
Cyathura polita

This brackish water species is found from Maine to the Gulf of Mexico (Gosner, 1979). It is most abundant at salinity of from ca. 0.5 to 8.0 ppt but has been found at 0 to 70 ppt (Burbank, 1967).

In the Delaware River Estuary it ranges from the mouth of the Bay (Watling et al., 1976) north to Newbold Island, New Jersey (RK 201; RM 125) (Crumb, 1976).

Near Artificial Island C. polita was collected during all months and annually ranked among the six most abundant benthic taxa in density and the eight most abundant in biomass. It was collected in all substrate types but was most abundant in clay and to a lesser extent in sandy-mud. Although variable, greatest density (ca. 620-2,100/m^2) generally occurred during August and September (Fig. 57). Specimens 3.0 to 4.0 mm were taken every month, indicating reproduction throughout the year. Burbank (1967) reported several generations per year in the warmer southern climate in contrast to one in northern climates (e.g., Massachusetts). Timing of reproduction near Artificial Island corresponds to that of the southern climate. The seasonality in abundance of juveniles (1.5-3.0 mm) indicates that June through September is the major reproductive period.

C. polita is important in the diet of many fishes and some waterfowl. In the present study it was found in stomachs of weakfish, silver perch, black drum, and Atlantic croaker (Thomas, 1971), and in stomachs of black duck, mallard, and green wing teal from New Jersey and Delaware marshlands (Annual Progress Report, 1974).



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ARTIFICIAL ISLAND STUDIES

Monthly mean density and biomass - C. polita.

Figure 57

Order Amphipoda

Amphipods are crustaceans typified by a laterally compressed body form, i.e., flattened from side to side, ranging from 1.6 to 39 mm in length (Gosner, 1979). Development is similar to isopods and mysids, with juveniles hatching directly from eggs carried in a brood pouch (Gosner, 1971). They are ecologically important in the breakdown of detritus (Fenchel, 1970; Hargrave, 1970) and as food for many fishes. Near Artificial Island amphipods were numerically important in the benthos and dominant in the macroinvertebrate plankton. They occurred throughout the year and comprised to 15 percent of monthly benthos samples and to 97 percent of monthly macroinvertebrate plankton samples.

Gammarus spp. and *Corophium lacustre*, based on density, were the dominant amphipods in the macroinvertebrate plankton and benthos and are discussed.

Gammarus spp.

This taxon is comprised of three species, *G. fasciatus*, *G. daiberi*, and *G. tigrinus*, which overlap in distribution. *Gammarus* spp., commonly known as a scud, is the dominant amphipod taxon near Artificial Island.

G. fasciatus is found in Atlantic rivers and streams from southern New England southward to at least the Chesapeake Bay region. It is essentially a freshwater, benthic, semi-pelagic organism which may range into the oligohaline portions of estuaries to salinity of 3 ppt (Bousfield, 1969).

G. daiberi (= *fasciatus* Cronin et al., 1962) is a more southern species found from the Chesapeake Bay-Delaware Bay region to South Carolina (Bousfield, 1969). It is dominant in the oligohaline portion of the Delaware River Estuary (Cronin et al., 1962) and co-occurs with *G. tigrinis* at salinity of 1.8 to 7.6 ppt (Bousfield, 1969).

G. tigrinus ranges from the Gulf of St. Lawrence to North Carolina, with a population in the St. Johns River, Florida. It has been reported to salinity of 14 ppt, although it may occur to 25 ppt (Bousfield, 1969, 1973).

In the Delaware Estuary, abundance of *Gammarus* spp. generally increases with decreasing salinity. Cronin, et al. (1962) collected few individuals at above 10 ppt salinity. Similarly, in the present study during late summer 1974, density was significantly ($p \leq 0.05$) lower near Ship John Shoal (RK 51-63; RM 32-39), at mean salinity of 13.6 ppt, than near Artificial Island, at mean salinity of 4.6 ppt. Greatest density occurred north of Salem in the vicinity of the Delaware Memorial Bridge (RK 111-122; RM 69-77), where salinity is typically below 1 ppt (Morrisson, 1975, 1976a). During 1974 and 1975, density near the Delaware Memorial Bridge was often greater than $200/100m^3$, and exceeded $2,500/100m^3$ on several occasions.

Near Artificial Island it annually ranked among the four most abundant macroinvertebrate plankters. Although the period of peak abundance was variable, density was generally greatest from April through September (Fig. 58). During this period *Gammarus* spp., with mean density of ca. 20 to $1,600/100m^3$, comprised from 1 to 91 percent of monthly macroinvertebrate plankton samples.

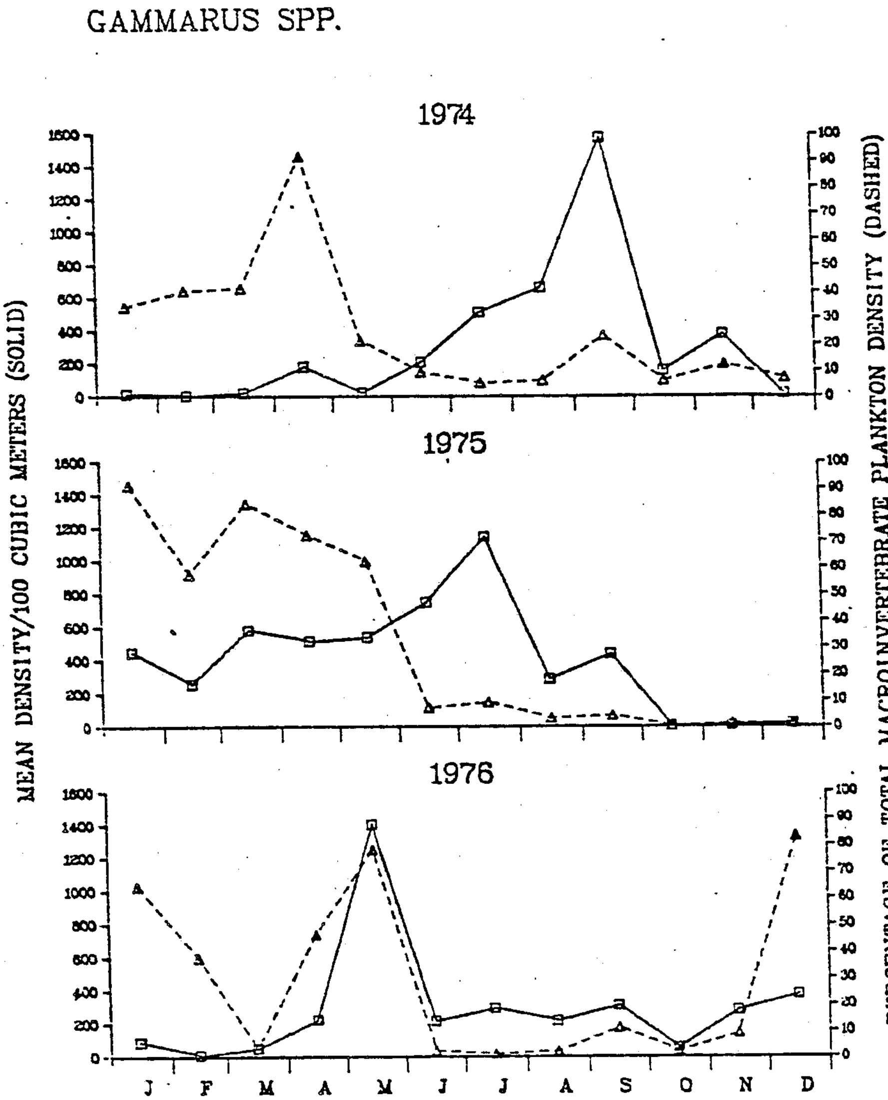
Gammarus spp. demonstrated a diurnal vertical migration pattern. Mean density increased from 4 percent of the surface-bottom total during daylight to 12 percent of the total during darkness (Fig. 55).

G. fasciatus, *G. daiberi*, and *G. tigrinus* have an annual life cycle. The reproductive season of *G. fasciatus* and *G. daiberi* extends from spring through fall, while *G. tigrinus* reproduces in the summer. Females of all species may produce several broods per year (Bousfield, 1973).

Length-frequency analysis indicated that April through December is the major reproductive period.

Gammarus spp. is ecologically important in the food web near Artificial Island. It is probably an omnivorous scavenger and an important food source for many fishes. It is included in the diet of weakfish (Thomas, 1971; Bason et al., 1975, 1976), striped bass (Bason, 1971; Bason et al., 1975, 1976), white perch (Meadows, 1976; Bason et al., 1975), yellow perch (Bason et al., 1975, 1976), and Atlantic croaker (Bason et al., 1975, 1976; Keirsey et al., 1977). *G. daiberi* has been noted in the stomach of the American eel (Wenner and Musick, 1975).

Based on its abundance and ecological importance, both within the Bay and near Artificial Island, *Gammarus* spp. was selected as a target species for subsequent study during operation of Salem. The study will attempt to further delineate population movement and their potential involvement with Salem.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density, and percent of total monthly macroinvertebrate plankton - Gammarus spp.
	Figure 58

Corophium lacustre

This tube dwelling amphipod, the predominant species of Corophium near Artificial Island, inhabits shallow and intertidal zones, marshy banks, pilings, and aids to navigation (Bousfield, 1973).

Its distribution and abundance in the Delaware River Estuary is determined largely by salinity, with greatest density occurring at approximately 0.5 to 7 ppt. During August and September 1974, its densities were significantly ($p \leq 0.05$) greater near Artificial Island (mean salinity 4.6 ppt) than near Ship John Shoal (mean salinity 13.6 ppt). Williams and Bynum (1972) similarly reported C. lacustre to be 3 to 16 times more abundant in oligohaline than mesohaline reaches of the Neuse and Pamlico River Estuaries in North Carolina. In the Delaware Estuary its density decreased substantially in the limnetic reaches near the Delaware Memorial Bridge (RK 111-122; RM 69-76) (Morrisson, 1975, 1976a).

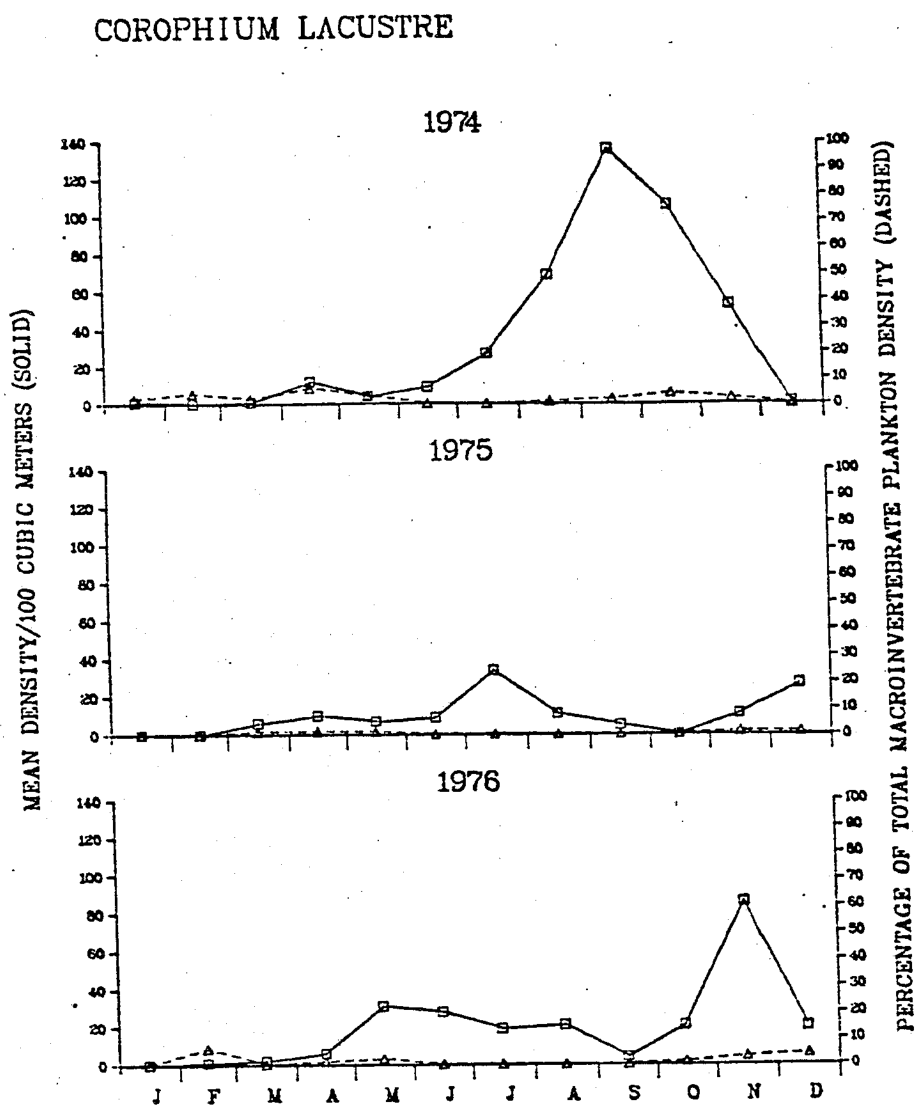
Near Artificial Island it annually ranked among the top eight macroinvertebrate plankters and was typically collected throughout the year. Densities increased in the summer, and generally remained high through the fall and early winter (Fig. 59). Peak density (ca. 35-135/100m^3) occurred during July, September, or November.

It was abundant in the benthos on hard substrates such as clay, mud-clay, gravel-shell and sand-clay. A large concentration of C. lacustre occurred in mud-clay substrate at the mouth of the Appoquinimink River, a tidal tributary opposite Artificial Island. Density at this location during 1973 accounted for 43 percent of the total benthos sample. In Delaware Bay C. lacustre was found on oyster beds where the bottom sediments are interspersed with muddy-shell and mud (Watling and Maurer, 1972). It was also found in consistently high density in the plankton near Sunken Ship Cove, perhaps because of the hard substrate provided by the sunken, wooden barges which encircle the cove.

C. lacustre demonstrated a diurnal vertical migration pattern. Mean surface density increased from 10 percent of the surface-bottom total during daylight to 42 percent of the total during darkness (Fig. 55).

It has an annual life cycle, with ovigerous females occurring from May through September (Bousfield, 1973). Near Artificial Island juveniles occur throughout the year; however, peak reproduction occurred during the fall to early winter.

C. lacustre is important in the local food web. As a tube dwelling amphipod it probably feeds upon vegetation and



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density, and percent of total monthly macroinvertebrate plankton - C. lacustre.
	Figure 59

detritus (Gosner, 1971). In turn, it passes energy on to several important fishes and some waterfowl. In the present study Bason (1971) and Thomas (1971) found *Corophium* common in the diet of young striped bass in tidal creeks near Artificial Island. It is also included in the diet of silver perch (Thomas, 1971; de Sylva et al., 1962), black drum (Thomas, 1971), Atlantic croaker (Bason et al., 1975; Keirsey et al., 1977), bay anchovy, and weakfish (Meadows, 1976). *C. lacustre* as an important faunal constituent in the diet of the black duck (Annual Progress Report, 1977).

Infraorder Caridea

Carideans, commonly known as shrimp, share a common developmental pattern. Young hatch as shrimplike protozoea and pass through a mysis stage (resembling mysid shrimp) before attaining the adult form (Gosner, 1979). Adults range from 15 to 175 mm in length (Gosner, 1971). They are ecologically important as predators, scavengers, and as food for fishes. Near Artificial Island, carideans occurred in the macroinvertebrate plankton from February through December, but were most abundant from May through October when they comprised to 3 percent of monthly samples. Although caridean density was typically lower than other dominant macroinvertebrate groups, their relatively great biomass indicated their ecological importance.

Palaemonetes pugio and *Crangon septemspinosa* were the only carideans collected and are discussed.

Palaemonetes pugio

This species, commonly called the grass shrimp, inhabits shallow waters along the Atlantic coast and occurs from approximately Cape Hatteras to Cape Cod (Gosner, 1971). It is especially adapted for survival in highly stressed systems, tolerating the wide range of salinity, temperature, and oxygen levels which exist in a tidal marsh environment (Welsh, 1975).

In the Delaware River Estuary, its northern range extends at least to the Delaware Memorial Bridge (RK 111-122; RM 69-76) (Morrisson, 1975, 1976a). It probably occurs south to the Bay mouth.

Near Artificial Island *P. pugio* annually ranked among the top eight macroinvertebrate plankters and was typically collected from May or June through December (Fig. 60). Its abundance in the plankton from fall through spring was low. During late spring juveniles moved into the river from shallow water near shore environments. During the period of maximum abundance, June through August, it was collected at temperature of 21 to 27 C and salinity of 3 to 7 ppt. During this period, P. pugio, with a monthly mean density of ca. 5 to $170/100m^3$, comprised to 2 percent of monthly macroinvertebrate plankton samples.

Near Artificial Island its spatial distribution is primarily determined by habitat. It was most abundant near shore, in shallow drainage ditches, and near structures such as docks and pilings.

No pattern of diurnal vertical migration was evident (Fig. 55).

Small post-larval individuals (3-4 mm) were abundant from June through August, indicating a summer reproductive season. A similar reproductive period was indicated by Herman et al. (1968) who took larvae from May through August and again in early fall in the Patuxent River Estuary, Virginia. Sandifer (1973) collected Palaemonetes spp. larvae from June through October in the York River Estuary, Virginia, with greatest abundance in July.

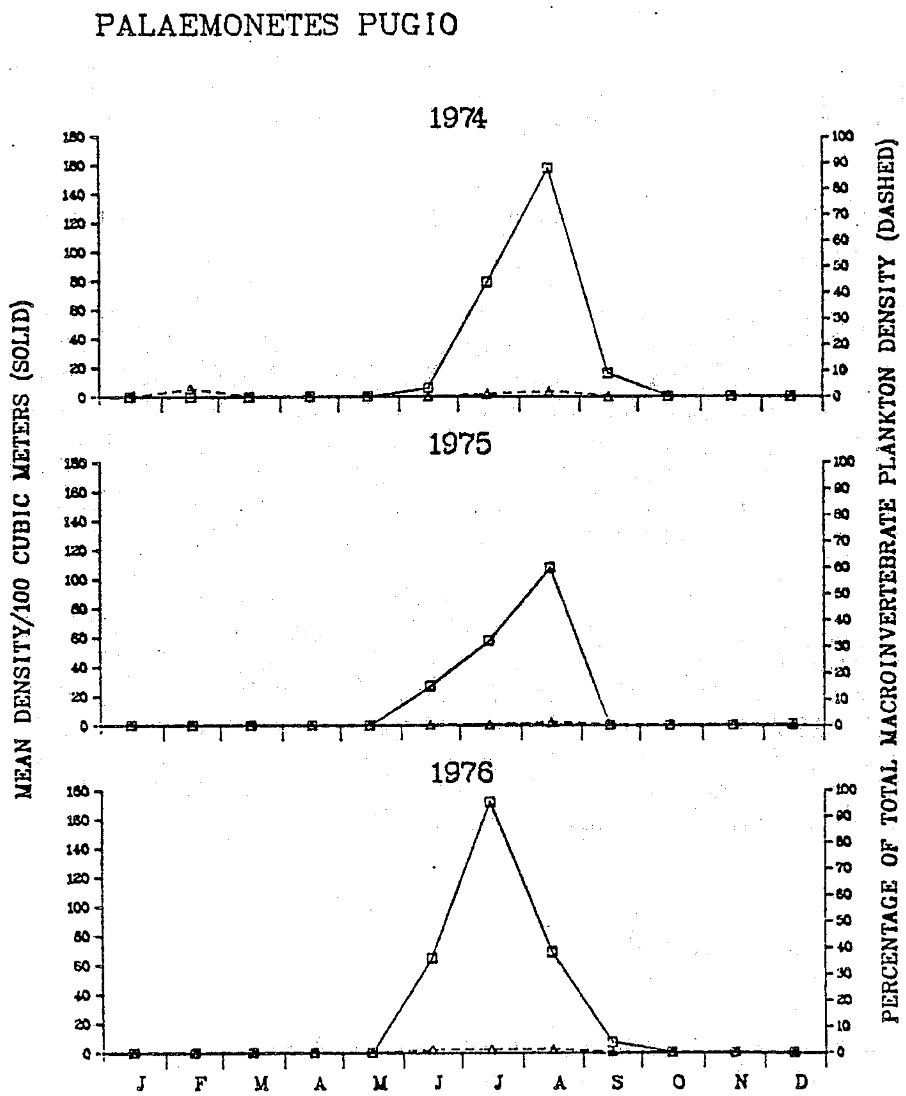
The grass shrimp is ecologically important in reducing detrital particle size, thus accelerating decomposition and recycling (Nixon and Oviatt, 1973; Welsh, 1975). It is also important in the diet of fishes including striped bass (Bason, 1971) and killifish (Nixon and Oviatt, 1973). Thomas (1971) took Palaemonetes from weakfish, silver perch, black drum, and spot. It is also fed upon by the American eel (Nixon and Oviatt, 1973).

Crangon septemspinosa

This species, commonly known as the sand shrimp, is a bottom dweller which often occurs in shallow waters and estuaries along the Atlantic coast from Baffin Bay to Florida (Whitley, 1948; Gosner, 1971).

Abundance is greatest at high salinity. Morrison (1975, 1976a) found only scattered occurrence of C. septemspinosa in the plankton community near the Delaware Memorial Bridge (RK 111-122; RM 69-76), where salinity is typically below 1 ppt.

Near Artificial Island it annually ranked among the ten most



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density, and percent of total monthly macroinvertebrate plankton - P. pugio.
	Figure 60

abundant macroinvertebrate plankters, and was typically collected from February or April through November or December (Fig. 61). Although timing of peak abundance was variable a bimodal pattern was observed in 1975 and 1976, possibly the result of a bimodal reproductive season in Delaware Bay described by Price (1962).

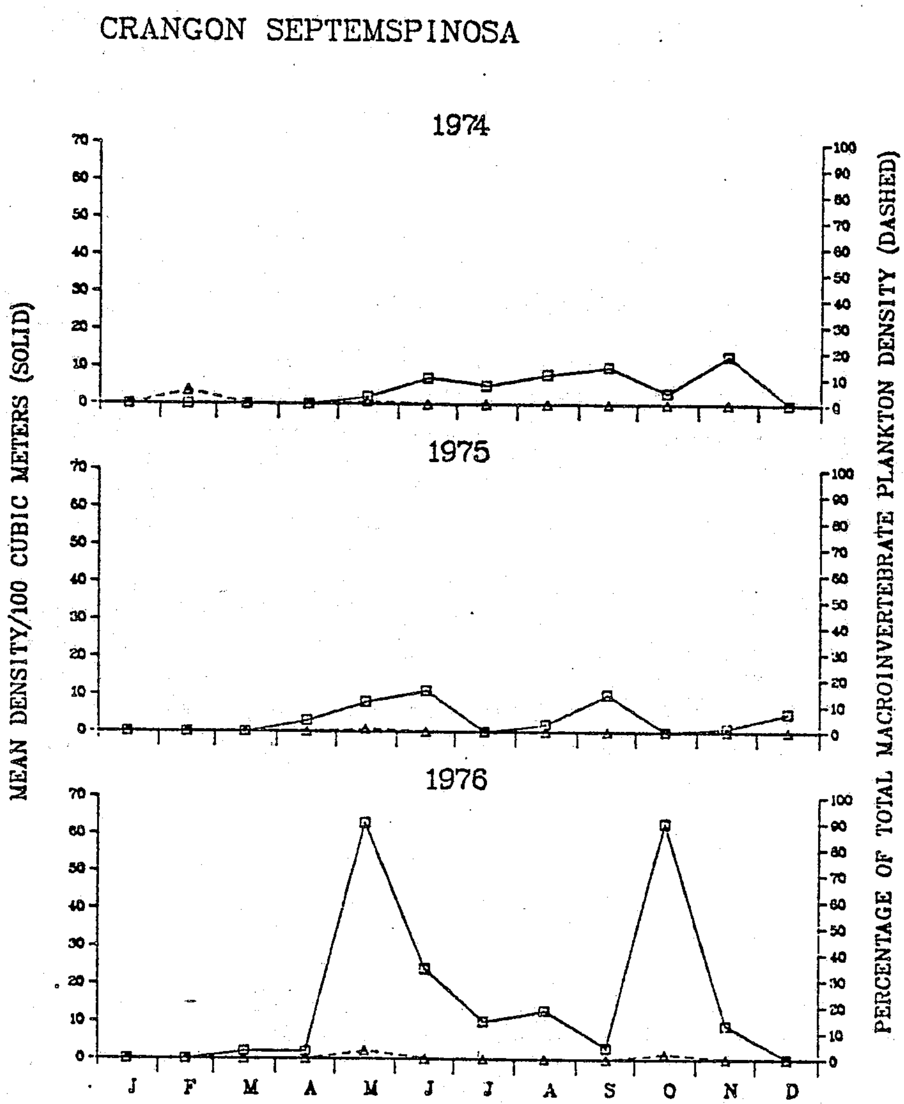
C. septemspinosa demonstrated a diurnal vertical migration pattern. Mean surface density increased from 1 percent of the surface-bottom total during daylight to 17 percent of the total during darkness (Fig. 55). This is possibly related to predation on other crustaceans. Herman (1963a) reported that it preyed heavily at night upon Neomysis americana, the opossum shrimp.

In the Delaware River Estuary females live approximately three years and males approximately two. Reproduction occurs south of Artificial Island at salinity greater than 17 ppt (Price, 1962). Near Artificial Island larvae were not observed and, although adults were taken, most individuals captured were juveniles ranging from 5 to 20 mm in length. Adults, greater than 20 mm but mostly less than 35 mm in length, were generally most abundant from September through December. In downbay regions females may attain length to 70 mm and males to 47 mm (Price, 1962).

The sand shrimp is ecologically important as a scavenger and predator (Price, 1962; Herman, 1963a). It is preyed upon by fishes including striped bass (Bason, 1971; de Sylva et al., 1962), weakfish (Daiber, 1959; de Sylva et al., 1962; Bason et al., 1975, 1976), silver perch, black drum, spot, Atlantic croaker (Thomas, 1971), skates (Fitz, 1956), and rays (Hess, 1961).

Infraorder Brachyura

Brachyurans, the true crabs, are typified by four well developed pairs of walking legs (Gosner, 1979). They share a developmental pattern characterized by two distinct and sequential larval forms, the zoea and megalopa. Zoeae are an entirely planktonic series of stages. Swimming involves use of the maxillipeds (accessory mouth parts). Megalopae are more crablike in appearance, with well developed walking legs and maxillipeds no longer modified as swimming appendages. They molt to the first stage crab (Chamberlain, 1961). Brachyuran adults are ecologically important as scavengers, predators, and food for fishes, birds, and mammals. Larvae are also important as food for larval and planktivorous fishes.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density, and percent of total monthly macroinvertebrate plankton - C. septemspinosa.
	Figure 61

The blue crab (Callinectes sapidus), the brackish water mud crab (Rhithropanopeus harrisii), and the red-jointed fiddler crab (Uca minax) were the dominant brachyurans near Artificial Island. Since blue crab was the subject of a more intensive investigation than the others it is discussed last.

Rhithropanopeus harrisii

This species, commonly known as the brackish water mud crab, is widely distributed in estuaries along the eastern coast at below 18 ppt salinity (Williams, 1965).

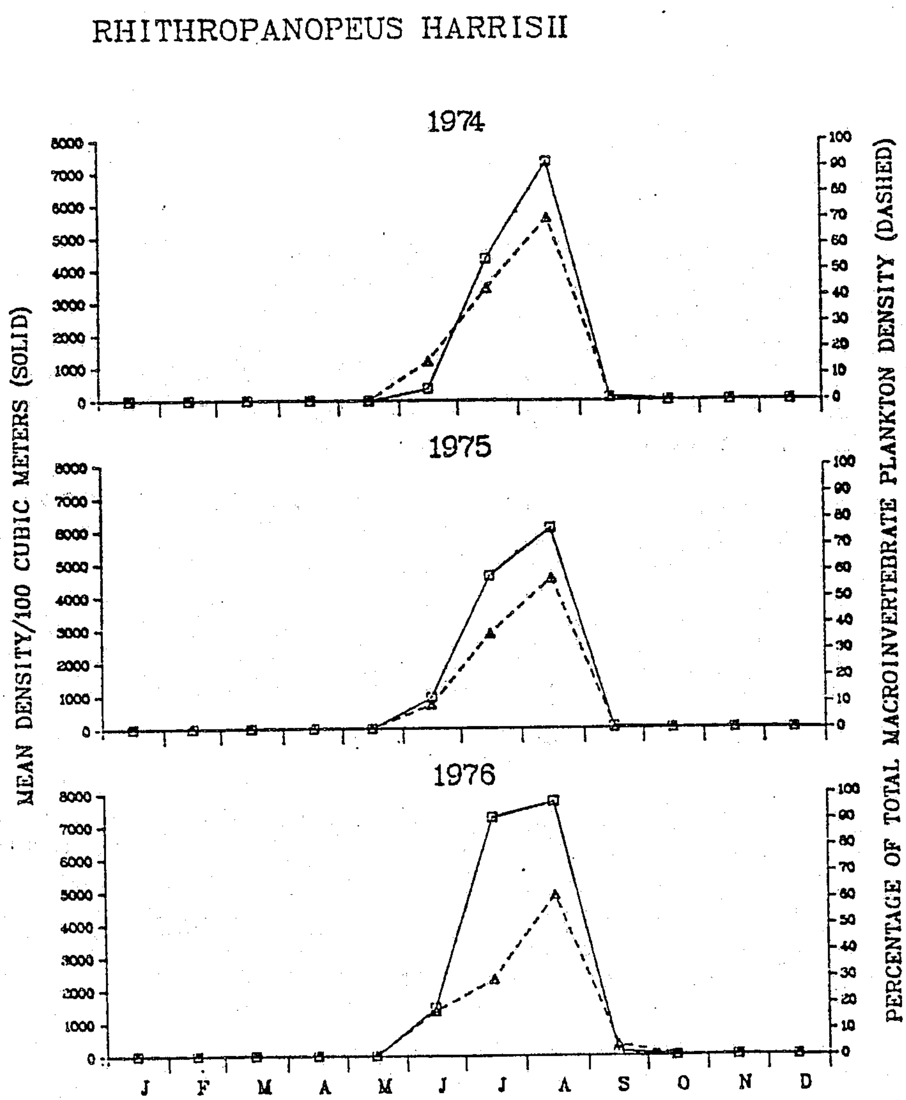
The main occurrence and distribution of larvae and probably adults in the Delaware River Estuary is generally at 3 to 10 ppt salinity. Its upriver distributional limit is approximately the Delaware Memorial Bridge (RK 111-122) where salinities are typically less than 1 ppt (Morrisson, 1975, 1976a). Ryan (1956) described it as the only mud crab found in fresh water.

Near Artificial Island larvae annually ranked second in abundance among macroinvertebrate plankters. They were abundant from June through August at temperature of 20 to 30 C and salinity of 3 to 10 ppt. Peak density occurred from July through August (Fig. 62). During this period R. harrisii, with mean density of ca. 4,300 to 7,800/100m^3, comprised from 29 to 70 percent of monthly macroinvertebrate plankton samples.

Adult crab occurred in greatest density on substrate affording shelter. Although such substrate is not common near Artificial Island it does occur, e.g., the gravel-shell bottom off Hope Creek, local jetties, and the rocky intertidal beaches near New Castle, Delaware (RK 101, RM 63). McDermott and Flower (1952) observed high crab abundance on shell substrate in Delaware Bay.

Only the megalopa stage demonstrated vertical diurnal migration. Surface density typically increased from 7 percent of the surface-bottom total during daylight to 20 percent of the total during darkness (Fig. 55).

Both larval and post larval crab are important in the food web of the Delaware River Estuary. Larvae are fed upon by bay anchovy and Atlantic menhaden (Stevenson, 1958; Shuster, 1959; McHugh, 1967). In the present study post larval stages of R. harrisii were fed on by the oyster toadfish, channel catfish, white perch, and striped bass (Annual Progress Report, 1972).



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density, and percent of total monthly macroinvertebrate plankton - *R. harrisii*.
	Figure 62

Uca minax

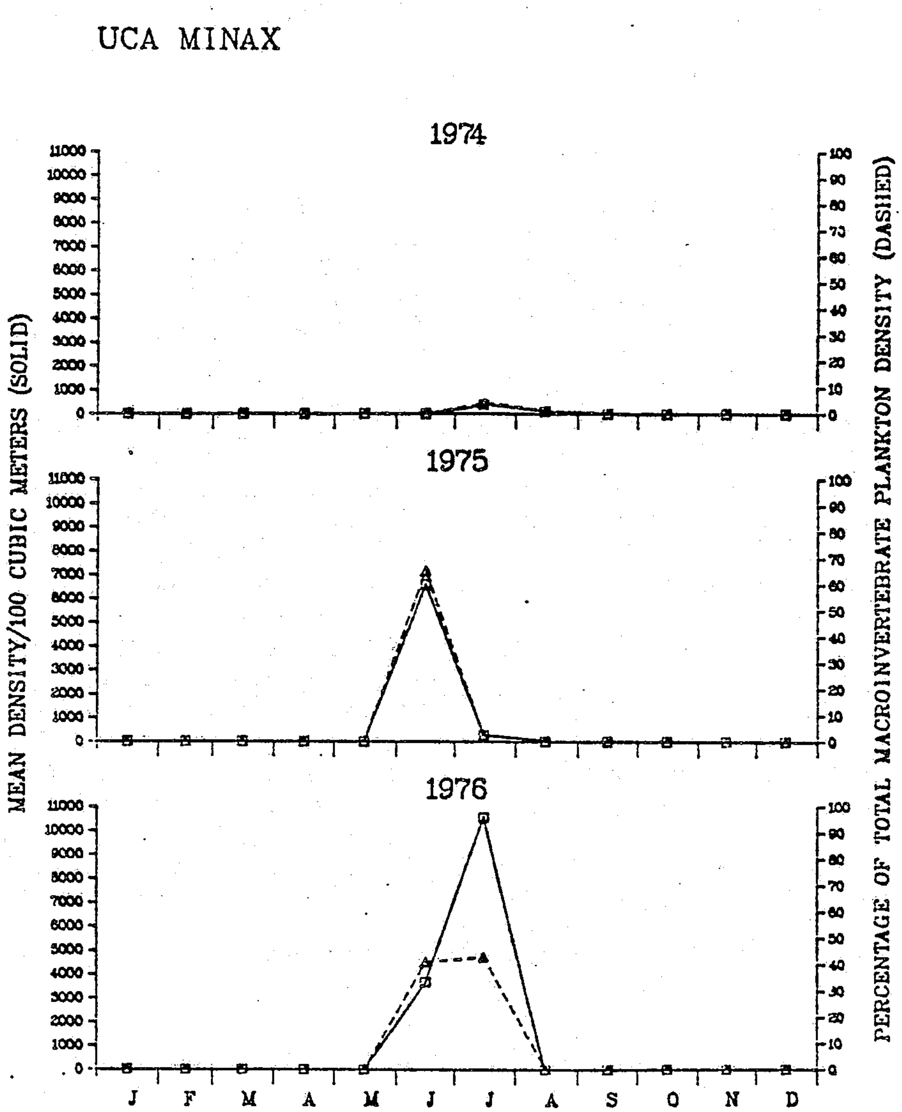
This species, commonly known as the red-jointed fiddler crab, is typically found in low salinity portions of salt marsh systems along the Atlantic coast from Cape Cod to Columbia, often co-occurring with *U. pugnax* and *U. pugilator* (Gray, 1942; Teal, 1958). Adults live in burrow colonies at the high tide level, often in association with cord grasses, *Spartina* spp. (Gray, 1942; Teal, 1958; Kerwin, 1971; Miller and Maurer, 1973). This association is possibly due to the existence of a suitable burrow substratum or increased food availability.

In the Delaware River Estuary it probably occurs along the entire range of ambient salinity. Miller and Maurer (1973) reported it at salinity of 0 to 29 ppt with greatest abundance at 0 to 12 ppt. It overlapped in range with the more salinity tolerant *U. pugnax* at 8 to 12 ppt. Kerwin (1971) reported it to be widely distributed in marshes at salinity of 2 to 16 ppt.

Near Artificial Island its larvae are an important component of the mid-summer plankton community. Larval density peaked in mid June or July, two to three weeks after first occurrence, and then sharply declined to minimal levels in early August (Fig. 63). During the period of peak density *U. minax*, with a mean density of ca. 400 to 10,600/100m^3, comprised from 4 to 65 percent of monthly macroinvertebrate plankton samples. Although larvae were collected at temperature greater than 17 C, most were collected at above 21 C. Larval density was greatest in near shore zones or off tidal creeks, reflecting reproductive input from the intertidal marsh banks. Its low density in the Chesapeake and Delaware Canal throughout the year (typically only 10 percent of that observed near Artificial Island) (Sheppard and Dommermuth, 1977; Dommermuth, 1978) was probably related to the lack of intertidal mud along the canal banks.

No pattern of diurnal vertical migration was observed (Fig. 55).

Adult crab feed on detritus, with its associated bacteria, algae, and dead fish (Gray, 1942; Teal, 1971; Williams, 1971). Crab larvae (probably including *U. minax*) are fed upon by the bay anchovy and Atlantic menhaden (Stevenson, 1958; Shuster, 1959; McHugh, 1967). Adults are fed upon by several animals, including the clapper rail, skunk, and raccoon (Annual Progress Report, 1972).



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Monthly mean density, and percent of total monthly macroinvertebrate plankton - U. minax.
	Figure 63

Callinectes sapidus

The blue crab, Callinectes sapidus, an annual resident of the Delaware River Estuary, migrates extensively in the system and utilizes a wide variety of habitats during its 2 to 3 year life span. It ranges from tidal freshwater near Burlington, N.J. (RK 189; RM 117) (J. Lynch, pers. comm.) to as far as 32 KM (20 miles) off the Bay mouth in full seawater (C. Epifanio, pers. comm.). From Marcus Hook, Pennsylvania (RK 128; RM 80) south to the Bay mouth blue crab are seasonally abundant and support one of the drainages most important commercial fisheries.

The species has been reported in estuarine and coastal waters from Nova Scotia, Canada, to northern Argentina, South America (Oesterling, 1976). Along the Atlantic and Gulf coasts of the United States it is abundant from New Jersey to Texas and supports major commercial and recreational fisheries.

For the species to successfully complete its relatively complex life cycle requires distinctly different portions of the estuary for each major developmental phase.

Juvenile development and maturation, and subsequent mating of the adult occurs in the lower salinity waters of the mid- and upper Estuary (RK>37; RM>23), including the area near Artificial Island. The loci of spawning and larval development are far removed in the higher salinity regions of the lower Bay and near coastal waters.

The temporal and spatial distribution, abundance, and harvest, of blue crab vary with temperature, salinity, sex, and maturity. In winter, crab congregate in the deeper waters of the estuary in a state of semi-hibernation. While in this relatively inactive condition the species is the subject of a commercial dredge fishery which concentrates on the deep bay channels and sloughs from Port Mahon, Delaware (RK 47; RM 29) to just off the Bay mouth. The annual composition of this catch indicates definite distributional patterns by sex. During the 1975 and 1976 seasons, mature females comprised to 86 percent while mature males and juveniles were taken in low numbers (ca. 12 percent and 2 percent, respectively) (R. Coles, unpublished data). The overwintering grounds of mature males and juveniles is not well defined, but is believed to include the deep waters of the upper Bay and adjacent tidal tributaries.

In spring, crab become more active with increasing temperature and migrate toward the warmer shoal waters. Mature females, which prefer higher salinities (Tan and Van Engel, 1958), remain in the lower Bay to spawn, having mated the previous summer. Mature males and juveniles migrate progressively upstream, typically reaching the waters near Wilmington, Delaware (RK 116; RM 72) by early May (Morrisson, 1976b), with a few individuals moving as far north as Philadelphia, Pennsylvania (RK 148; RM 92) by June (B. Hassinger, pers. comm.). Movement upstream of Philadelphia is effectively blocked by seasonal near-zero dissolved oxygen levels (Friedersdorff et al., 1978).

It is likely that many of the crab migrating upriver disperse into the tidal tributaries and surrounding marshland. These highly productive areas contain an abundant food supply, and the surrounding vegetation provides excellent protection from predation.

By mid-spring, with the species resumption of active migration and feeding, an intensive commercial crab pot fishery has begun.

Summer is the season of essentially all growth, and of maturation, mating, spawning, and new year-class development. Since blue crab have an inflexible exoskeleton they must shed or molt their restricting shell at regular intervals in order to grow. The molting process involves the formation of a new pliable shell underneath the existing shell. Once the old shell is shed, the soft shell crab swells with water and increases by about 25 percent in width before the new shell fully hardens (Tagatz, 1968a). The molt cycle is most rapid during the warmest months, and the intermolt period increases with specimen size. Maturity is attained, after 18 to 20 post-larval molts, when the crab is from 13 to 16 months old (Van Engel, 1958).

Once mature, the female ceases to grow while the male continues through an additional 3 to 4 molts.

Immediately following the terminal molt the mature female, while still soft, mates with a male. The sperm is stored in the females seminal receptacles where it remains viable for at least a year and may be used in one or more spawns.

Mating is concentrated in the lower salinity waters of the Estuary, north of Bowers Beach, Delaware (RK 37; RM 23). After mating, these females migrate to the higher salinity waters of the lower Bay to spawn. It is adaptive for the mated females to seek out waters of relatively high salinity to spawn, since hatching success has been shown to be greatest in salinities ranging from 23 to 28 ppt (Sandoz and Rogers, 1944).

Essentially all spawning in the Delaware River Estuary occurs between Bowers Beach, Delaware (RK 37; RM 23) and the Bay mouth (Porter, 1956). Spawning may occur in late spring or summer, depending on when mating occurred. If a female mates in late spring the ovaries develop in 2 to 3 months, enabling her to spawn by mid to late summer. If mating occurs in mid-summer the ovaries develop but spawning is delayed until the following spring.

A spawning female may produce from 700,000 to over 2,000,000 eggs, which are attached underneath her abdominal flap forming a sponge or egg mass. It has been estimated that of every million eggs spawned, only one adult is eventually produced (Van Engel, 1958).

The eggs develop and hatch, releasing the zoeae in about two weeks. The zoeal stage develops through seven molts, which takes from 31 to 49 days, and culminates in the megalopa. The megalopal stage lasts from 6 to 20 days and metamorphoses into the first recognizable crab (Costlow and Bookhout, 1959). These new crab migrate upstream toward fresher water, with a few individuals traveling as far upriver as Philadelphia, Pennsylvania (RK 148; RM 92) by September (B. Hassinger, pers. comm.).

In fall, with decreasing temperature, growth slows and blue crab begin a return migration to their downbay overwintering grounds.

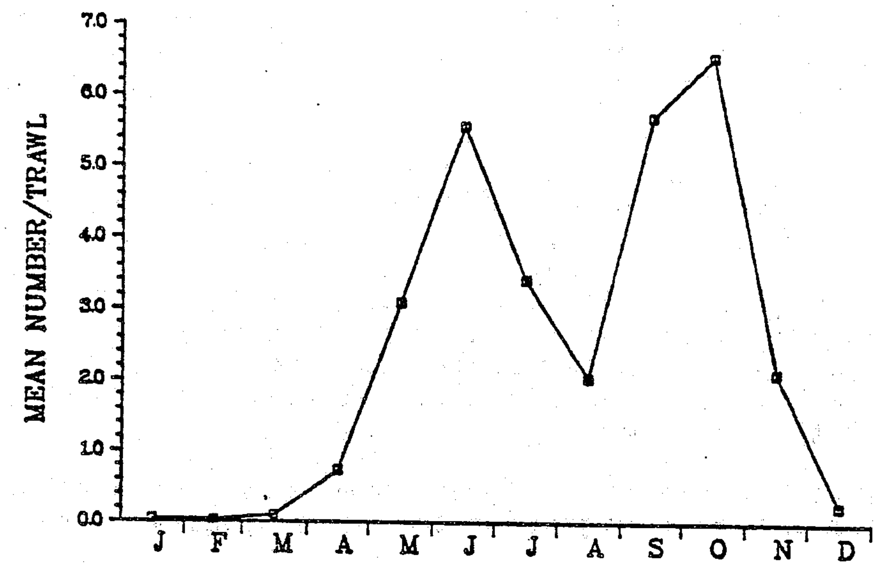
Near Artificial Island blue crab are rarely collected in January and February; the first captures typically occur in mid-March in the southern portion of the study area (Fig. 64). As temperature increases crab become more numerous and migrate progressively northward. By May crab are common and well distributed throughout the area and the first of two abundance peaks occurs usually in June.

Crab abundance has declined in July and August, primarily due to mortality (commercial fishery and natural) and continued upstream migration out of the study area.

During this same period, monthly mean size (carapace width) has steadily increased from March (30.1 mm, Fig. 65) through August (108.5 mm), reflecting growth and migration.

By mid-August the new year class begin to move into the study area. Essentially all have completed their larval development and are juveniles, though a few megalops are taken (Annual Progress Report, 1973). The influx of these young crab results in the second abundance peak in September and October (Fig. 64), with a corresponding decrease in mean size (47.7 mm and 40.5 mm, respectively; Fig. 65).

As temperature decreases in fall, crab migrate southward toward their downbay overwintering grounds. This migration is reflected in the rapid decline in local crab abundance in



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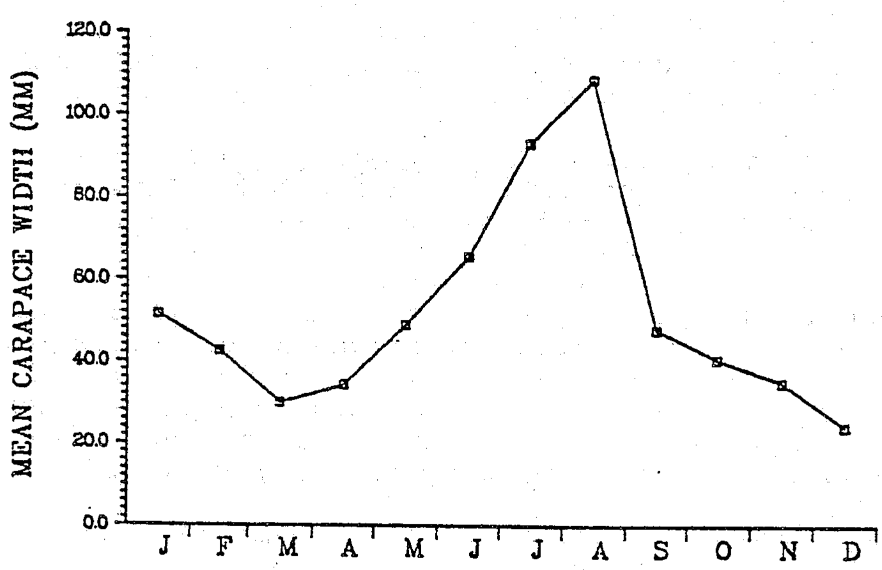
Monthly mean catch of blue crab per trawl haul near Artificial Island, 1971-1976 combined.

Figure 64



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ARTIFICIAL ISLAND STUDIES

Monthly mean carapace width (mm) of blue crab collected by trawl near Artificial Island, 1971-1976 combined.

Figure 65

November and December samples (Fig. 64). Mean size also continues to decrease through this period (34.9 mm and 24.1 mm, respectively, Fig. 65).

Annually, blue crab abundance in the Artificial Island area has increased from north to south on both the east and west sides of the Delaware River (Figs. 66 and 67; respectively). This reflects the seasonal nature, direction, and origin of the crab migration in the estuary.

Blue crab are omnivorous and feed upon a wide variety of plant and animal material. While larvae they are dependent on the plankton, but with increasing size they feed on progressively larger items. The juveniles and adults frequently feed on salt marsh grasses (Spartina spp.) in addition to other aquatic vegetation (Truitt, 1939). The species is considered an important estuarine scavenger, but also is an active swimmer and is able to capture live fish (Barnes, 1968).

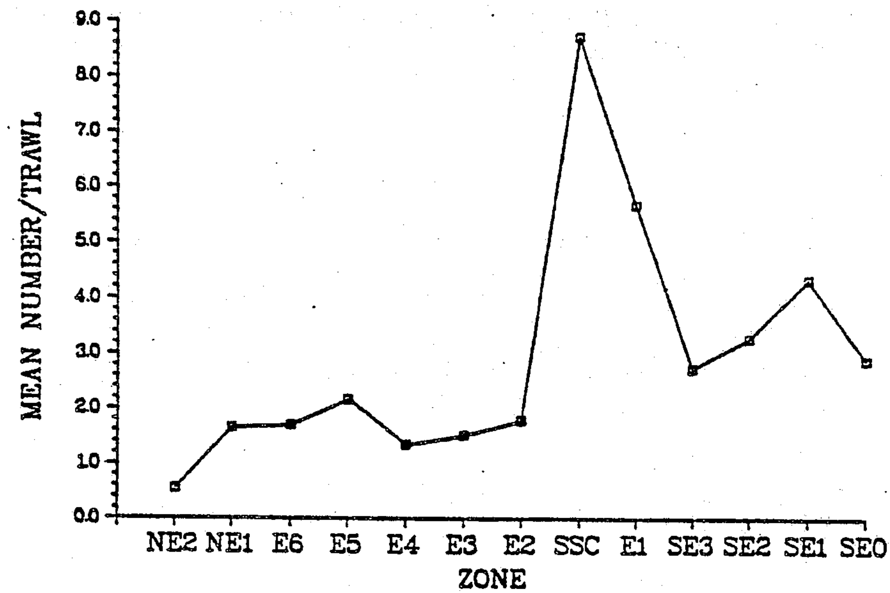
Community Discussion

The invertebrates of an aquatic system are typically divided on the basis of habitat into two primary components. The plankton are those organisms with limited mobility which spend all or part of their life cycle in the water column. The benthos are those which spend all or part of their life cycle in or on the bottom sediments. Although most taxa primarily occupy only one of the two basic habitats, in the Delaware River near Artificial Island several taxa occur and function in both (e.g., mysids, amphipods, and larval stages of benthic invertebrates).

The following sections discuss the members of each component as a group, i.e., the community, in relation to the local environment, particularly to those physicochemical factors which seem most to control or determine the local biota.

Zooplankton

The zooplankton community near Artificial Island consists of larval stages of benthic invertebrates, organisms that spend their entire life cycle in the water column, and those which utilize both the bottom substrate and the water column. It includes those organisms discussed in the previous pages but also a large variety of still smaller organisms, e.g., protozoa, which, because of size or behavior, were not



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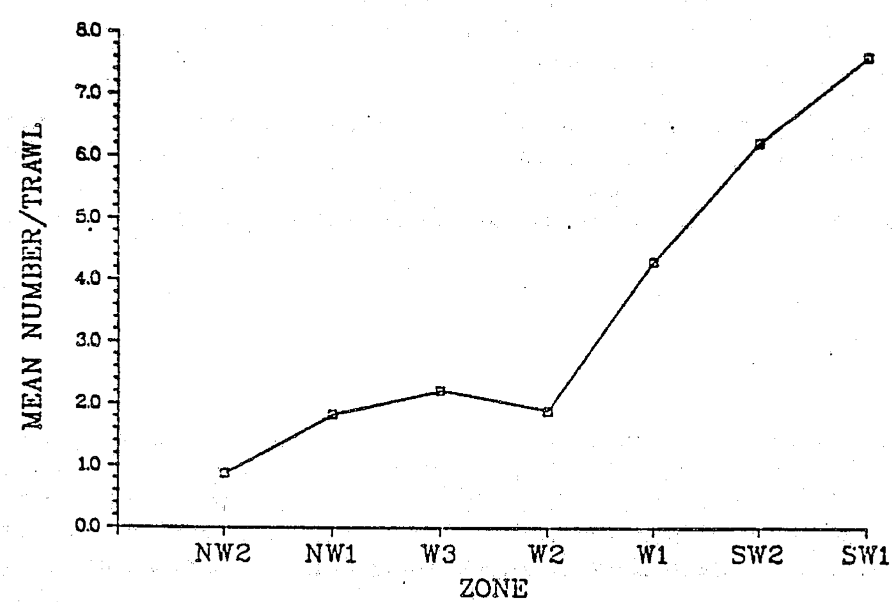
Mean catch of blue crab per trawl haul east of the shipping channel near Artificial Island, 1971-1976 combined.

Figure 66



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ARTIFICIAL ISLAND STUDIES

Mean catch of blue crab per trawl haul west of the shipping channel near Artificial Island, 1971-1976 combined.

Figure 67

taken in our samples. However, the taxa discussed herein do comprise the major fraction of total biomass and it is these that are the prime and characteristic constituents of the local zooplankton.

The zooplankton community is an essential part of an aquatic food web, but is especially so in a region such as the study area where detritus is an important part of the food base. Zooplankton convert the energy bound up in the lower trophic levels (i.e., phytoplankton and plant detritus) and make it available to higher level consumers such as fish.

The community near Artificial Island reflects the location and physicochemical characteristics of the Delaware River in this region and is typical of the type found in oligo-mesohaline reaches of mid-Atlantic coastal plain estuaries. The wide range of seasonal, and often daily changes in salinity, the high concentration of plant detritus, and the dynamic pattern of current flow has shaped a highly productive community which is numerically dominated by a few taxa including Acartia tonsa, Eurytemora affinis, Rhithropanopeus harrisii (larvae), Uca minax (larvae), copepod nauplii, "rotifer" spp., Neomysis americana, and Gammarus spp.

Changes in the community composition reflect seasonal variation in factors such as freshwater flow, salinity, and temperature, and within a more reduced time frame, tidal currents, light intensity, and predation. During seasons of high freshwater runoff, late winter and spring, the freshwater rotifers, "rotifer" spp., Brachionus angularis, and Notholca sp.; the cyclopoid copepod, Halicyclops fosteri; and the amphipod, Gammarus spp. predominate. During late summer and fall, with low freshwater flow and attendant greater tidal intrusion, more saline forms such as ctenophores and the copepods, Acartia tonsa and Pseudodiaptomus coronatus, predominate.

Numerical abundance (size) of the zooplankton community also varies seasonally, related to water temperature. During spring and summer, it increases, reflecting reproductive activity, increased larval density, and growth.

The horizontal distribution of the local zooplankton is primarily determined by flow direction and velocity. Many species are passively transported into the area from the upper and lower regions of the Estuary, and through the Chesapeake and Delaware Canal. Others have evolved behavioral mechanisms in response to the dynamic nature of the estuarine system that allow them to selectively control their position within the estuary. One such mechanism is vertical migration. By varying position in the water column, often on a diurnal basis, these are able to utilize

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the two-layer circulation system to remain within or move to a preferred water mass. This may be related to physicochemical factors, feeding activity, avoidance of visually orienting predators, and reproduction. This behavior was demonstrated by the macroplankters, Neomysis americana, Gammarus spp., Corophium lacustre, Crangon septemspinosa, Edotea triloba, and Rhithropanopeus harrisii (megalops). Microzooplankton also demonstrated vertical movement but to a lesser degree.

The distributions of larval stages of species whose adults live in or on specific substrates reflects their origin in these localized areas. Examples include the grass shrimp, Palaemonetes pugio, the fiddler crab, Uca minax, and the mud crab, Rhithropanopeus harrisii. Larvae and juveniles of the grass shrimp were collected in greatest density in inshore areas, of the fiddler crab near intertidal mud banks and at the mouths of tidal creeks, and of the mud crab near oyster-shell beds such as off Mad Horse Creek. Tidal dispersion quickly distributes these forms throughout the region.

Biotic factors such as predation, competition, and parasitism may be significant in controlling zooplankton abundance. Predation is probably most significant. A predator-prey relationship is suggested in the lagged response between macroinvertebrate and microzooplankton abundance. This is especially evident from late spring through summer. During late summer-early fall the ctenophores and hydromedusae prey extensively on microzooplankton. This phenonenon has been evidenced by Miller (1970) who estimated that ctenophores may reduce the standing crop by 25 percent per day.

Benthos

The invertebrates that make up the benthic community near Artificial Island are primarily resident euryhaline forms that are physiologically tolerent of the wide range of conditions occurring in this reach of the estuary. Most are primary consumers which feed on phytoplankton and detritus. Both pelagic larvae and adults of benthic organisms are essential components of the estuarine food web as prey for higher level consumers such as fishes. The attached benthos (e.g., hydroids, oysters, and barnacles) are also important as habitat formers (e.g., shelter and attachment surfaces) for other invertebrates.

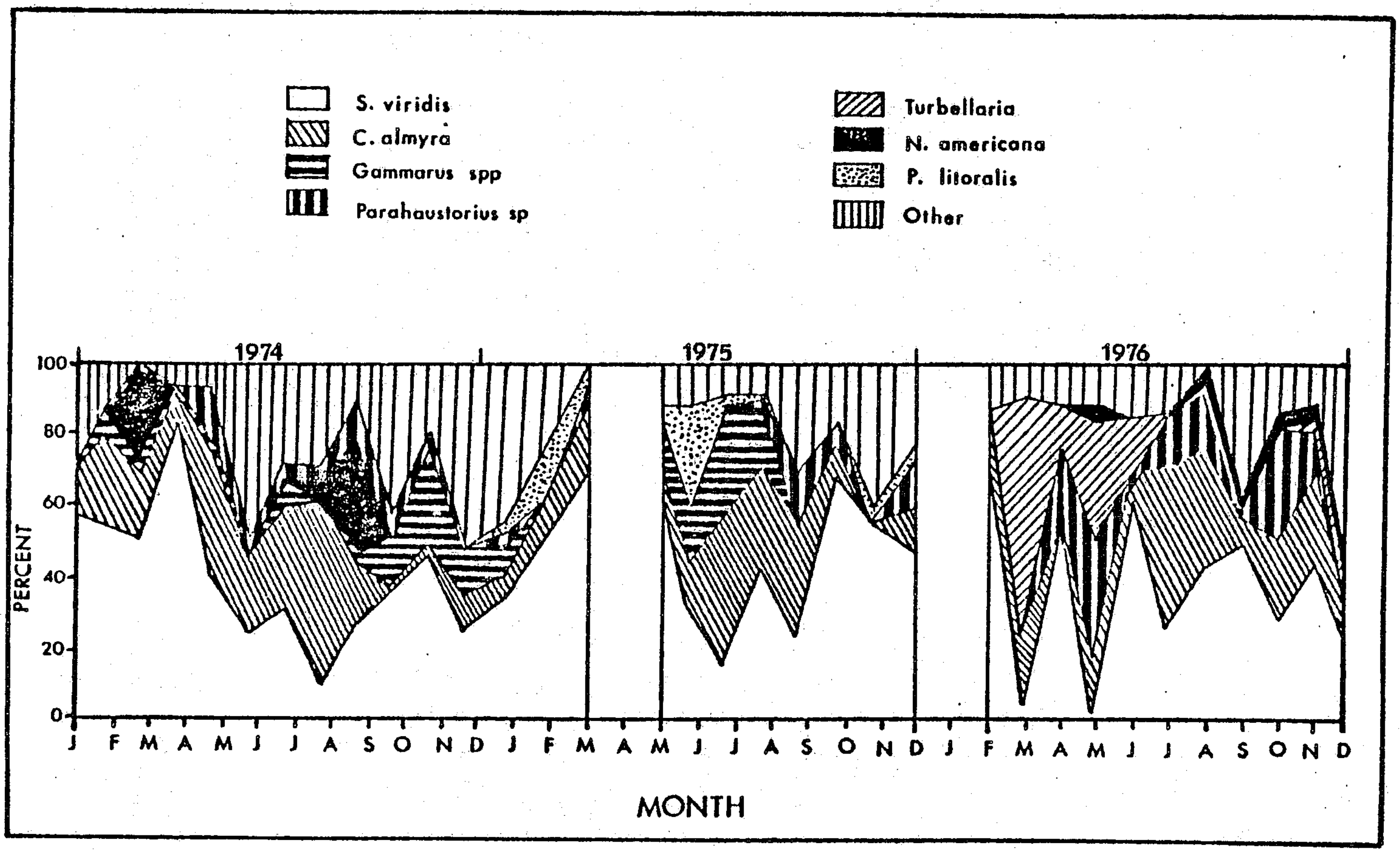
The local community consists of all benthic species occupying the Delaware River near Artificial Island. This discussion considers only those organisms that were retained on a 0.5-mm mesh sieve. These macrofauna are the major, as well as representative, constituents of the local community, and they reflect the variety of local habitat.

The principal factors regulating community composition, distribution, and abundance are salinity, temperature, and substrate. Only those organisms that have adapted mechanisms, physiological or behavioral, that enable them to tolerate the local daily and seasonal fluctuations in salinity and temperature can succeed. However, the availability of suitable substrate is the factor most limiting distribution and abundance of many taxa in this reach of the estuary (e.g., barnacles). The combined effect of these factors is reflected in a community characterized by a relatively low diversity with a few numerically dominant taxa including Scolecolepides viridis, Polydora sp., Paranais litoralis, Balanus improvisus, and Cyathura polita.

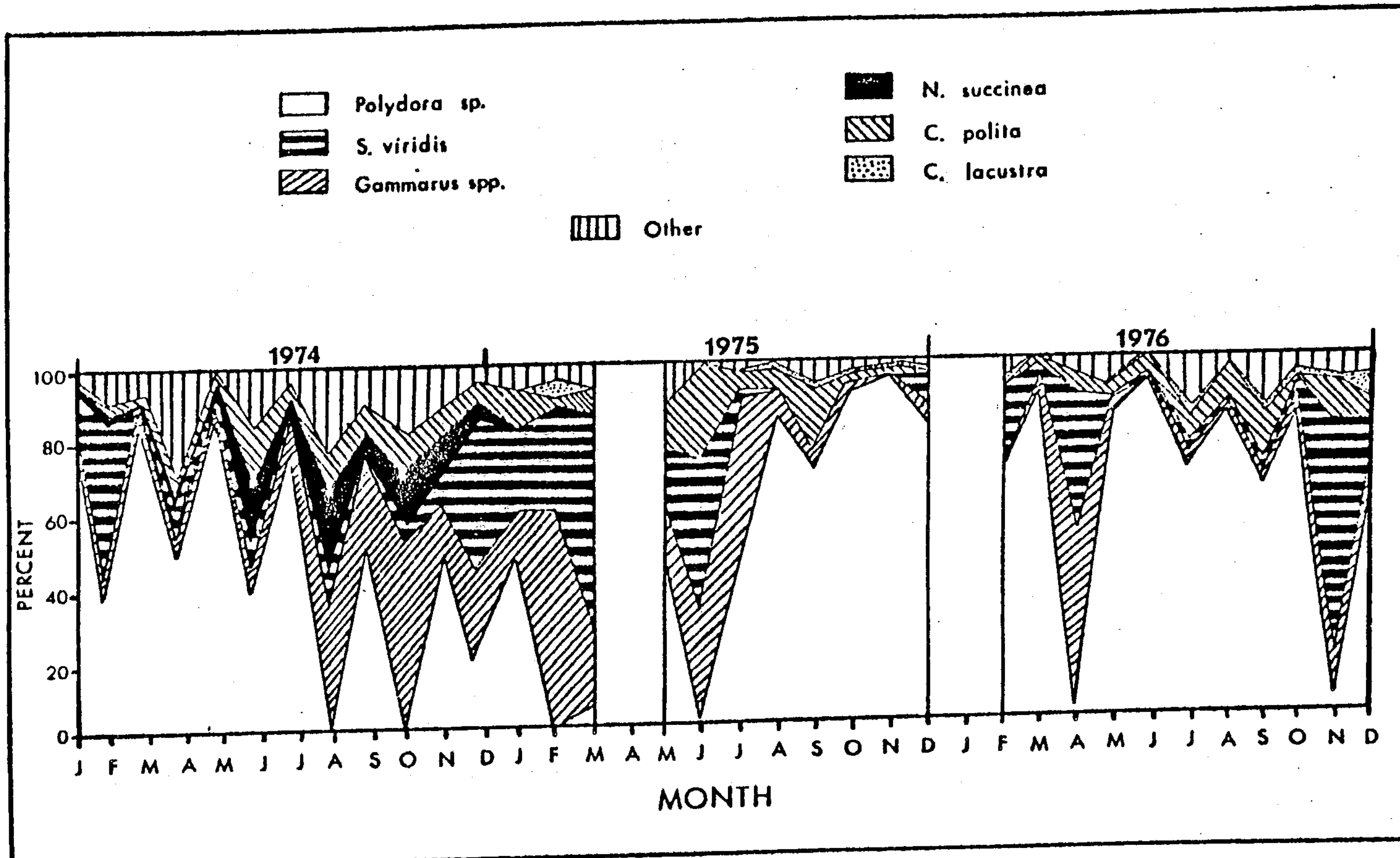
As a result of species specific habitat preference and/or dependence, each substrate type has its characteristic assemblage of organisms. Some species are limited to one type while others occur in all. Substrate type is primarily determined by water velocity as it affects deposition of sediments. Near Artificial Island the basic types are sand, clay, mud, and to a lesser extent gravel-shell. In this discussion all data from each substrate type are considered; however, data from only one station, representative of each type, are presented graphically.

Sand substrate has low organic content, is subject to scouring by strong currents, and has a lack of attachment surfaces. Species richness (from 7 to 10 annually), density, and biomass were least in this substrate. The limited ability of sand to support infauna or epifauna is reflected by Scolecolepides viridis, which although dominant in sand (Fig. 68), was much more abundant in other types. However, some organisms seem especially adapted to utilize a sand substrate; Chiridotea almyra, also dominant in sand, was less abundant elsewhere, and Parahaustorius sp. was taken only in sand. Other common occupants of the sand community were Gammarus spp., Neomysis americana, Turbellaria, and Paranais litoralis.

Clay substrate is also characterized by low organic content, high susceptibility to scouring, and little attachment surface. It consists mostly of clay, silt, and some detritus. Species richness (9-12), density, and biomass were moderate. Polydora sp. was the dominant taxon in clay and was less common elsewhere (Fig. 69). Other members of the clay community were Gammarus spp., Scolecolepides viridis, Cyathura polita, Corophium lacustre, and Nereis succinea.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Relative temporal abundance of dominant benthic invertebrates in sand substrate. Figure 68



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Relative temporal abundance of dominant benthic invertebrates in clay substrate.
	Figure 69

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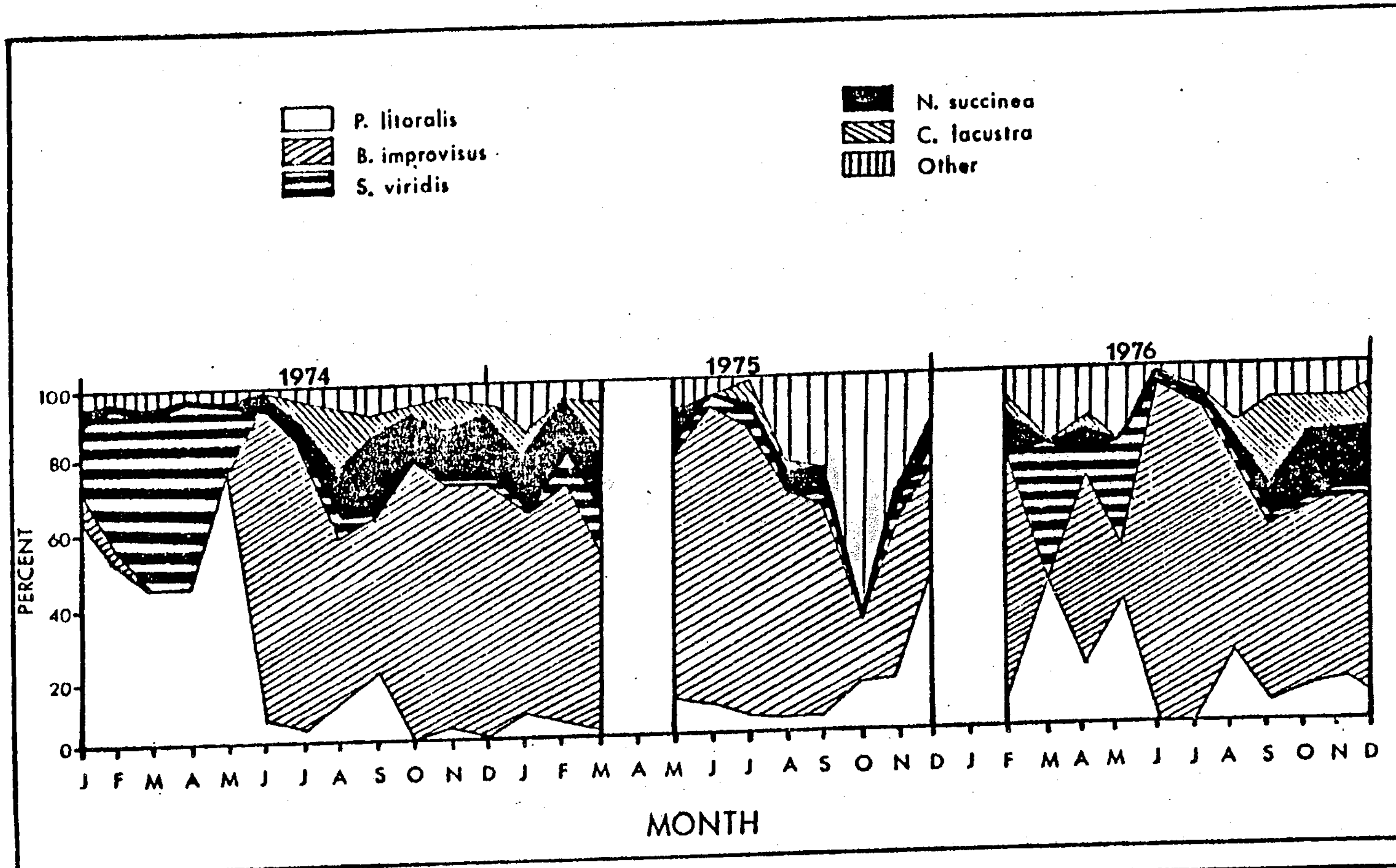
Mud is characterized by high organic content, little attachment surface, and is typical of depositional areas with a slow current velocity. Species richness (12-13), density, and biomass were moderate. Paranais litoralis was the dominant taxon in mud (Fig. 70); it was less common in other types. Other members of the mud community were Scolecolepides viridis, Oligochaeta #1, Rhynchocoela, and Cyathura polita.

Gravel-shell substrate is characterized by high organic content and a wide range of attachment surfaces including small rocks, gravel, and shell. It provides food and habitat for many benthic organisms. Species richness (16-19), density, and biomass were greatest in these areas. Balanus improvisus, which requires firm substrate for attachment, was the dominant taxon (Fig. 71). Other components of the gravel-shell community were Paranais litoralis, Scolecolepides viridis, Nereis succinea, and Corophium lacustre. Taxa utilizing the surface attachment aspect of this substrate include the mussel, Modiolus demissus;the oyster, Crassostrea virginica; the anenome, Diadumene leucolena; and some ectoprocts (bryozoans). The nudibranch, Doridella obscura, which feeds on ectoprocts, was taken only on gravel-shell.

Seasonal changes in salinity and temperature are reflected in the local community structure. Salinity as it affects species number and distribution is probably the more important of the two. Its effect is reflected in the greater diversity when salinity is high, primarily summer and fall, due to movement of species into the study area from downbay such as the isopod, Edotea triloba, and the cumacean shrimp, Leucon americanus. Larval stages of several species immigrate into the study area in summer and fall and become temporarily established in low density in the benthos; e.g., the polychaetes, Glycera dibranchiata, Glycinde solitaria, and Sabellaria vulgaris; the pelecypods, Mulinia lateralis and Mya arenaria; and the tunicate Molgula manhattensis.

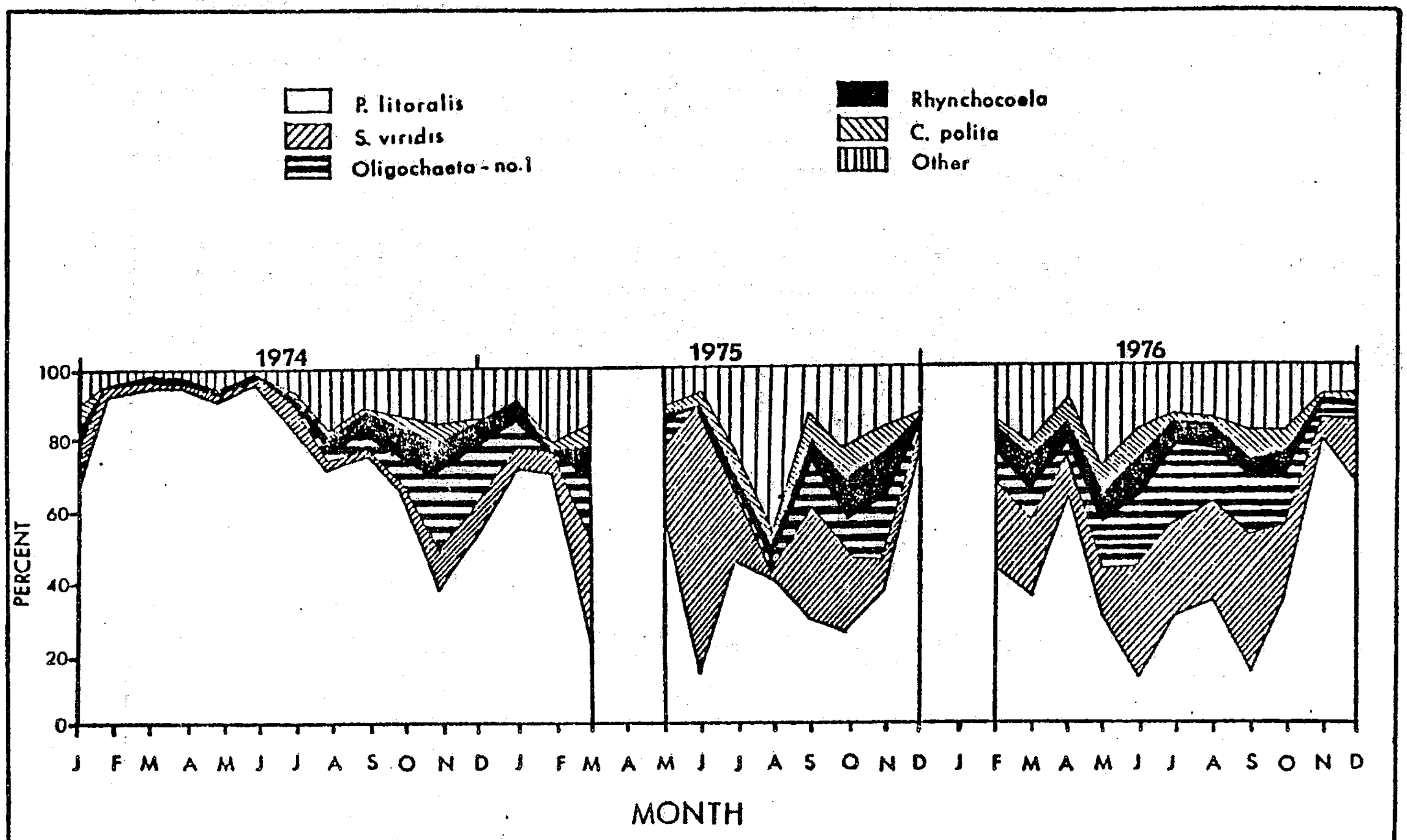
Water temperature determines timing of reproductive activity for many species and is closely associated with seasonal increases in benthic populations. This is best evidenced by the occurrence of recently set larvae of Balanus improvisus shortly after optimum temperature for reproduction.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ARTIFICIAL ISLAND STUDIES

Relative temporal abundance of dominant benthic invertebrates in gravel-shell substrate.

Figure 70



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Relative temporal abundance of dominant benthic invertebrates in mud substrate.
	Figure 71

AQUATIC VERTEBRATE FAUNA

INTRODUCTION

Fishes are the principal upper level consumers in the Delaware River aquatic ecosystem, being at or near the pinnacle of energy transfer. They continue the predator-prey relationship established in lower trophic levels and in their inter- and intracommunity relationships occupy a diversity of habitats.

Since mid-1968 the fishes in the river and tidal tributaries have been sampled with a variety of gear. The initial objective was to inventory the fishes that occur in the Artificial Island area. After a period of extensive and intensive sampling, the seasonality of community structure was defined and study goals were expanded to include seasonal and spatial distribution and annual variation by life stage. Studies of life history aspects, e.g., age, growth, and food habits, of selected obviously important species were conducted. Results were presented in Annual Progress Reports. This discussion concentrates on 16 fishes which, because of numerical abundance and/or economic and ecological importance, are especially important and representative in the local community. It summarizes information on their life cycles, relates their local occurrence to species behavior and requirements, and discusses general patterns in temporal and spatial occurrence and activity.

MATERIALS AND METHODS

Samples were taken with a variety of gear including surface and bottom trawls, various seines, staked and drifted gill nets, trap nets (1968 only), and 1-m and 1/2-m plankton nets. The widest assortment was used during the early years to ensure adequate sampling of most habitats, again, in inventory mode. Because of tidal variation, weather related non-predictability of passive gear retrieval (staked nets, traps, etc.), and local bottom conditions, not all gear could be used in quantitative, scheduled sampling. Eventually, a program of standardized trawling and seining was established as being the most suitable and dependable in defining structure and behavior of the fish community during the monitoring program. Table 3 shows chronology of primary gear deployment; it does not include additional occasional exploratory or corroborative sampling. The following briefly describes gear and procedures. For details of annual sampling see Annual Progress Reports.

Table 3
Chronology of primary sampling gear deployment in the Delaware River and tidal tributaries near Artificial Island, 1968-1976.
* = inventory; X = monitoring, scheduled; + = special study.

Gear	Trawl							Seine								Simultaneous		Gill Net						Plankton Net		
Spec.	2.7 m	4.9 m		7.6 m				3.0 x 1.2 m				7.6 x 1.2 m		68.6 x 3.0 m		4.9-m Trawl 3.0-m Seine 7.6-m Seine 68.6-m Seine		7.9-cm (3.1-in) str 2 x 183 m	7.9-cm (3.1-in) str 2 x 91 m		14-cm (5.5-in) str 3 x 183 m 6 x 183 m	14-cm (5.5-in) str 3 x 91 m 6 x 91 m		1/2-meter		
Area Sampled	Trib. (Bottom)	River (Bottom)		River (Bottom)		River (Surface)		River		Trib.		River		River		River (Entire Water Column)		River (Surface, Drifted)	River (Bottom, Staked)		River (Surface, Drifted)	River (Bottom, Staked)		River		Trib. (Surface/ Midwater/ Bottom)
Day: Night	D	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D	D	N	D	D	N	D	N	D
Year																										
1968		*	*	*	*	*	*					*	*													
1969	*	*	*	*	*	*	*	*	*	*	*	*	*					*			*					
1970	X	X	+	+	+			X	+	X	+	X	+	*	*			X			X	*	*			
1971	X	X	+					X	+	X	+	X	+			+	+	X			X			*	*	
1972	X	X	+					X	+	X	+	X	+			+	+	X	+	+	X	+	+	*	*	
1973	X	X	+					X	+	X	+	X	+			+	+	X			X			X	+	
1974	X	X	+					X	+	X	+	X	+			+	+	X			X			X	+	*
1975	X	X	+					X	+	X	+	X	+			+	+	X			X			X	+	X
1976	X	X	+					X	+	X	+	X	+			+	+	X			X			X	+	X

134

Sampling Techniques and Schedules

Semi-balloon otter trawls were used in the river and tidal tributaries because of their capture efficiency in deeper waters. In the inventory phase, 7.6-m and 4.9-m trawls were fished in the river at surface and bottom during the day and night. Tidal tributaries were sampled with 4.9-m and 2.7-m trawls on the bottom during daylight. Intensive sampling (sometimes weekly) evidenced that a biweekly sampling schedule would adequately describe temporal trends, and in 1970 the standardized trawl program was initiated. It involved biweekly sampling in the river with the 4.9-m bottom trawl during daylight in 21-27 zones from 14.5 km north to 16.1 km south of Artificial Island. Night bottom trawling was done in from five to eight zones annually. Trawls were hauled for 10 min with the tide at boat speed of 3-4 knots. Onshore and offshore hauls were made in each zone. Local tidal tributaries were sampled with 5-min hauls of the 2.7-m trawl on a similar schedule. Beginning in 1973, 20-min hauls were made in five additional deepwater zones in the river in or near the shipping channel.

Seines were used to sample fishes in the shallow waters of the shore zone. In the inventory phase, 68.6-, 22.9-, 7.6-, and 3.0-m seines were fished during day and night at locations throughout the study area. In 1970 the standardized seine program was initiated. It involved fishing a 7.6- by 1.2-m, 0.6-cm mesh bag seine and a 3.0- by 1.2-m, 0.3-cm mesh flat seine during daylight, generally biweekly at from seven to ten stations and at night at selected stations. The smaller seine was used at 6-12 stations in local tidal tributaries. In 1974, sampling effort in the river was further standardized to include one 27- to 37-m haul with the larger seine and three 6-m hauls with the smaller seine to allow semi-quantitative spatial and temporal comparison.

A day-night program of simultaneous seining and trawling was initiated in 1971, as a semi-quantitative supplement to the standard seine and trawl programs to evidence distributional differences between day and night, inshore and offshore, and east and west sides of the river. Four types of gear were used at each of two sites. The shallow inshore zone was sampled with a 3.0- by 1.2-m, 0.3-cm mesh flat seine and a 7.6- by 1.2-m, 0.6-cm mesh bag seine. The intermediate zone was sampled with a 68.6- by 3.0-m, 1.3-cm mesh bag seine. The deeper offshore waters were sampled with a 4.9-m semi-balloon otter trawl towed at the bottom. A standard sampling effort consisted of four or five hauls with the smaller seines, one haul with the larger seine, and two, five-min trawl hauls. Generally, day and night samples were taken within 24 hours of each other and at the same tidal stage.

Gill nets with stretched mesh size ranging from 1/2-in to 5 1/2-in were fished throughout the river and in tidal tributaries during day and night in the inventory period. Nets were anchored, staked, and drifted. During the scheduled monitoring period, 3 1/8-in and 5 1/2-in nets were drifted in the river to sample the larger size classes and the more pelagic species that are less susceptible to capture by trawl. Effort was concentrated in spring to sample immigrating species such as the anadromous river herrings, shad, and striped bass which pass through the area during that season. Nets were also fished in mid-summer to sample older age groups of summer resident species, and in fall to sample the new year class of anadromous species as they emigrated past Artificial Island and out of the estuary.

The procedure for processing the catch of young and adults was the same for all gear. When fewer than 200 specimens of a species were taken (the usual case) all were enumerated and up to 30 were measured to the nearest mm. When more than 200 specimens of a species were taken the sample was estimated and a subsample of 30 was measured. Fork length (FL) was the standard measured. Fish with convex caudal fins were measured by total length (TL). Dissolved oxygen, water temperature, and salinity were measured at surface with each seine collection and at surface and bottom with each collection by other gear. For a more detailed description of procedures see Annual Progress Reports.

Early life stages (eggs and larvae) were sampled annually with 1/2-m, 0.5-mm mesh conical plankton nets since 1971. Earlier, 1.0-m nets and a specially adapted 2.7-m bottom trawl were also tried and found less suitable. Samples were taken simultaneously at surface and bottom at 9 to 11 stations in the river. Bottom nets were fitted with 17-kg depressors to keep them fishing about 0.6 m above bottom. All tows were made with the tide for five minutes. In 1973 nets were fitted with flow meters and abundance was expressed as density (number of organisms per cubic meter of water filtered - n/m^3). Effective 1974, replicate samples were taken at selected stations and middepth samples were taken at three deepwater stations. Samples were taken at least monthly and more frequently during periods of greatest ichthyoplankton abundance (June-August). Specimens were preserved in the field and brought to the laboratory where they were identified to the lowest practicable taxonomic level and counted.

Data Reduction

The following statistics are used in the discussion of data: n = number of specimens, T = number of trawl hauls, n/T = number of specimens per trawl haul, n/c = number of specimens per seine collection, n/m^3 = number of specimens per cubic meter of water filtered.

RESULTS AND DISCUSSION

Some 93 fishes were collected in the Delaware River and tidal tributaries near Artificial Island from January 1970 through December 1976 (Table 4). These are listed, together with notes which characterize the seasonality, relative abundance, and habitat utilization of these fishes in this region, in Appendix B. More detailed accounts of sixteen species that were abundant and/or are of commercial or recreational value are presented in this section. The following summary briefly describes and characterizes the catch composition, by sampling program, over the seven-year period. For more detailed results within a particular year or by a specific gear see the Annual Progress Reports. Results of the simultaneous seine and trawl and night trawl programs will be included within the species discussions where relevant.

General Sample Composition

Nearly all species were represented by two or more life stages (Table 4) and nine, mostly residents of the estuary, were represented from the egg through adult stage. Those collected in all life stages were the blueback herring, alewife, bay anchovy, tidewater silverside, Atlantic silverside, white perch, striped bass, weakfish, and hogchoker. Young was the best represented (82 species) life stage which is indicative of the role of this region as a nursery. Although so many species were taken as young, only 29 were represented by the egg and/or larval stage. However, for many species these life stages would not be expected in this region due primarily to the remoteness of their spawning grounds. Most species represented by only a single life stage occurred in the region as strays.

Forty-two species were taken annually, but relative and absolute abundance varied reflecting variations in year-

Table 4

Fishes collected from the Delaware River and tidal tributaries near Artificial Island annually during January 1970 through December 1976. Life stages: E=egg, L=larva, Y=young, A=adult. Type of gear: P=plankton net, S=seine, T=trawl, G=gill net. Top 10 species in river samples are ranked.

Species	Life Stage	Type of Gear	70 Occur	70 Rank T;S	71 Occur	71 Rank T;S	72 Occur	72 Rank T;S	73 Occur	73 Rank T;S	74 Occur	74 Rank T;S	75 Occur	75 Rank T;S	76 Occur	76 Rank T;S
Sea lamprey	Y,A	P,T,G			+		+		+		+		+		+	
Cownose ray	A	T	+													
Atlantic sturgeon	Y	T,G			+		+				+		+		+	
American eel	Y,A	P,S,T	+	7;	+	10;	+	7;	+	7;	+		+	10;10	+	
Conger eel	Y	S									+					
Blueback herring	E,L,Y,A	P,S,T,G	+	6;3	+	8;5	+	9;	+	10;4	+	7;8	+	8;	+	8;10
Hickory shad	Y,A	S,T,G	+		+		+		+				+		+	
Alewife	E,L,Y,A	P,S,T,G	+	5;8	+	7;3	+	;4	+		+		+		+	10;
American shad	Y,A	S,T,G	+		+		+		+		+		+		+	
Atlantic menhaden	L,Y,A	P,S,T,G	+	;5	+	6;2	+	6;3	+	6;7	+	5;3	+	7;3	+	7;3
Atlantic herring	Y,A	T,G			+				+		+		+		+	
Gizzard shad	L,Y,A	P,S,T,G	+		+		+		+		+		+		+	
Striped anchovy	Y,A	S,T			+		+		+		+				+	
Bay anchovy	E,L,Y,A	P,S,T,G	+	1;2	+	1;4	+	1;2	+	1;2	+	1;1	+	1;2	+	1;1
Eastern mudminnow	A	S	+										+			
Redfin pickerel	Y,A	S	+		+		+		+							
Chain pickerel	Y,A	S	+		+		+									
Inshore lizardfish	Y,A	S,T							+		+				+	
Goldfish	Y,A	S,T	+		+				+		+		+		+	
Carp	Y,A	S,T,G	+		+		+		+		+		+		+	
Silvery minnow	Y,A	P,S,T	+		+		+	;7	+	;6	+	10;	+		+	9;
Golden shiner	Y,A	S,T	+		+		+		+		+		+		+	
Satinfin shiner	Y,A	S,T	+		+		+		+		+		+		+	
Spottail shiner	Y,A	S,T	+		+		+		+		+		+		+	
Creek chub	A	S			+											
White sucker	A	S	+		+										+	
Creek chubsucker	Y	S	+		+											
White catfish	Y,A	S,T,G	+		+		+		+		+		+		+	
Brown bullhead	L,Y,A	P,S,T,G	+	10;	+		+	10;	+		+		+		+	
Channel catfish	Y,A	S,T,G	+		+		+		+		+		+		+	
Oyster toadfish	L,Y,A	P,T	+		+		+		+		+		+		+	
Silver hake	Y	T			+						+		+			
Red hake	Y	T			+		+		+		+		+			
Spotted hake	Y	T	+		+		+		+		+		+	9;	+	
Striped cusk-eel	Y,A	P,T	+				+		+		+	9;	+		+	
Halfbeak	Y	S			+										+	
Atlantic needlefish	Y,A	S,T	+		+		+		+		+		+		+	
Sheepshead minnow	Y,A	S	+		+		+		+		+		+		+	
Banded killifish	L,Y,A	P,S,T	+		+		+		+		+		+		+	
Mummichog	L,Y,A	P,S,T	+	4;	+	;7	+	;5	+	;5	+	;6	+	;5	+	;5
Striped killifish	Y,A	S,T	+		+		+		+				+		+	
Rainwater killifish	Y,A	S							+							
Mosquitofish	A	S	+				+									
Rough silverside	Y,A	P,S,T	+	;9	+		+		+	;10	+	;10	+	;8		;6
Tidewater silverside	E,L,Y,A	P,S,T	+	;10	+		+		+	;8	+	;4	+	;4		;8

Table 4
Continued

Species	Life Stage	Type of Gear	70 Occur	70 Rank T;S	71 Occur	71 Rank T;S	72 Occur	72 Rank T;S	73 Occur	73 Rank T;S	74 Occur	74 Rank T;S	75 Occur	75 Rank T;S	76 Occur	76 Rank T;S
Atlantic silverside	E,L,Y,A	P,S,T	+	;1	+	;1	+	1	+	;1	+	;2	+	;1	+	;2
Fourspine stickleback	A	S	+		+											
Threespine stickleback	L,Y,A	P,S,T	+		+				+		+		+		+	
Lined seahorse	A	T			+											
Northern pipefish	L,Y,A	P,S,T	+		+		+		+		+		+		+	
White perch	E,L,Y,A	P,S,T,G	+	3;7	+	2;9	+	2;6	+	3;	+	4;9	+	6;	+	4;9
Striped bass	E,L,Y,A	P,S,T,G	+	8;6	+	9;8	+	8;9	+	8;	+		+		+	
Black sea bass	Y	T									+		+		+	
Bluespotted sunfish	Y,A	S			+						+					
Pumpkinseed	L,Y,A	S,T	+		+		+		+		+		+		+	
Bluegill	L,Y,A	S,T	+		+		+		+		+		+		+	
Smallmouth bass	Y	S									+					
Largemouth bass	Y,A	S	+		+		+		+		+		+		+	
White crappie	Y,A	S,T	+		+		+		+		+		+		+	
Black crappie	Y,A	S,T	+		+		+		+		+		+		+	
Tessellated darter	Y,A	S,T	+		+		+		+		+		+		+	
Yellow perch	L,Y,A	P,S,T,G	+		+		+		+		+		+		+	
Bluefish	Y,A	P,S,T,G	+	9;	+	;10	+	;10	+	;9	+	;7	+	;7	+	;7
Crevalle jack	Y	P,S,T	+		+		+		+		+		+		+	
Lookdown	Y	T									+		+			
Pinfish	Y	S									+					
Silver perch	L,Y,A	P,S,T	+		+		+		+		+		+		+	
Weakfish	E,L,Y,A	P,S,T,G	+	2;	+	3;	+	4;	+	4;	+	6;	+	3;	+	6;
Spot	L,Y,A	P,S,T,G	+		+	5;6	+	3;8	+	2;3	+	2;5	+	4;6	+	3;4
Northern kingfish	Y	T									+					
Atlantic croaker	L,Y,A	S,T	+		+		+		+	9;	+	8;	+	2;	+	2;
Black drum	L,Y	P,S,T	+		+		+		+		+		+			
Spotfin butterflyfish	Y	T									+					
Striped mullet	Y,A	S							+		+				+	
White mullet	Y	S	+		+											
Northern stargazer	Y	T	+								+		+		+	
Sand lances	L	P											+			
Naked goby	L,Y,A	P,S,T	+		+		+		+		+		+		+	
Seaboard goby	A	T					+									
Atlantic mackerel	A	T			+											
Spanish mackerel	A	G													+	
Butterfish	Y,A	P,T,G	+		+				+		+		+		+	
Northern searobin	Y,A	T					+				+				+	
Striped searobin	Y	P,T			+		+				+		+		+	

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Table 4
Continued

Species	Life Stage	Type of Gear	70 Occur	70 Rank T;S	71 Occur	71 Rank T;S	72 Occur	72 Rank T;S	73 Occur	73 Rank T;S	74 Occur	74 Rank T;S	75 Occur	75 Rank T;S	76 Occur	76 Rank T;S
Smallmouth flounder	Y,A	P,S,T	+				+						+			
Summer flounder	L,Y,A	P,S,T,G	+		+		+		+		+		+		+	
Fourspot flounder	Y	T											+			
Windowpane	L,Y,A	P,T	+		+		+		+		+		+		+	
Winter flounder	L,Y	P,S,T	+		+		+				+		+			
Hogchoker	E,L,Y,A	P,S,T,G	+	4;	+	4;	+	5;	+	5;	+	3;	+	5;9	+	5;
Blackcheek tonguefish	Y,A	T											+		+	
Smooth trunkfish	Y	T											+			
Northern puffer	Y	S,T	+		+						+					

class production, changes in distribution patterns, availability of food organisms, etc. Especially variable were Atlantic menhaden and spot. Fluctuations in annual abundance for most species appeared to be random. However, some species, particularly members of the drum and temperate bass families, exhibited a pattern which may be part of some long-term cycle and/or trend.

Nineteen fishes were taken in all months; the others occurred seasonally. Among those taken year-round were the American eel, bay anchovy, brown bullhead, mummichog, white perch, and hogchoker. Thirty-four species, including most drums, minnows, herrings, and sunfishes, were taken in six or more months. Eighteen species, mostly classified as strays, e.g., conger eel, halfbeak, lined seahorse, and mackerels, were taken in only one or two months.

Ichthyoplankton Program

A total of 758,742 eggs and/or larvae of 44 taxa (33 identified to species) were taken in 4,394 plankton net collections. From 19 to 26 species were taken annually; most were taken each year. Annual density of ichthyoplankton increased from 1971 through 1974, decreased by some 60 percent in 1975, and increased by more than 300 percent in 1976.

Species variety was greatest during spring-summer and lowest in winter. Ichthyoplankton abundance was greatest during summer reflecting the abundance of bay anchovy which comprised more than 77 percent of each annual sample. Bay anchovy eggs annually comprised from 96.0 to 99.9 percent of annual egg samples, and larvae comprised from 68.7 to 98.2 percent. Other fishes taken annually and common in one or more years were naked goby, blueback herring, alewife, Atlantic menhaden, weakfish, and the silversides.

Daylight River Trawl Program

A total of 537,646 specimens of 71 species were taken in 5,567 collections. Annual adjusted catch (n/T) ranged from 65.2 to 127.2. Catch was typically largest during spring and fall and smallest from December through March. From 36 to 53 species were taken annually. Species variety was typically greatest during April, June, October, and/or

November and least from December through March. Generally, five or six species together comprised more than 95 percent of each annual sample. Over the seven-year period nine species were included in the top 95 percent of one or more annual samples. Bay anchovy ranked first in all years and typically comprised more than 50 percent (as much as 77 percent) of each annual sample. Spot ranked second in the combined seven-year sample, followed by white perch, weakfish, Atlantic croaker, hogchoker, Atlantic menhaden, blueback herring, and alewife.

River Seine Program

A total of 148,447 specimens of 55 species were taken in river seine collections. Forty-three of these also appeared in the river trawl sample. Catch was typically largest in May, June, August, and September and smallest from January through March. From 27 to 41 species were taken annually. Species variety was typically greatest during June, July, and October and least from January through March. Generally, some five or six species comprised 95 percent of each annual sample. Over the seven-year period eleven species were included in the top 95 percent of one or more annual samples. Atlantic silverside and bay anchovy ranked first and second in all years and together comprised 70 percent or more of each annual sample. Atlantic menhaden ranked third in the combined seven-year sample, followed by alewife, blueback herring, spot, mummichog, tidewater silverside, white perch, striped bass, and silvery minnow.

Gill Net Program

Some 8,648 specimens of 24 species were taken in 324 collections totaling 320.2 drift hr and 642.8 staked hr. Blueback herring, alewife, and American shad were taken annually. Other species collected and taken in abundance were Atlantic menhaden, bluefish, white perch, and striped bass.

Creek Trawl Program

A total of 13,629 specimens of 41 species were taken in 874 collections. Thirty-eight of these also occurred in the river trawl sample. Annual adjusted catch (n/T) ranged from

9.7 to 23.7. Large monthly catches occurred in nearly all months from March through November over the seven-year period. From 18 to 27 species were taken annually. Species variety was typically greatest in September and least during winter months. Annual samples were much more evenly distributed among species than were those of the river trawl program. Generally, some 7-11 species together comprised more than 95 percent of each annual sample but 4-6 species comprised 80 percent or more. Over the seven-year period nine species were included in the top 80 percent of one or more annual samples. White perch ranked first in all but one year. Brown bullhead ranked second in the combined seven-year sample, followed by spot, hogchoker, American eel, channel catfish, bay anchovy, white perch, and Atlantic menhaden.

Creek Seine Program

A total of 49,014 specimens of 51 species were taken in 648 collections. Forty-four of these also occurred in the river seine sample. Catch was typically largest during summer and smallest during winter. From 21 to 42 species were taken annually. Species variety was typically greatest in July and least during winter months. Generally, some 9-16 species together comprised more than 95 percent of each annual sample but 4-8 species comprised 80 percent or more. Over the seven-year period eleven species were included in the top 80 percent of one or more annual samples. Bay anchovy ranked first in the combined seven-year sample, followed by Atlantic silverside, white perch, mummichog, banded killifish, silvery minnow, Atlantic menhaden, alewife, tesselated darter, spot, and gizzard shad.

Species Discussion

Of the 93 fishes taken during the seven years of study, sixteen, because of their numerical abundance and/or commercial and recreational importance, are discussed. These fishes, in phylogenetic order, are the American eel, blueback herring, alewife, American shad, Atlantic menhaden, bay anchovy, mummichog, tidewater silverside, Atlantic silverside, white perch, striped bass, weakfish, spot, Atlantic croaker, naked goby, and hogchoker. Typically, each is discussed as a species; however, the two silversides and the two river herrings and shad are discussed by genus since the species life histories are similar.

Each discussion includes general information on the species and its life history and an account of its occurrence in and utilization of the study area. The first statement briefly addresses the utilization. This is followed by a life history compendium, which puts the species local occurrence into best perspective. Emphasis is on information obtained from studies within the Delaware River system, particularly for resident species. Finally, each discussion describes, in summary form, the local occurrence in the study area. This considers data collected in all sampling programs; however, it emphasizes the sampling gear that best quantitates the local population (e.g. seine for silversides, trawl for hogchoker). In addition, focus is on riverine sampling (versus tributaries) since all species during much of the year were more abundant in the river. For several species additional data are included from species-specific programs.

American eel

The American eel, Anguilla rostrata (Lesueur), of the family Anguillidae, is a catadromous semi-demersal inhabitant of the Delaware River Estuary and tributaries. Elvers and adults occur annually in the Delaware River near Artificial Island. Eels occur throughout the year but are typically most abundant from April through October.

The American eel has been reported at salinity of 0-37 ppt (Raney, 1959; Jeffries, 1960) and at temperature as low as -0.8 C (Herman, 1958). It has several sequential developmental stages which occur in different environments including eggs and leptocephalus larvae in the open ocean; glass eels in the open ocean and coastal waters; elvers in coastal waters, estuaries, and fresh water; and juveniles and adults in lakes, rivers, estuaries, and coastal marine waters (Fahay, 1978). Females have been reported to a length of 1,275 mm TL, males to 725 mm TL, and both sexes live to perhaps 20 years (Vladykov, 1966; 1973).

Eels range along the Atlantic and Gulf coasts from Labrador to the Guianas. They are present throughout the Caribbean and ascend freshwater streams and lakes east of the Rocky Mountains (Fahay, 1978).

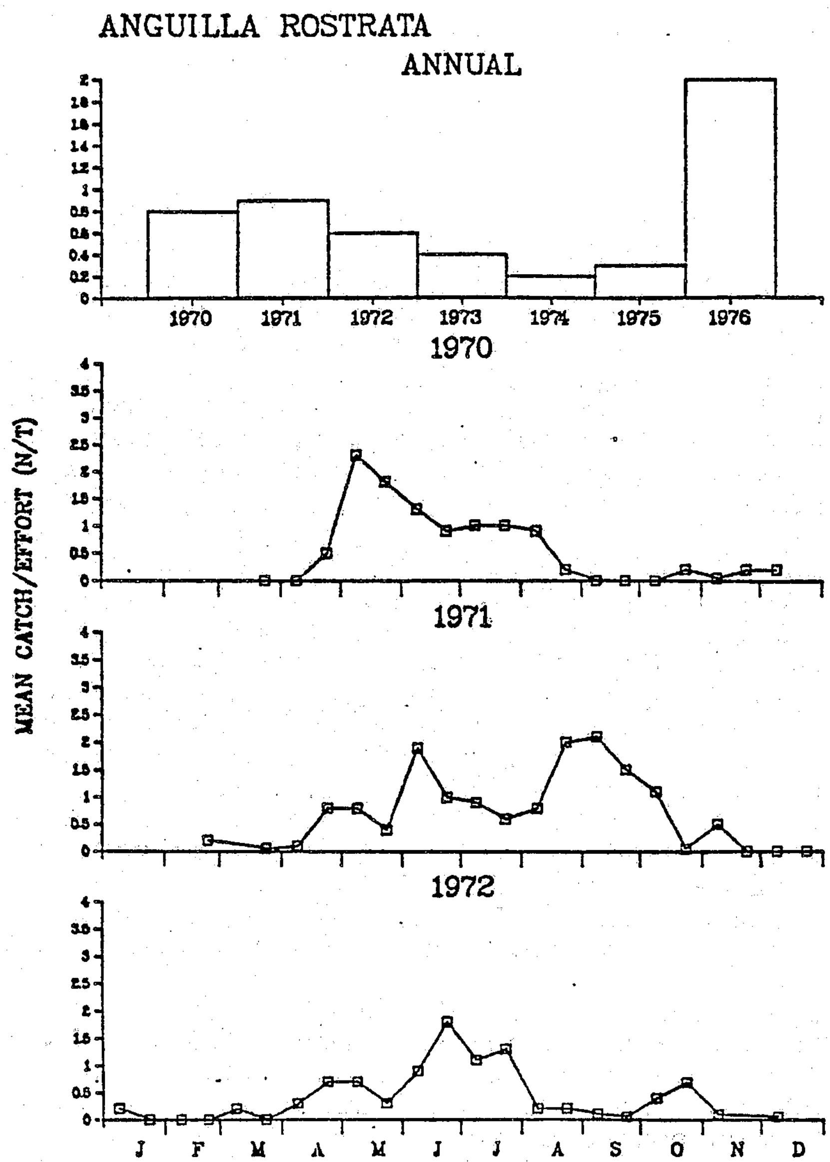
Fahay (1978) reported that eels were taken commercially in the Gulf and along the Atlantic Coast of the United States and Canada. In the United States, the mid-Atlantic region accounts for much of the landings, with reported revenues from 1965 through 1973 ranging between $416,000 (1971) and $88,000 (1973) on landings of 1,788,000 lbs and 349,000 lbs, respectively (Fahay, 1978). Much of the American catch is sold to foreign markets.

Although much of the eel's complex life cycle has been well documented (Schmidt, 1925; Bigelow and Schroeder, 1953; Vladykov, 1955; Bertin, 1956; Tucker, 1959; Eales, 1968), spawning behavior is virtually unknown and speculation concerning the subject is controversial (Fahay, 1978; Wang and Kernehan, 1978). It is believed to occur in the Sargasso Sea, east of the Bahamas. Eggs are thought to be pelagic and to float in the upper to intermediate water layers (Hildebrand and Schroeder, 1928; Wenner, 1973; Bertin, 1956).

Hatching probably occurs as early as February as the smallest leptocephali larvae have been found in that month (Fahay, 1978). Vladykov and March (1975) took small leptocephali from March through July and, on the basis of Smith (1968) having found two small leptocephali in August, they concluded that hatching occurs from February through July. After hatching, leptocephali are distributed along the North American coast by ocean currents. Towards the end of the period of dispersal, but within one year, they metamorphose into the glass eel stage while still offshore of the watershed in which they will spend perhaps the next twenty years of their lives (Vladykov, 1966). Prior to penetration of the watershed they develop cutaneous pigments and enter the pre-juvenile, or elver, stage (Raney, 1959; Jeffries, 1960). Those that are destined for residence in watersheds that take more than one year to reach may spend more time in the glass eel stage (Vladykov, 1966). Their subsequent distribution throughout watersheds is sexually related; females penetrate upstream into headwater regions while males remain in estuarine waters (Livingstone, 1951; Everhart, 1958; Vladykov, 1970). Mature adults throughout the range begin their spawning migration at various times from late summer through fall in order to arrive at the spawning area at essentially the same time and in the same state of reproductive development (Wenner and Musick, 1974).

Females may mature at age 7-10 (> 460 mm) and males at age 5-7 (> 280 mm) (Bigelow and Schroeder, 1953). Fecundity counts of 21 fish taken in the Chesapeake Bay ranged from ca. 413,000 to 2,561,000 eggs (Wenner and Musick, 1974). Other reported estimates vary from 3 to 20 million eggs (Shulman and Paine, 1974; Vladykov, 1955; Eales, 1968). There is no evidence of repeat spawning (Fahay, 1978).

In the present study elvers were taken annually (Fig. 72) from December through July, appearing earliest in the river and after June in the tidal creeks. Eels have been most abundant in areas of reduced tidal flow with debris covered mud bottoms such as near the Salem River, Reedy Island,



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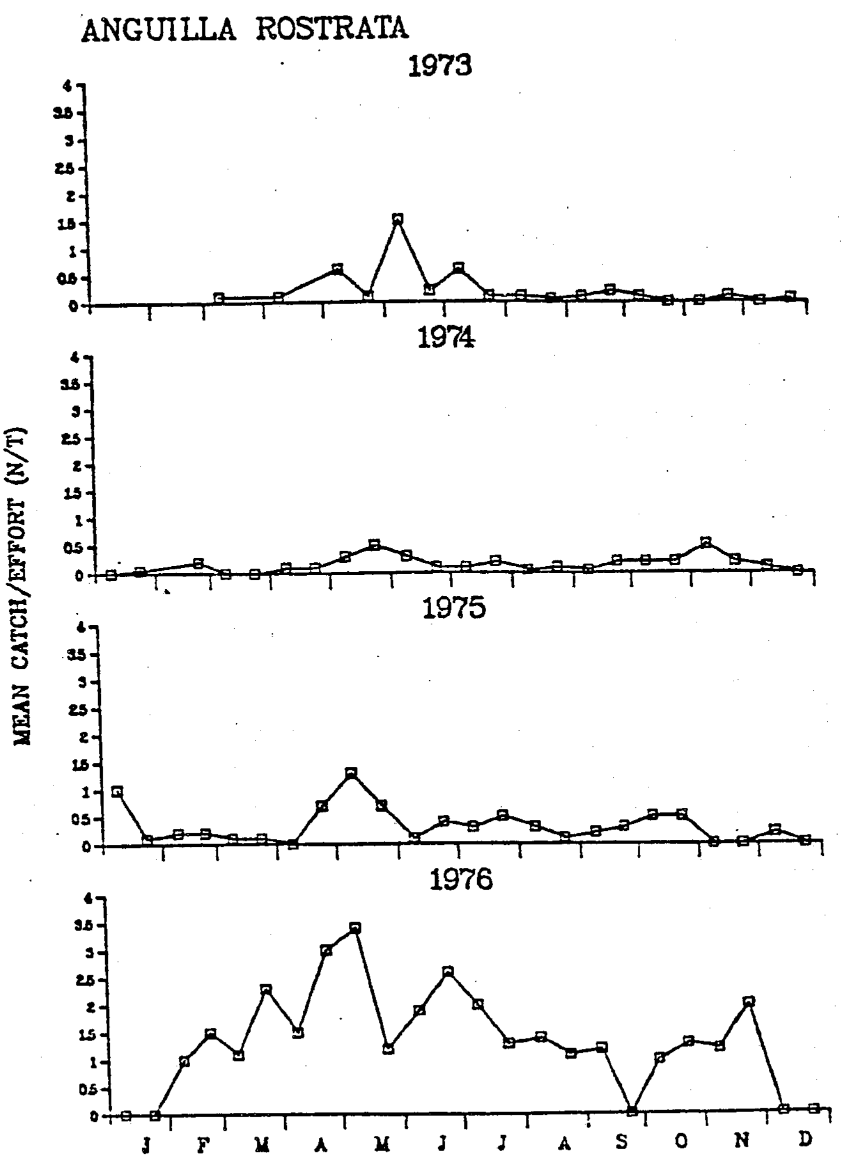
ARTIFICIAL ISLAND STUDIES

Annual and semi-monthly river trawl catch, adjusted for effort - American eel.

Figure 72



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ARTIFICIAL ISLAND STUDIES

Figure 72 - (continued)

between Blackbird Creek and Smyrna River, and Sunken Ship Cove. Eels taken in the present study ranged from 40-760 mm TL. Because of the species migratory behavior and elusive habits, abundance and density patterns are difficult to quantitatively describe. However, annual mean catch decreased gradually from 1971 through 1975 but increased markedly in 1976 (Fig. 72).

Shads and river herrings

The family Clupeidae is well represented in the Delaware River Estuary, especially by members of the genus Alosa, or river herrings and shads. Four species: A. pseudoharengus (Mitchell), the alewife; A. aestivalis (Mitchell), the blueback herring; A. sapidissima (Wilson), the American shad; and A. mediocris (Mitchell), the hickory shad, occur in the study area. However, A. mediocris has been taken only infrequently and mostly as adults, and since no spawning has been reported in the estuary (Wang and Kernehan, 1979), only the first three listed species can be considered important members of the local fish community.

These three species have much in common. All are anadromous with strong schooling behavior and occur in the Artificial Island area during spring pre-spawning migration to freshwater spawning regions situated far upriver (in New York and Pennsylvania) for the American shad, and in less remote and occasionally local streams for alewife and blueback herring. Although the primary importance of the study area to young of all three species is as an emigration route to the open sea in the fall, some young of alewife and blueback may use it as a nursery in spring and summer.

American shad may live to about 11 years (Hildebrand, 1963); however, few survive beyond seven years (Chittenden, 1969). Maximum life expectancy is eight years for alewife and seven years for blueback herring (Marcy, 1969). Females may live longer than males (Hildebrand, 1963; Marcy, 1969). Maximum reported lengths are about 380 mm for alewife and blueback herring (Hildebrand, 1963) and 760 mm for American shad (Mansueti and Kolb, 1953). Both adults and young of all three species occur at a salinity range of 0-33 ppt. Upper water temperature limits are about 32 C for alewife (Lindenberg, 1976) and 30 C for American shad (Marcy et al., 1972). The upper limit for blueback herring was not described in the available literature but specimens were taken at 32.8 C in the present study. Lower limits are also undefined; however, young alewife, blueback herring, and shad were taken in the present study at temperature of 0.2, 1.0, and 2.8 C, respectively. Chittenden (1969) suggested shad may not survive prolonged exposure to temperature less than 6 C.

Blueback herring ranges along the Atlantic coast from Nova Scotia to the St. Johns River, Florida (Hildebrand, 1963); alewife is found from Newfoundland (Winters et al., 1973) to South Carolina (Berry, 1964); American shad ranges from Labrador (Hare and Murphy, 1974) to the St. Johns River, Florida (Bigelow and Schroeder, 1953). The shad has been introduced successfully along the Pacific coast. All three species are common in many mid-Atlantic bays and rivers including the Chesapeake Bay (Hildebrand and Schroeder, 1928) and the Delaware River Estuary (de Sylva et al., 1962; Smith, 1971; Wang and Kernehan, 1979).

River herrings and American shad have sport and commercial importance throughout their range. In the Delaware Bay and lower River, American shad is fished commercially from March through June, primarily by gill net. All three species are angled for during spawning runs in spring, with most effort concentrated from Trenton (RK 214; RM 133) northward to Hancock, New York (RK 531; RM 330) and in some tributary streams below the fall line.

Shad stocks throughout its range have declined from levels reported in the 1700s and 1800s (Friedersdorff, 1976). This reduction is particularly evident in the Delaware River Estuary where spawning runs have been limited since 1900 and occasionally lacking since 1920 and were especially small in the 1940s and 1950s (Chittenden, 1969). Overfishing, environmental degradation, and dams, which block spawning runs, have contributed largely to the decline. Additionally, within the Delaware River Estuary poor water quality in the Philadelphia-Camden area (RK 130-170; RM 81-106), which often resulted in low dissolved oxygen levels during summer and fall, formed a formidable block to spent fish attempting to return to sea during summer and to young emigrating downriver during early fall. With improving environmental conditions and general conservation measures, shad runs have increased markedly in recent years in eastern rivers including the Delaware where large runs were reported in 1963 (Chittenden, 1969) and 1976 (Wang and Kernehan, 1979).

American shad tagged by Nichols (1960) in Virginia waters were recaptured in their natal rivers, often near the original tagging site. He further noted that no tagged fish were recaptured in other than their natal rivers. While no such data specific to the Delaware River appear in the literature, a similar homing of adults to their natal river is probable. This homing behavior suggests that the size of spawning runs in a given river reflects previous spawning success in that river rather than significant recruitment from other stocks.

Conditions in the Delaware River may affect the population of the two river herrings less than the American shad. While young of all species spawned upriver must traverse the Philadelphia-Camden area when returning to the ocean, some young of the alewife and blueback herring move downriver before the lowest dissolved oxygen levels occur. In addition, both species spawn extensively downstream of the oxygen deficient area.

Most alewife on spawning runs in Connecticut waters were age 5 and 6 (Marcy, 1969). Most males spawned first at age 4 and most females at age 5. Most blueback herring males spawned first at age 3 or 4; most females spawned first at age 5. No age 1+ or 2+ fish were taken on the spawning grounds. While no similar age studies have been conducted on either species in the Delaware River, a similar age composition is probable. Fecundity in Connecticut waters has been estimated at 45,800 to 349,700 eggs for blueback herring (Loesch, 1969) and 48,000 to 659,000 eggs for alewife (Kissil, 1974). Estimates for Delaware River stocks were not available.

American shad spawns in the Delaware River and its tributaries from late April through July (Chittenden, 1972) at a water temperature of about 12-18 C, with peak activity at about 17 C (Joseph P. Miller, Del. R. Bas. Fishry Pro., per. comm.). Spawning in other systems along the Atlantic coast may occur at water temperature of 8.0-26.0 C (Walburg and Nichols, 1967).

Only a few age groups of American shad comprise the spring spawning population in the Delaware River (Chittenden, 1969). Most males are age 4 or 5; a few are age 3 or 6. Nearly all females are age 5 or 6. Chittenden (1969) reported a few age 7 fish but none older. La Pointe (1958) reported similar spawning age classes in the St. Johns (FL), Neuse (SC), and Susquehanna (MD) rivers. Fecundity has been estimated at 58,534 to 659,000 eggs (Roy, 1969; Walburg, 1960) in Canadian and Florida waters, but has apparently not been estimated for Delaware River shad.

Although repeat spawning has been reported in most mid-Atlantic rivers, it is not common in the Delaware River. Chittenden (1969) reported that only 0-6.5 percent returned to spawn a second time from 1960 through 1965. Similarly, Sykes and Lehman (1957) reported less than 2 percent return spawners in the 1940s and 1950s. Repeat spawners in other mid-Atlantic rivers (e.g. Hudson, Potomac, York rivers) typically comprise 17-51 percent of spawning stocks (Sykes and Lehman, 1957). Chittenden (1969) noted that the percentage (less than 3 percent) in rivers south of the

Chesapeake Bay are more similar to the Delaware River. The particularly long run to the upriver spawning areas and losses of adults in the River near Philadelphia due to low water quality from late spring through early fall are probably among the major causes of limited repeat spawning in the Delaware River.

Within the Delaware River Estuary alewife occasionally run upriver to Belvidere (RK 317; RM 197), while blueback rarely run north of Trenton Falls (RK 214; RM 133) (Mihursky, 1962). In the vicinity of Artificial Island spawning by both species occurs in creeks and possibly in the C & D Canal (Daiber, 1963; Smith, 1971). That little or no spawning occurs in the Delaware River proper near Artificial Island is evidenced by the small number of larvae collected in annual ichthyoplankton samples.

American shad typically run much farther upriver than do blueback herring or alewife, with major spawning grounds from Port Jervis to Hancock (RK 409-531; RM 254-330) (Mihursky, 1962). Locally, very limited spawning may occur in the Brandywine Creek (RK 113; RM 70), and possibly in the C & D Canal (Wang and Kernehan, 1979).

After hatching, river herring larvae may be quickly carried downstream or remain in the spawning area for a brief period (Wang and Kernehan, 1979). Conversely, shad larvae usually remain near the spawning area or a short distance downstream (Chittenden, 1969). The young remain in adjacent nursery areas until water temperature declines to ca. 13 C in the fall, and a downriver migration to high salinity waters begins. Generally, larger young move downriver first.

Near Artificial Island, adults of all three species have been most abundant during spring spawning runs (March through May), although blueback herring were taken sporadically through August and alewife through July. American shad were much less abundant than either river herring. Local summer catches were of late spawners and spent fish returning to the ocean. Migrating adults typically ranged in length from 221 to 300 mm FL for blueback herring, 225 to 310 mm FL for alewife, and 335 to 580 mm FL for American shad. Some sub-adults (age 1+ and 2+) blueback herring and alewife appear to accompany adults upriver during spawning runs.

Alewife may spawn as early as March in Appoquinimink and Blackbird creeks, while blueback runs usually commence in April and May (Wang and Kernehan, 1979). While alewife usually precede blueback herring by two or three weeks, spawning periods may overlap to a considerable extent. Both species may spawn into June and possibly July.

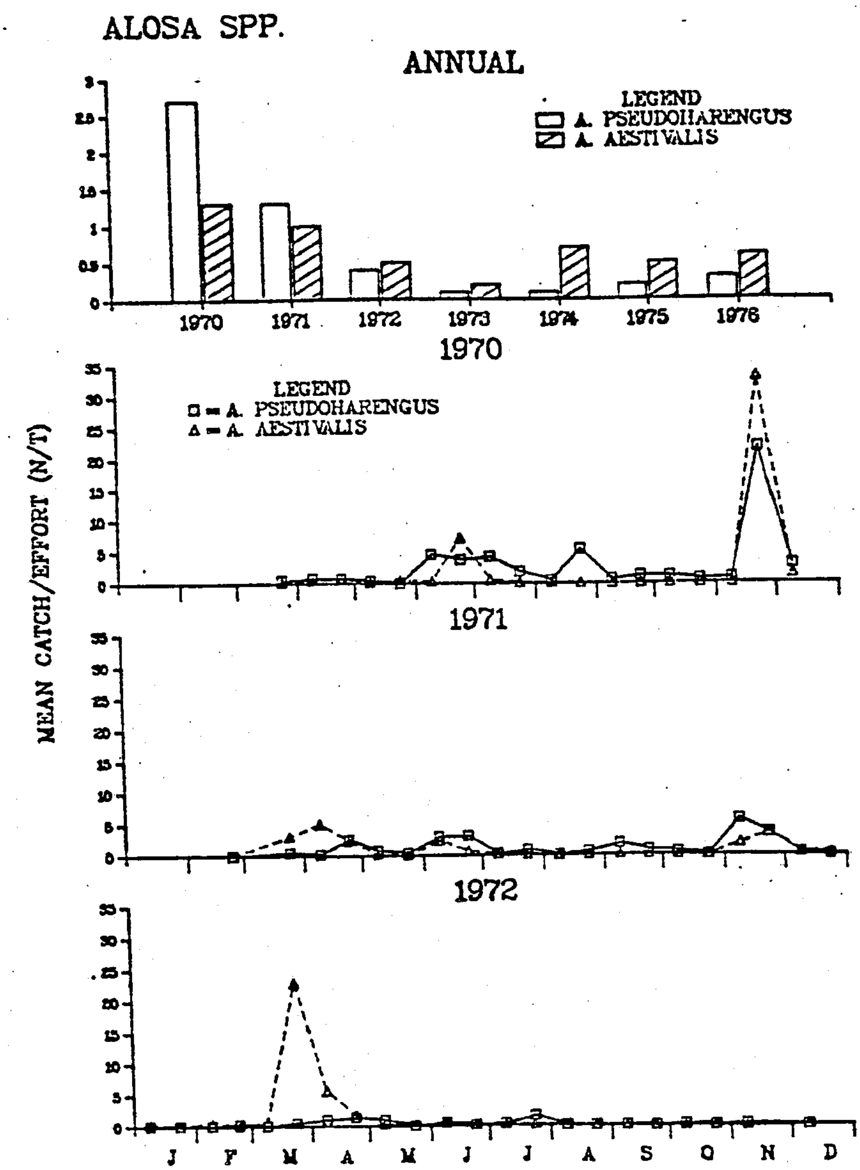
Local spawning takes place over a temperature range of 19-24 C for blueback herring and 12-20 C for alewife (Smith, 1971). Somewhat wider temperature ranges have been reported in Connecticut waters, i.e., 14.0-27.0 C for blueback herring (Loesch, 1969) and 10.5-22.5 C for alewife (Cianci, 1969).

Eggs, larvae, and early young of the river herrings were a minor component of annual ichthyoplankton samples in the Delaware River near Artificial Island (less than 0.1 percent in most years), and no early life stages of the American shad were collected. They were most abundant in 1971 and 1972 (to 2.8 percent). Eggs were uncommon and taken only in April at water temperature from 11.5 to 12.5 C and at a salinity of 0.0 ppt. They were generally taken in near-bottom samples north of Artificial Island. Upriver, at Burlington (RK 191; RM 119) and Trenton (RK 214; RM 133), Lynch et al. (1979) reported river herring eggs only in May and June, with the greatest density in late May.

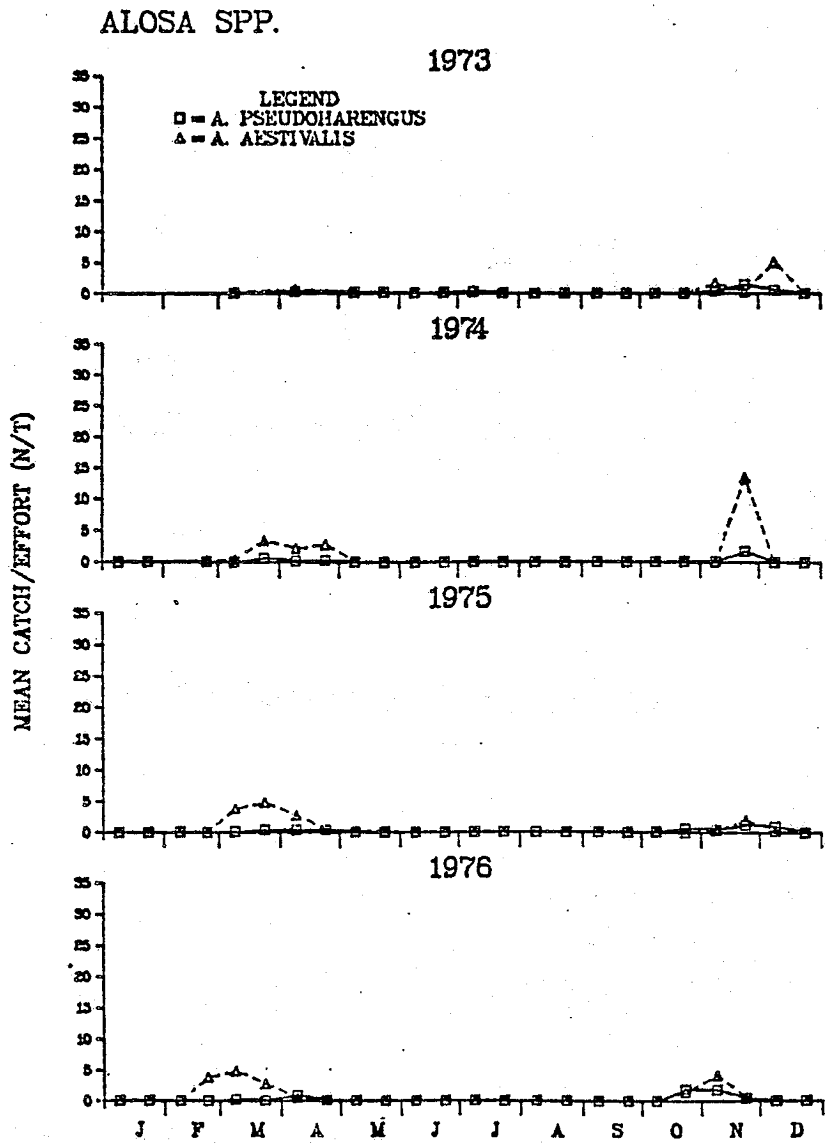
Larval blueback herring and alewife occurred from late April through late July but were most abundant from late April through May. At capture, water temperature was 11.0-29.0 C and salinity was 0.0-12.0 ppt. Larvae were most common in 1971 and 1972 in daylight near-surface samples north of Artificial Island. Lynch et al. (1979) collected larvae upriver near Burlington and Trenton only in May and June, with greatest density in late May.

Young alewife and blueback herring recently transformed from the larval stage were occasionally taken in late spring and summer. However, the largest number of young has annually occurred in the study area in the fall during seaward emigration (Fig. 73). Peak abundance for all three species has occurred during late October through early December at a water temperature of ca. 7-10 C. Most emigrating young were blueback herring and alewife. Few American shad have been taken due either to behavior during or rapidity of their movement through this area.

Small numbers of age 1+ and 2+ young of all three species were taken from January through April. Most young herring in the Delaware and other rivers move downstream in summer and fall and into high salinity waters to overwinter; however, the occurrence of age 1+ and 2+ herring in the study area early in the year suggests that not all young herring enter the ocean after migrating downriver the previous fall. Instead, some may overwinter in deeper areas of the Delaware Bay and stray back into the study area. Similar overwintering was reported in Chesapeake Bay by Hildebrand and Schroeder (1928).



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Annual and semi-monthly river trawl catch, adjusted for effort - river herrings. Figure 73



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ARTIFICIAL ISLAND STUDIES

Figure 73 - (continued)

Blueback herring young in the vicinity of Artificial Island reach 40-100 mm FL by November. They reach 60-120 mm at age 1 and 120-170 mm by age 2. Alewife in the study area reach 65-130 mm FL by November, 65-140 mm by age 1, and 135-190 mm by age 2. Similar growth rates were reported for both species in the Chesapeake Bay by Hildebrand (1963).

The few young shad taken in the study during October and November ranged in length from 77 to 113 mm FL. Chittenden (1969) noted that most age 0+ American shad young have left nontidal freshwater areas of the Delaware River by 80-100 mm. He further reported lengths of 185-200 mm at age 1, 302-325 mm at age 2, 386-429 mm at age 3, 424-528 mm at age 4, 490-587 mm at age 5, and 533-597 mm at age 6, with females being somewhat larger than males. These length intervals are slightly greater at a given age than those reported in Connecticut waters (Borodin, 1925) and the Bay of Fundy (Leim, 1924).

Atlantic menhaden

The Atlantic menhaden, Brevoortia tyrannus (Latrobe), of the herring family Clupeidae, is annually one of the most common fishes throughout the Delaware River Estuary, including the study area, due primarily to the abundance of age 0+ fish. Young, spawned offshore in ocean waters during fall and winter, first appear in the Delaware River near Artificial Island as larvae during early spring, and they remain through late fall before moving downbay and offshore. Yearling and older fish also appear annually and throughout the year in the lower River.

Atlantic menhaden are pelagic, primarily inhabiting near-surface waters, and, like other herrings, congregate in dense schools. The species has been reported at salinity from less than 1 to 36 ppt (Reintjes, 1969). Age 0+ young prefer low salinity through much of their first year. Both young and adults have been taken over a wide temperature range, but the adults reportedly prefer from 15 to 21 C (Reintjes, 1969). Adults reach an average length of 300-350 mm (Hildebrand, 1963); the largest reported was 500 mm TL (Hildebrand, 1963). The maximum age reported was twelve years but fish older than seven years are uncommon (Reintjes, 1969).

Atlantic menhaden ranges along the eastern coast of the United States and Canada from New Brunswick to southern Florida (Peppar, 1974; Kushlan and Lodge, 1974). Along the mid-Atlantic coast, it is distributed throughout the estuaries and along the coast from New Jersey to Virginia

(Hildebrand and Schroeder, 1928; de Sylva et al., 1962; Hildebrand, 1963).

The Atlantic menhaden has been commercially important since colonial times. During much of this century it supported the largest commercial fishery, by weight, along the Atlantic coast, with peak annual catches often exceeding one billion pounds (Henry, 1971). Although historically important to the Delaware fishery, it has been of little economic value since the mid-1960s. Rarely used for human consumption because of its oily flesh, menhaden is processed largely into fish meal and oil. Ecologically, it is an important link in the food chain as a plankton feeder and a prey species for many commercially and recreationally important fishes including the bluefish, weakfish, striped bass, and the cods.

Atlantic menhaden relies heavily on production of large or strong year classes, and the earliest catch records show the widely fluctuating annual catch patterns which have continued through present time. In addition to annual fluctuations, the stock experienced a drastic, continuous decline during the late 1950s and 1960s (Henry, 1971; Nicholson, 1975) that resulted from a series of weak year classes and overexploitation by an increasingly efficient fishery. This decline was particularly evident in the mid- and north Atlantic areas where older fish comprise much of the population. Subsequently, the commercial fishery has had to exploit younger fish, which fact has increased the population's dependence on year-class strength. Recovery of the population has been inhibited by limited recruitment into the spawning population due to this exploitation by the commercial fishery (Schaaf and Huntsman, 1972).

Atlantic menhaden undertake two extensive seasonal migrations along the coast (Nicholson, 1971). From major overwintering grounds off the South Atlantic States, a northward movement begins during late winter and continues through summer. During this period the population (excluding age 0+) stratifies along the coast by age and size. By summer, age 1+ fish rarely occur north of New Jersey, age 2+ rarely north of Long Island, while fish 3 years or older further segregate off the New England coast (Nicholson, 1971). A reverse southern migration takes place during fall, beginning as early as September for fish north of Cape Cod. By November, nearly all fish north of the Chesapeake Bay are migrating south (Nicholson, 1971).

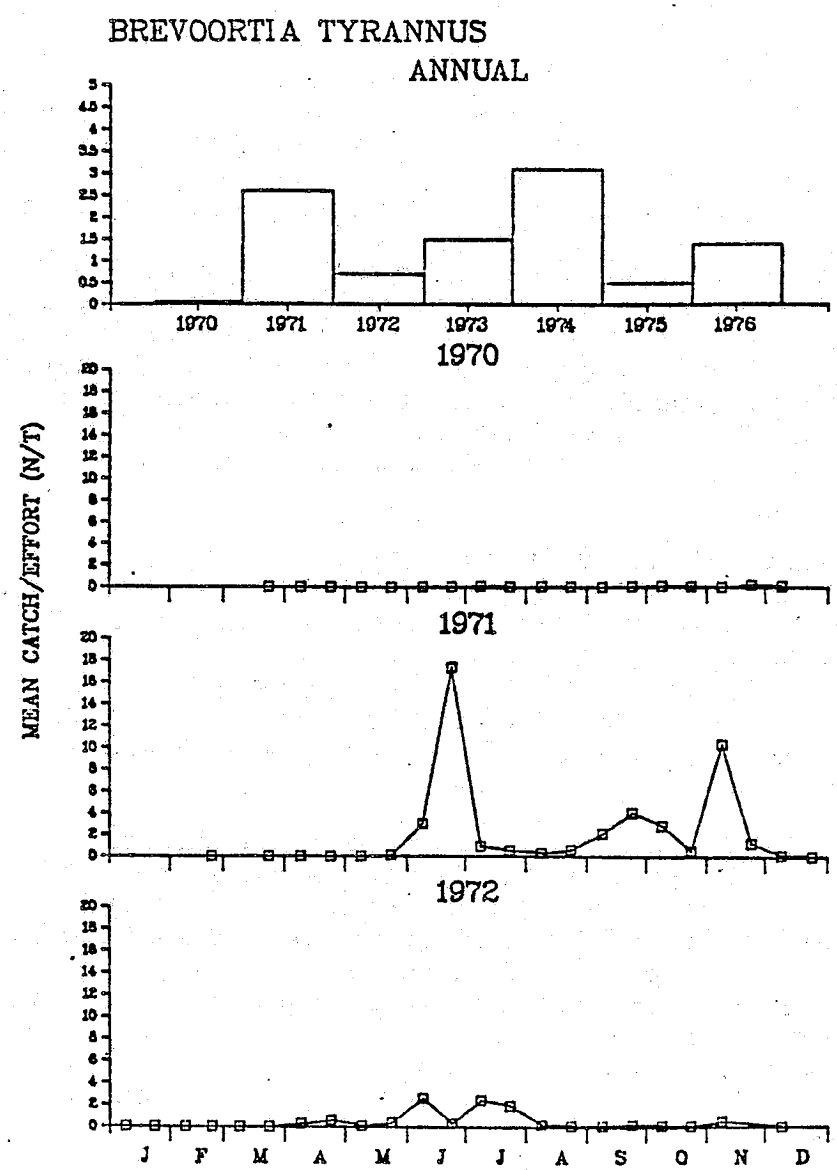
Atlantic menhaden spawn during both migrations (Higham and Nicholson, 1964; Nicholson, 1972), chiefly at sea (Hildebrand, 1963) and occasionally within estuarine waters (Pearson, 1941; Reintjes, 1969). Spawning takes place from late fall to early spring off the South Atlantic States, during spring and fall in the mid-Atlantic region, and during summer and early fall along the New England coast (Higham and Nicholson, 1964). It may occur at salinity as low as 10 ppt (Dovel, 1971) but is more common above 25 ppt (Reintjes, 1969); reported water temperature range is 4.4-23.6 C (Dahlberg, 1970). Some fish reach sexual maturity at age 1+ but most are mature at age 2+ and all at age 3+ (Higham and Nicholson, 1964). Fecundity estimates based on range-wide data are from 38,000 to 631,000 eggs (Higham and Nicholson, 1964).

Larvae are pelagic and spend about one month at sea before entering estuarine waters; in mid-Atlantic estuaries this begins in fall and abundance peaks in January (Higham and Nicholson, 1964). Larvae enter the Delaware River Estuary probably from December through May (Wang and Kernehan, 1979). They then migrate or are transported upstream to the near upper limits of saltwater intrusion (ca. 1-3 ppt); some may penetrate well up into fresh water (Massman et al., 1954). They remain distributed in these low salinity waters until fall and then move downbay and offshore in response to decreasing water temperature. Young apparently migrate to overwintering grounds off the southern Atlantic coast, arriving there in late December or early January, where they integrate with young produced all along the coast (Kroger et al., 1971).

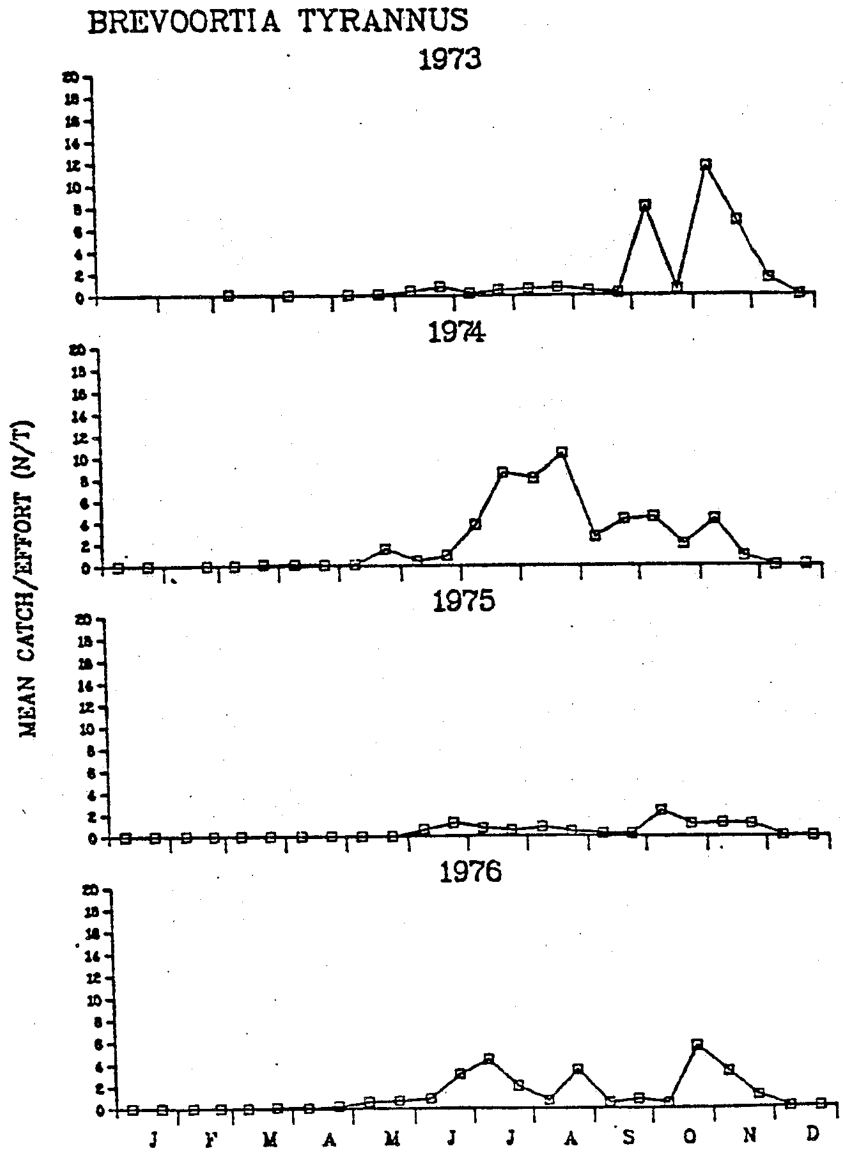
No eggs were collected in the present study and there is no record of their collection in the Delaware River Estuary (Wang and Kernehan, 1979). Larvae generally first appear in the lower River during March and continue to be recruited into the study area through July. Only a few were taken thereafter. Peak larval abundance typically occurred during April and May. More than 90 percent were taken in near-surface waters.

Although age 0+ and older Atlantic menhaden were taken annually in the present study, these fish are not particularly vulnerable to our sampling gear and catch levels may not be truly indicative of local abundance. However, it is apparent that the abundance of age 0+ and, to a lesser extent, 1+ fish which together comprised more than 75 percent of the annual menhaden catch except in 1973 and 1974, fluctuated widely (as much as a factor of 65) between years (Fig. 74), probably reflecting variation in year-class strength.

Young were collected from April through December. Annual temporal abundance patterns, based on trawl catch data, indicate two periods of abundance (Fig. 74). Generally, the first occurred from late May through June as large numbers of the current year class moved into the study area. Their abundance then declined as fish emigrated from the area



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Annual and semi-monthly river trawl catch, adjusted for effort - Atlantic menhaden.
	Figure 74



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ARTIFICIAL ISLAND STUDIES

Figure 74 - (continued)

probably upriver in response to increasing local salinity. During fall, as water temperature declined, local abundance again increased as fish passed down from upriver nursery areas. The fall peak typically occurred at water temperature of 10-13 C.

Yearling and older fish were taken locally in January and from March through December; most occurred from May through August.

Local distribution of menhaden was patchy through much of the year except during late spring and early summer when large numbers of young were taken in both deep and shallow areas of the river. However, by late summer and through fall, few were taken near shore, and those taken offshore were patchy in distribution and concentrated north of Artificial Island. Atlantic menhaden were also distributed throughout the local tidal tributaries from late spring through fall.

Specimen length was 19-365 mm FL. Several age groups (to at least age 4) were taken throughout the year. The growth of age 0+ fish is rapid once they reach the river. Specimens which were 30-35 mm (modal length) in May attained a mean length of some 80-100 mm (range 50-130 mm) by November, with most rapid growth during June through August.

Bay anchovy

The bay anchovy, Anchoa mitchilli (Valenciennes), of the anchovy family Engraulidae, is a resident forage species of the Delaware River Estuary, and all life stages have occurred annually in abundance in the study area. Although spawning may occur here, the principal importance of this area to the species is as a nursery. Bay anchovy typically occur from April through December with seasonal peaks in early spring and late summer.

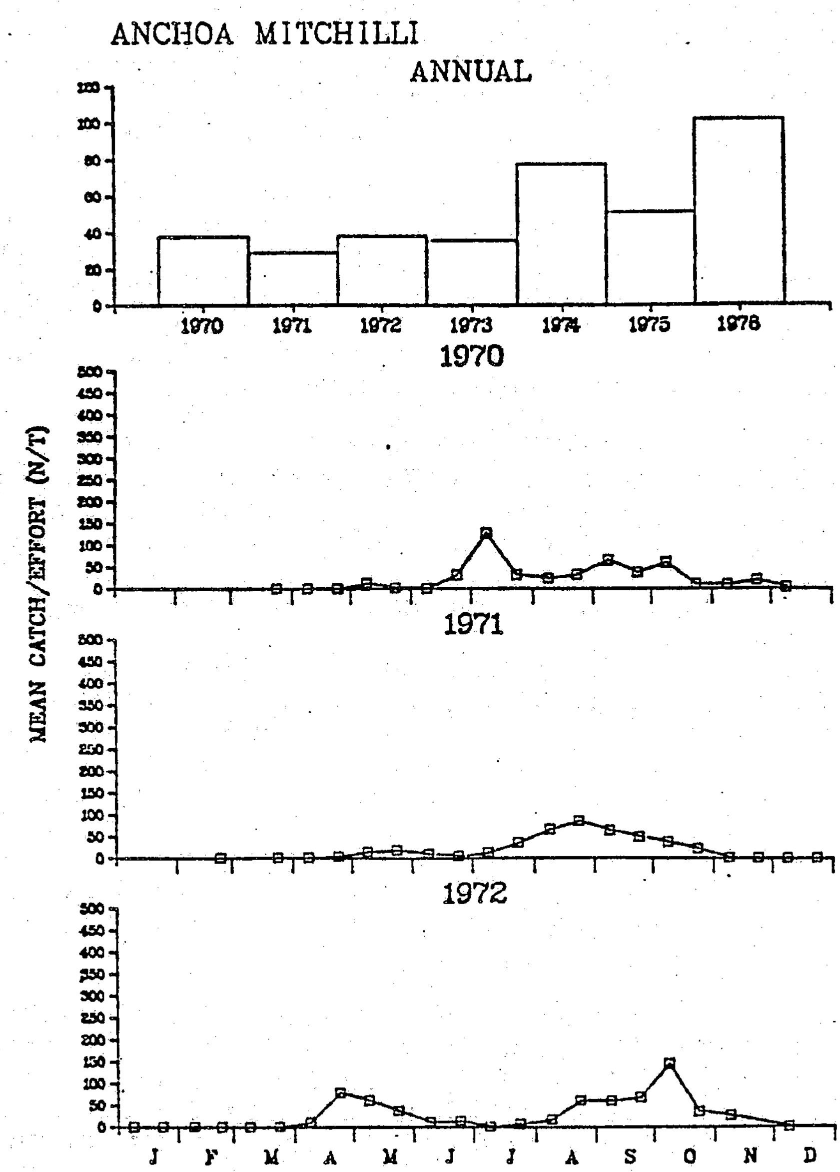
It is a pelagic, schooling, eurythermal, and euryhaline species, regularly occurring at temperature of 9-31 C (Dovel, 1971) and salinity of 0-31 ppt (Stevenson, 1958), and recorded at 80 ppt (Simmons, 1957). Young prefer low salinity regimes (3-7 ppt) and are most abundant near the saltwater-freshwater interface during summer (Dovel, 1971).

The bay anchovy ranges along the Atlantic and Gulf coasts from Maine to the Yucatan Peninsula, Mexico (Dahlberg, 1975), occurring primarily in bays, estuaries, and in near shore coastal waters (Springer and Woodburn, 1960). Although it comprises more biomass than any other estuarine fish along the south Atlantic and Gulf coasts (Gunter and Hall, 1963), it supports no commercial fishery (Hildebrand and Schroeder, 1928). However, throughout its range it is an important forage fish for many commercially and recreationally important fishes.

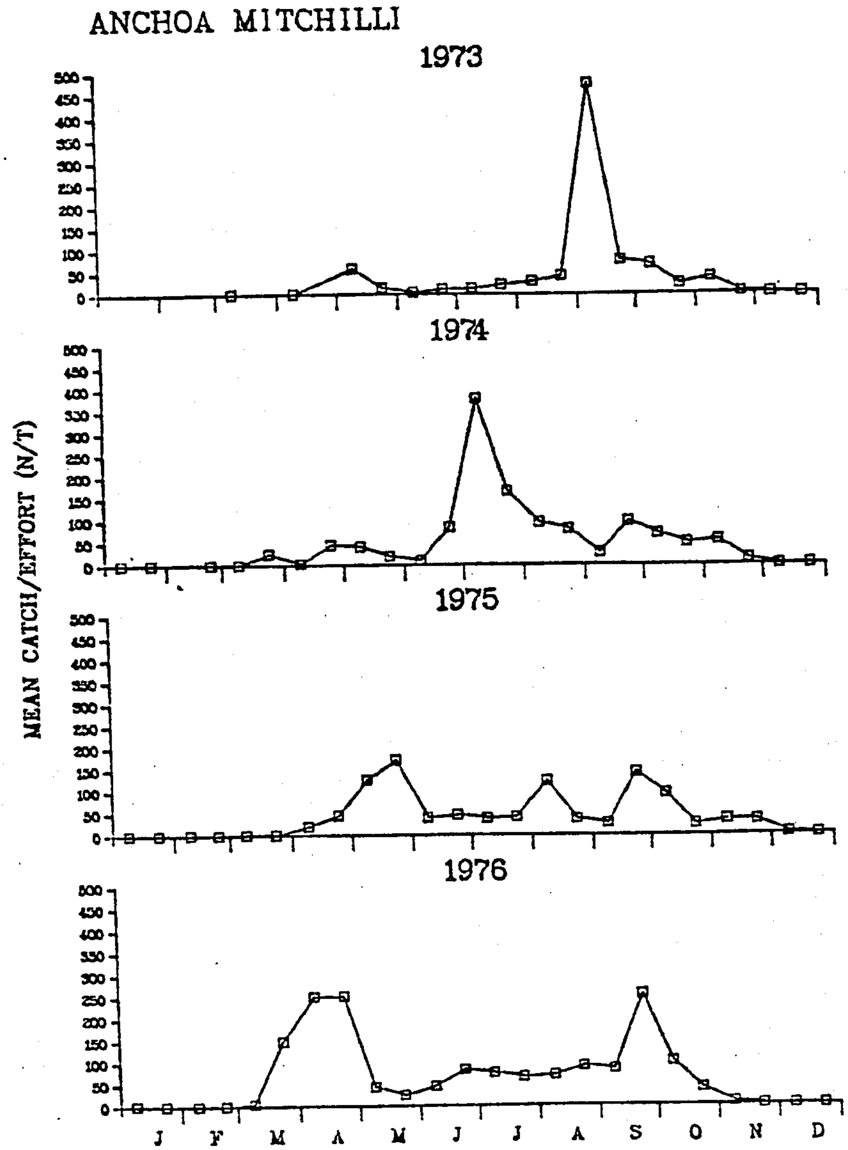
Within the Delaware River Estuary the bay anchovy is ubiquitous and abundant and demonstrates both in-offshore and up-downstream movements in seasonal and age specific response to changes in water temperature and salinity. In spring, as water temperature increases, the population disperses from deeper overwintering areas in the lower Bay to shallow areas throughout the estuary (Hildebrand and Schroeder, 1928; Stevenson, 1958). As temperature increases to levels more favorable for spawning larger individuals begin to move from the shallows to deeper offshore waters; this movement continues through July (Stevenson, 1958). Stevenson (1958) postulated that larger fish spawn earliest and that subsequent spawning is the end product of growth and maturation of smaller individuals. He further stated that the season was protracted because of sequential spawning by these groups rather than multiple spawns by single individuals. Spawning occurs in the mid to lower portions of the Delaware River Estuary from May through September at water temperature of 15.0-30.0 C and salinity of 5.0 ppt and greater (Wang and Kernehan, 1979). Spawning activity usually peaks from mid-July to mid-August at water temperature of 22.0-27.0 C and salinity of 10-20 ppt.

Eggs are pelagic and have an incubation period of approximately 24 hrs at 27 C (Kuntz, 1914). Larvae may be epibenthic for at least 24 hrs after hatching (Wang and Kernehan, 1979), then become pelagic and are transported into the low salinity nursery grounds. They remain there through the summer and early fall until declining water temperature initiates the downstream movement to deeper overwintering areas. By December this movement is complete and virtually all anchovy have left the low salinity nursery areas.

Generally, annual abundance of bay anchovy during the seven year period (1970-1976) has increased from an annual catch per unit effort (n/T) of 29.2 in 1971 to 102.2 in 1976 (Fig. 75). They have been taken annually in the Artificial Island area typically from April through early December, occurring as early as February (1975) and as late as January (1976). Their occurrence here is the result of movements of adults into the lower River in the spring and the recruitment of juveniles into the low salinity nursery area during the summer and early fall. These movements result in two seasonal peaks in abundance, a spring peak comprised of adults and a summer peak comprised principally of age 0+ specimens. The adult peak has occurred typically in April or early May and adults have been taken until December.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Annual and semi-monthly river trawl catch, adjusted for effort - bay anchovy.
	Figure 75



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ARTIFICIAL ISLAND STUDIES

Figure 75 - (continued)

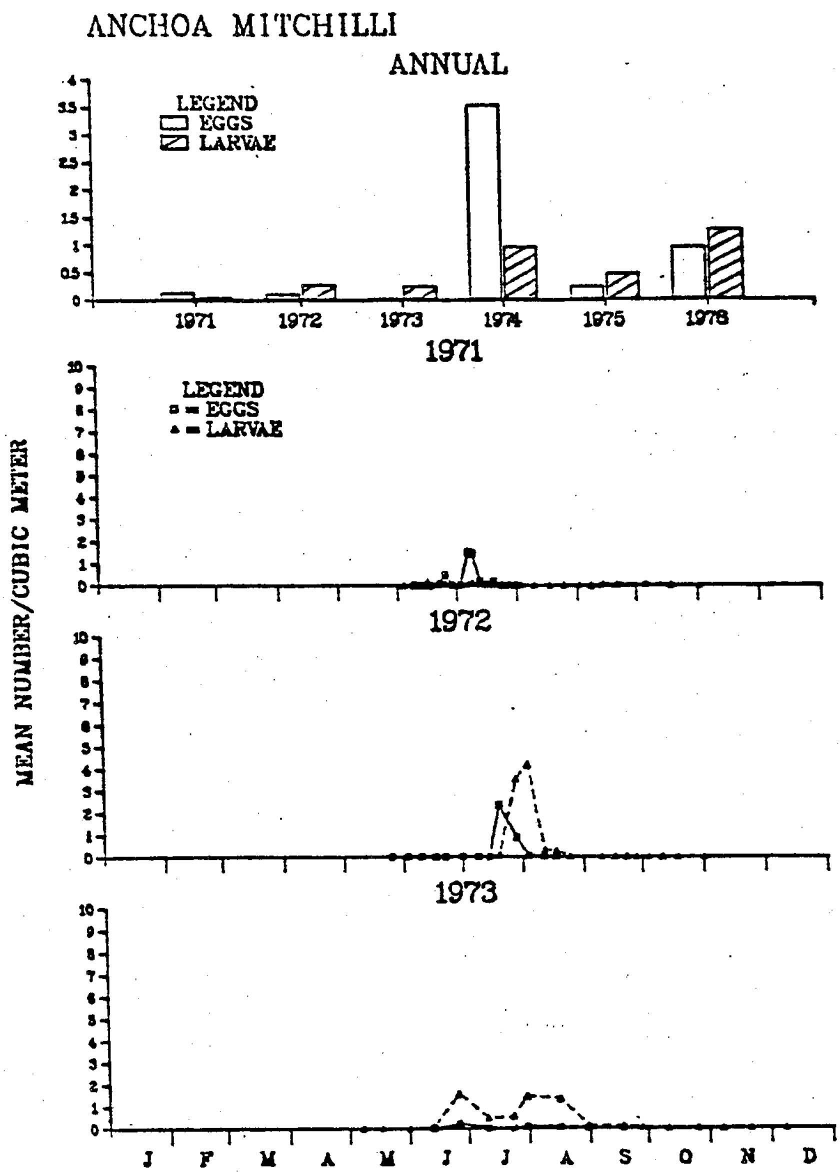
However, length-frequency data indicate decreasing abundance of adults as the season progresses. They also indicate two distinct size groups within the adult catch, a group of larger individuals (< 55 mm) consisting of progeny of the earliest spawning during the previous year (and possibly some age 2+ specimens) and a group of smaller (> 55 mm) individuals resulting from the later spawning during that year. Larger individuals have become less abundant in May, indicating their movement to higher salinity spawning grounds downbay. This movement becomes less apparent as salinity and temperature increase in June and July and the conditions favorable for spawning occur further upstream and closer to the Artificial Island area.

The common occurrence of eggs in regions north of Artificial Island indicates that spawning occurs within the study area. However, the annually variable abundance of eggs and their relatively low viability indicate the marginality of the study area as a spawning ground (Fig. 76). This is due to relatively low salinity levels during the spawning season, e.g. biweekly mean salinity in July 1970-1976 ranged from 1.4 to 8.6 ppt. This is below the level associated with peak spawning activity. Data collected in the vicinity of Ship John Shoal (RK 59) in 1974 also place perspective on egg occurrence in the study area. On the date of peak abundance (July 18) in both areas, the catch of eggs was over 1.5 times greater and viability nearly 2 times greater near Ship John Shoal (15-20 ppt) than near Artificial Island (3.0-12.5 ppt).

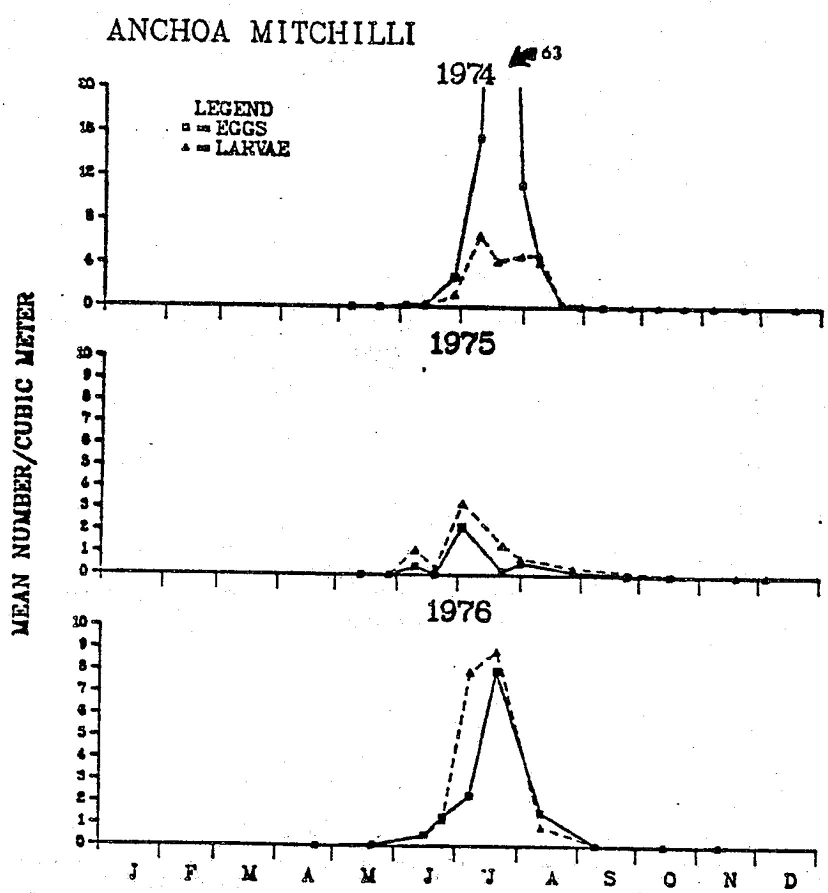
Bay anchovy eggs have typically been taken in the study area from May through September, occasionally as late as October (Fig. 76), at water temperature of 17.0-30.0 C and salinity to 13.0 ppt. Egg abundance has annually peaked between late June and mid-July (25-28 C; 1-8 ppt). Although eggs have been taken throughout the study area, they were typically most abundant south of Artificial Island.

The low salinity nature of the study area makes it suitable as a nursery area. Larval or juvenile anchovy have been taken annually in the study area from May through December (0.6-11.8 ppt; 5.0-27.6 C). Larvae (< 20 mm) occur from May through October (0.6-11.8 ppt; 15.4-27.6 C) and are most abundant in July (0.6-8.6 ppt; 21.3-27.6 C) (Fig. 76). Juveniles first appear in June and peak in abundance during mid-August to early September. The increase during this period is the result of larval growth and the continuous recruitment of juveniles from downbay into the Artificial Island study area. By December virtually all bay anchovy have left the study area.

Larval and juvenile bay anchovy are distributed throughout the Delaware River Estuary and tidal tributaries but are



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Relative annual abundance, and annual patterns of daily mean density, eggs and larvae - bay anchovy.
	Figure 76



PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ARTIFICIAL ISLAND STUDIES

Figure 76 – (continued)

most common in the shallow inshore zones. During the fall abundance, juveniles are found in high concentrations in regions of reduced tidal flow such as Sunken Ship Cove and the regions northeast of and directly west of Artificial Island.

Size of bay anchovy in the vicinity of Artificial Island has ranged from 2 TL to 107 mm FL. Inferrence to growth is tenuous because of the short-lived nature of the species, difficulties in age determination through standard means (i.e., scale, bone, or otolith analysis), and the protracted nature of the spawning season. Adults, principally age 1+, typically ranged from 24 to 107 mm FL during March and April. During March through August, their modal length, typically 50-65 mm, has varied only slightly, suggesting little growth during the reproductive period. However, the increase in minimum adult length from ca. 30 mm in March to 60 mm in November indicates that growth continues for the younger adults which were the product of late spawning during the previous year. This growth is also reflected in the increase in modal length to 71-75 mm in October.

Growth of juveniles near Artificial Island is relatively slow, with modal length typically increasing from 26-35 mm in July to 46-55 mm in October. In the fall of their first year juveniles have ranged from 20-65 mm. Similar ranges have been reported by Stevenson (1958) for the Delaware Bay (18-65 mm SL) and Perlmutter (1939) for Long Island Sound (20-55 mm SL).

The diet of bay anchovy in the Artificial Island region was comprised principally of dominant local zooplankton. Major food items, ranked on the basis of frequency of occurrence in analyzed stomachs, were copepods (65.8 percent), Neomysis americana (31.1), and Bosmina spp. (12.7) (Meadows, in Schuler, 1976). Similar findings have been reported by Stevenson (1958) for the Delaware Bay and Hildebrand and Schroeder (1928) for the Chesapeake Bay. However, Stevenson's results indicated that crab zoea and megalops constituted a larger portion of the diet of fish collected downbay than was observed in the Artificial Island area. Food habits of the bay anchovy change with growth, i.e. larger fish select larger food items. Neomysis americana is more common in the stomachs of large bay anchovy (55-98 mm), while copepods and Bosmina spp. were more common in smaller individuals (32-55 mm) (Meadows, in Schuler, 1976).

Mummichog

The mummichog, Fundulus heteroclitus (Linnaeus), of the killifish family Cyprinodontidae, is a small, short-lived resident of the entire Delaware River Estuary. It inhabits shallow inshore waters, tidal creeks, and marshes, and within the study area is one of the most abundant fishes in the shore zone of the river and tributaries. Locally, it occurs throughout the year and in all life stages.

Needler (1939) reported a maximum length of 130 mm. Few grow larger than 100 mm (Daiber et al., 1976), and most do not live more than three years (Valiela et al., 1977). It has been found in salinity of 0-41 ppt (de Sylva et al., 1962, Smith, 1971) but has survived under experimental conditions to 120.3 ppt (Griffith, 1974). It occurs naturally over a temperature range of 0.0-36.0 C (Daiber et al., 1976; Wang and Kernehan, 1979).

The mummichog ranges along the Atlantic coast from Newfoundland (Scott and Crossman, 1964) to northern Florida (Briggs, 1958) and has been introduced into freshwater drainages (Raney, 1938; Denoncourt et al., 1978). Locally, it is common throughout the Delaware and Chesapeake bays (Hildebrand and Schroeder, 1928; de Sylva et al., 1962) and in coastal waters of Delaware, New Jersey (Fowler, 1952), and Maryland (Schwartz, 1961), where it has a small commercial value as a bait fish (Hildebrand and Schroeder, 1928; Daiber et al., 1976). It is also often used in biological research. The mummichog is of greater ecological value as an important link in the food chain of the estuary. It feeds upon planktonic organisms (including mosquito larvae) and is in turn fed upon by game fishes and blue crab.

Mummichog populations are subject to large annual fluctuations. Being a short-lived species, its success is dependent on survival of the previous year class. Adverse environmental conditions (e.g., heavy runoff, unseasonably cold water temperature) on the spawning and nursery grounds may limit annual population levels.

Mummichog may mature in their first year and spawn in late summer; all mature by age 1+ (Tracy, 1910; Chidester, 1916). They may spawn several times per season. Available literature contain only fecundity estimates based on mature egg counts; they range from 460 to 800 eggs (Hardy, 1978). Spawning along the Atlantic coast occurs from April through August (Hildebrand and Schroeder, 1928), with peaks in activity coinciding with high spring tides and associated new and full stages of the moon (Schmelz, 1964). It occurs in shallow vegetated water at temperature of 16.5-25.0 C

(Smith, 1971) and salinity of 3-20 ppt (Wang and Kernehan, 1979). Eggs are demersal and in some habitats may be attached to aquatic vegetation or rocks, or in clumps to one another (Solberg, 1938; Battle, 1944; Bigelow and Schroeder, 1953). However, Wang and Kernehan (1979) found no attachment facility on eggs collected in Delaware waters. Eggs hatch in approximately 14 days at water temperature of 21.0-25.0 C. Larvae and young use the shallows as nursery grounds.

Even though spawning occurs in suitable habitat throughout the Artificial Island region, the catch of eggs and larvae was typically low because of the inaccessibility of these shallow spawning and nursery areas with conventional gear. Only one egg was collected, and larvae comprised less than one percent of annual larval samples, except during 1972 and 1973 when mummichog was among the top ten species taken. In these two years heavy flushing of the marsh area and tidal creeks during Hurricane Agnes in 1972 and heavy rains in 1973 may have displaced specimens from those inaccessible regions.

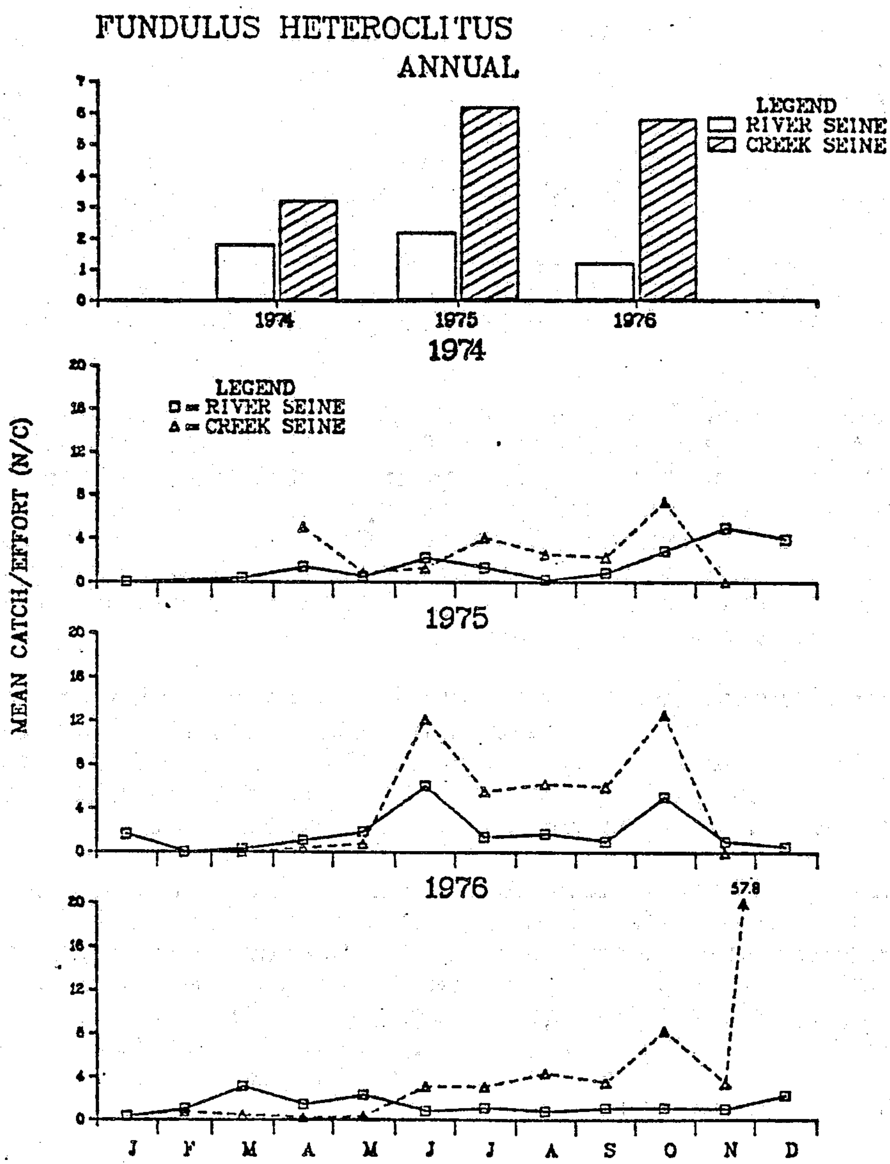
Young and adults have been annually abundant (Fig. 77) and taken at water temperature of 0.2-32.5 C and salinity to 15 ppt. They occur through the year in the creeks and river with peak abundance during late spring and early summer, reflecting recruitment of young (Fig. 77). Abundance remains relatively high through summer but decreases during fall and winter as fish burrow into the bottom or migrate to deeper waters to overwinter.

Mummichog are widely distributed throughout the shore zone of the local tidal creeks and adjacent marshes and in the river where they are common near the mouths of creeks and ditches and in shallow coves. They preferred areas of mud bottom and submergent or emergent vegetation.

Mummichog collected near Artificial Island ranged in length from 7 to 132 mm TL. The occurrence of larvae 7-8 mm TL from May through August and the subsequent wide length range found within the year class result from the protracted spawning season. They grow rapidly during the first year and reach some 25-60 mm by December. Age 1+ fish attain a length of 55-80 mm; age 2+ are 70-105 mm and all are greater than 80 mm at age 3+.

Silversides

The family Atherinidae (small, short-lived, pelagic fishes) is represented in the study area by three resident forage



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Annual and monthly river and creek seine catches, adjusted for effort - mummichog.
	Figure 77

species: the rough silverside, Membras martinica (Valenciennes); the tidewater silverside, Menidia beryllina (Cope); and the Atlantic silverside, Menidia menidia (Linneaus). The rough silverside, although taken annually, has occurred in low numbers and is not discussed. The Menidia species have been annually common in the shore zone of the Delaware River near Artificial Island. Although taken in all months, both have been most abundant during mid-spring and late summer. Due to general similarities in life history and occurrence in the Artificial Island region, they are discussed concurrently.

The tidewater and Atlantic silversides are euryhaline and eurythermal and inhabit shallow marine, estuarine, and tidal fresh waters from Massachusetts to Mexico and from Nova Scotia to northern Florida, respectively (Robbins, 1969; Wang and Kernehan, 1979). Although both have been collected over a wide range of salinity in the Delaware River Estuary (0-29 ppt and 2-35 ppt, respectively, Shuster, 1959; de Sylva et al., 1962), they demonstrate differential distribution by salinity. The tidewater silverside is most abundant at less than 10 ppt; the Atlantic silverside is most abundant at greater than 15 ppt. Both occur mainly over sand-gravel substrates but the former is more regularly found in vegetated areas. Both species have been taken at water temperature less than 3 C and greater than 32 C (Shuster, 1959; de Sylva et al., 1962; Smith, 1971). However, Atlantic silverside collected during summer avoided temperature above 30 C under laboratory conditions (Gift and Westman, 1972). Both species move to warmer, deeper portions of the Estuary during winter.

The silversides are utilized directly by man only as bait fish, but both are major forage species for commercially important piscivorous fishes. The tidewater silverside is a major component of the shore zone fish fauna of the oligohaline (0.5-5 ppt) waters of the Estuary (Wang and Kernehan, 1979). de Sylva et al. (1962) described the Atlantic silverside as the most widespread and, with the exception of bay anchovy, the most abundant fish in the meso-polyhaline (5-30 ppt) portions of the Bay.

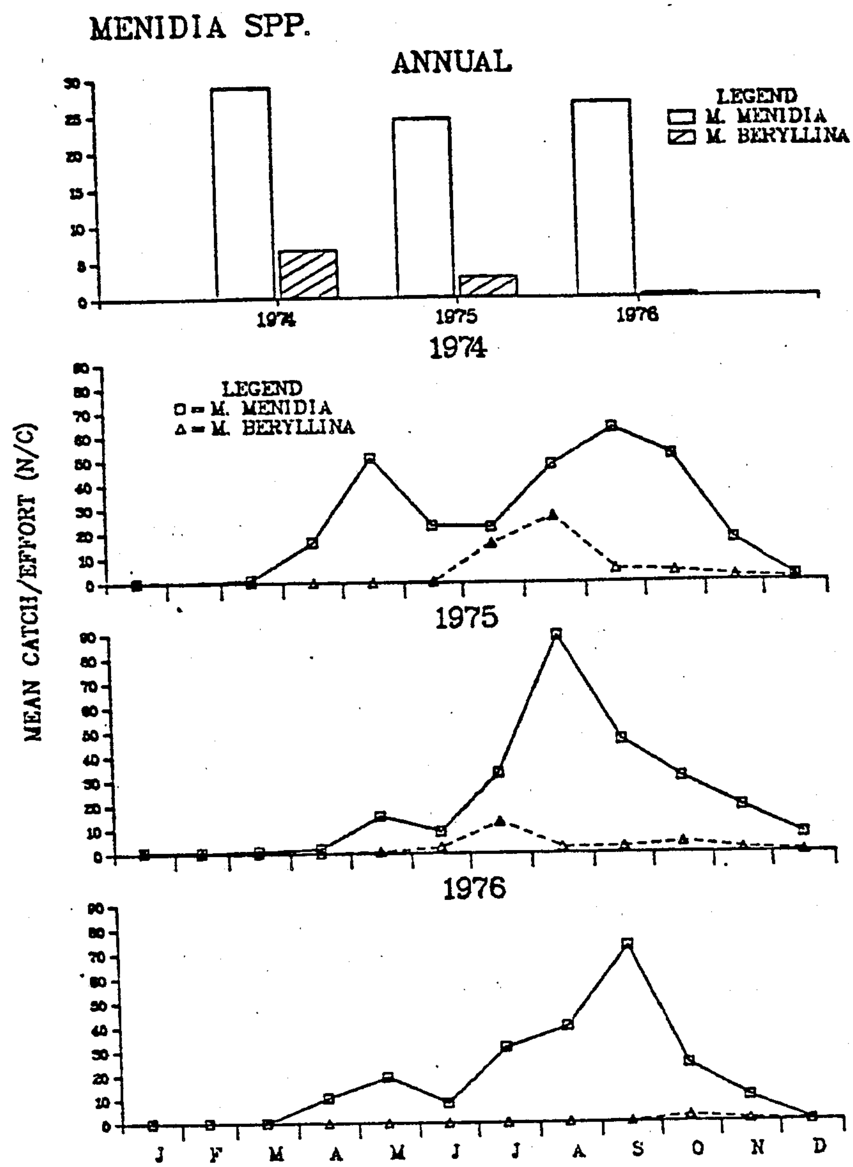
The spawning season for both silversides is protracted, with multiple spawns by individual females (Hildebrand, 1922). The tidewater silverside spawns in fresh and slightly brackish (0-5 ppt) water of the Estuary from May through August at water temperature of 16.0-30.5 C, while the Atlantic silverside spawns primarily in salinity greater than 15 ppt from April through August at 14.0-29.0 C (Wang and Kernehan, 1979). Eggs of both species, which are demersal with adhesive threads, are typically deposited in shallow, grassy areas (Lippson and Moran, 1974) and hatch in eight days at water temperature of 17.0-25.0 C for tidewater silverside and at 22.0-29.0 C for Atlantic silverside (Wang and Kernehan, 1979). Fecundity estimates for Atlantic silverside range from 500 (Hildebrand, 1922) to 1,413 eggs (Kendall, 1902). Available literature contain no fecundity estimates for tidewater silverside. Larvae are most abundant in the shore zone, and neuston sampling in the present study indicated that larvae were especially associated with the uppermost millimeters of the water column (Lindsay and Radle, 1978).

Atherinid eggs and larvae have been taken near Artificial Island during all years of study. However, identification to species was not practicable due to similarities in morphological and meristic characteristics, and they were considered collectively as Membras sp./Menidia spp. Although spawning occurs throughout the Artificial Island region in suitable areas, eggs and larvae have not been abundant, or perhaps representatively collected, because of the inaccessibility of the shallow shore zone spawning and nursery areas with conventional gear. Eggs and larvae have been taken from May through August and larvae typically were most abundant in July. The occurrence of small larvae (4.0 mm TL) in late August indicates a protracted spawning season.

Young and adults of both species have been annually abundant in the local shore zone. Atlantic silverside has been consistently the more abundant species, typically ranking first or second in annual seine samples. It has been collected in all months with two annually evident peaks in abundance; in April or May, reflecting movement of adults from overwintering areas to spawning grounds, and in August or September, reflecting the recruitment of the current year class (Fig. 78). The catch of tidewater silverside, although typically low, has decreased annually since 1974 (Fig. 78). Typically, it first appeared during May or June and peaked in abundance in late summer (Fig. 78). Abundance of both species decreased as water temperature declined during fall and early winter; specimens were occasionally taken as late as January.

Both silversides have been taken throughout the river near Artificial Island and in local tidal tributaries. Atlantic silverside were predominant in the river proper. Tidewater silverside dominated tributary samples. Spring and early summer distribution of both species has been characterized by large numbers taken in areas south of Artificial Island, while during fall and winter they have been generally more abundant north of Artificial Island.

Atlantic silverside collected near Artificial Island ranged from 10 to 125 mm FL; tidewater silverside ranged from 10 to 100 mm FL. Atlantic silverside is generally the larger and



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Annual and monthly river seine catch, adjusted for effort - Atlantic and tidewater silverside.
	Figure 78

faster growing; neither species lives beyond age 1+. Modal length of age 0+ Atlantic silverside in July has been 41-51 mm and 72-82 mm in November. The protracted spawning season results in a wide size range within the current year class, often exceeding 50 mm in November. Growth slows during winter; modal length of age 1+ in March has been 75-85 mm. Growth accelerates during the spring and summer of the second year, and by fall most age 1+ fish are more than 100 mm. Tidewater silverside typically attained a modal length of 46-56 mm by November of their first year. In late summer or early fall of their second year 70-80 mm specimens were common.

White perch

The white perch, Morone americana (Gmelin), of the temperate bass family Percichthyidae, is a semi-anadromous resident of the Delaware River Estuary. It is a schooling species which occurs throughout the study area, in all months, and in all life stages. Young and adults are abundant in shallow areas of the river during March through May and October through December and occur in local tidal creeks in all months.

Size rarely exceeds 300 mm FL, although specimens to 325 mm FL were taken in the present study. Mansueti (1961) reported specimens to ten years of age. The species is most common at salinity of 5-18 ppt (Johnson, 1972; Mansueti, 1964), but has been taken at 0-30 ppt by de Sylva et al. (1962), and was taken at water temperature of 0.2-32.5 C in the present study.

The species ranges along the Atlantic coast from the Gulf of St. Lawrence to South Carolina (Mansueti, 1964) and occurs in many freshwater lakes and ponds. In the mid-Atlantic region it is widely distributed in the coastal and bay waters of Delaware, New Jersey, Maryland, and Virginia (Mansueti, 1964; de Sylva et al., 1962).

It is of commercial and recreational importance over most of its range. It supports important winter fisheries in Delaware and Chesapeake bays and has ranked among the top five species annually in the commercial catch of the Delaware Bay and River.

Populations exhibit degrees of seasonal migration to the point of true anadromy (Hardy, 1978). All available evidence suggests that white perch within the Delaware River Estuary are semi-anadromous. Adults overwinter in the mesohaline (5-18 ppt) waters of Delaware Bay, but in spring they apparently migrate far upriver to spawn in low salinity or fresh waters. Spawning is most common upstream of Newbold Island (RK 201, RM 125) (Ashton et al., 1975) and may occur as far upriver as Lambertville, New Jersey (ca. RK 233, RM 145) (Mihursky, 1962). To date there is insufficient evidence to determine whether fish from the lower estuary move to mid-estuary and replace those that move to the upper extreme, or whether some individuals move from one extreme to the other. However, Mansueti (1964) reported larger than average size "Bay perch", which apparently overwinter in mid-Chesapeake Bay, spawn in extreme northern Chesapeake Bay in spring, and feed and concentrate in the upper Bay in summer. This would entail a movement of some 100-150 km, apparently the same distance that would be traveled by fish that overwinter in Delaware Bay and spawn in the upper estuary. Larger than average fish are known to concentrate in the Delaware Bay in winter. Fish that overwinter upriver are generally younger individuals. There is much evidence and inference that older fish overwinter in Delaware Bay, run upriver perhaps great distances to spawn, then move part way down the estuary to feed and summer in low salinity portions of the river or tidal creeks before returning to the Bay in late fall. Younger fish may move in a similar fashion but to a lesser degree.

The study area is probably the southern limit of spawning in the river proper. Local density of eggs and larvae is only ca. 25 percent of levels determined for the Trenton-Burlington-Bristol area (RK 191-214; RM 119-133). Local spawning, which occurs mostly near the headwaters of tidal creeks, begins in early April and peaks in May. It occurs at water temperature of 11.0-20.0 C and salinity of 0.0-5.0 ppt, inferred from timing of collected eggs. All age 2+ males and age 3+ females are capable of spawning (Miller, 1963). Fecundity of Patuxent River, Virginia fish was reported by Mansueti (1961) as from 50,000 to 150,000 eggs; Delaware levels are probably similar. Eggs are demersal and adhesive and usually attach to substrate or vegetation. For this reason their abundance is usually underestimated by plankton net samples.

White perch has been a minor component of the ichthyoplankton near Artificial Island; typically it comprised no more than 0.1 percent of annual ichthyoplankton samples. Eggs were taken from late April through mid-May at water temperature of 11.0-20.0 C and salinity of 0.0-5.0 ppt. They were most abundant near the bottom, especially near the C & D Canal where they may have originated. Wang and Kernehan (1979) reported high egg density in the Canal which has a net flow into the river. Larvae were taken at water temperature of 11.0-28.7 C and salinity of 0.0-6.0 ppt from late April through mid-July with most occurring prior to mid-June. They too were most abundant near the C & D Canal.

After spawning, adults leave spawning areas and begin to move in prolonged stages back down the river. They summer in low salinity or fresh waters, and seem especially associated with the saltwater-freshwater interface. In early summer, or in any season when heavy freshwater runoff causes salinity in the study area to be low (less than 5 ppt), adults and young are abundant in the shallow, sheltered areas immediately south of Artificial Island and near creek mouths west of Reedy Island Dike. As saltwater intrudes farther upstream during summer they move upriver and into local creeks. The areas of greatest abundance then are north of Artificial Island near the mouths of Alloway Creek, Salem River, and the C & D Canal.

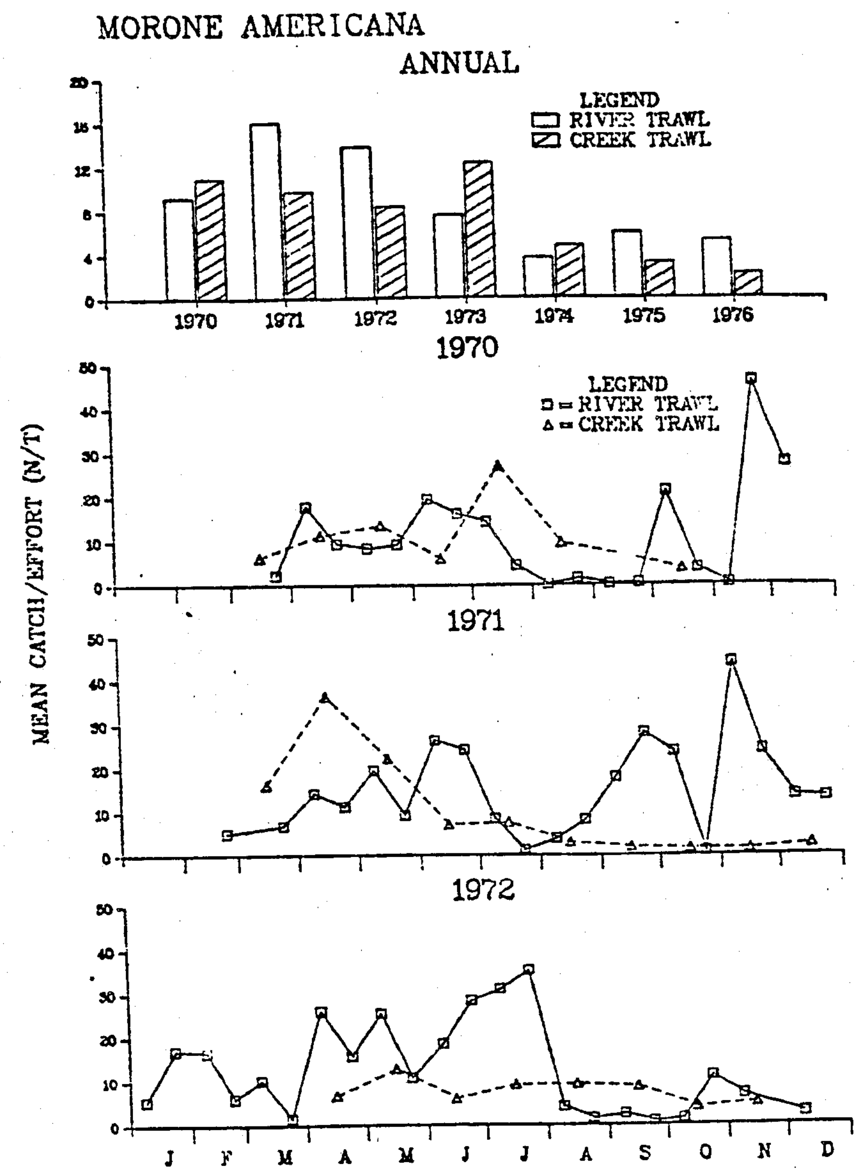
The species ranked second to sixth in abundance in the river and comprised as much as 21 percent of the annual catch. Annual abundance (measured by n/T) ranged from 4.1 to 17.7 (Fig. 79). It was consistently greater on the west side than east, and there was evidence of onshore movement at night. In five of the seven years it was also the most abundant species in the creeks.

As temperature and salinity decrease in late summer and fall adults continue the downriver movement that began in spring. Older fish leave the local areas first (Wallace, 1971). Most young follow the adults but some remain in the upper estuary through the winter. Local abundance increases through November as fish, particularly age 0+ and 1+, arrive from the major nursery area near Trenton and from local creeks (Fig. 79). By the end of November, most fish have left the upper Estuary (Ashton et al., 1975) and by the end of December have passed through the Artificial Island region. They spend the coldest months in the deeper, warmer waters of Delaware Bay until rising water temperature signals the start of another spring migration.

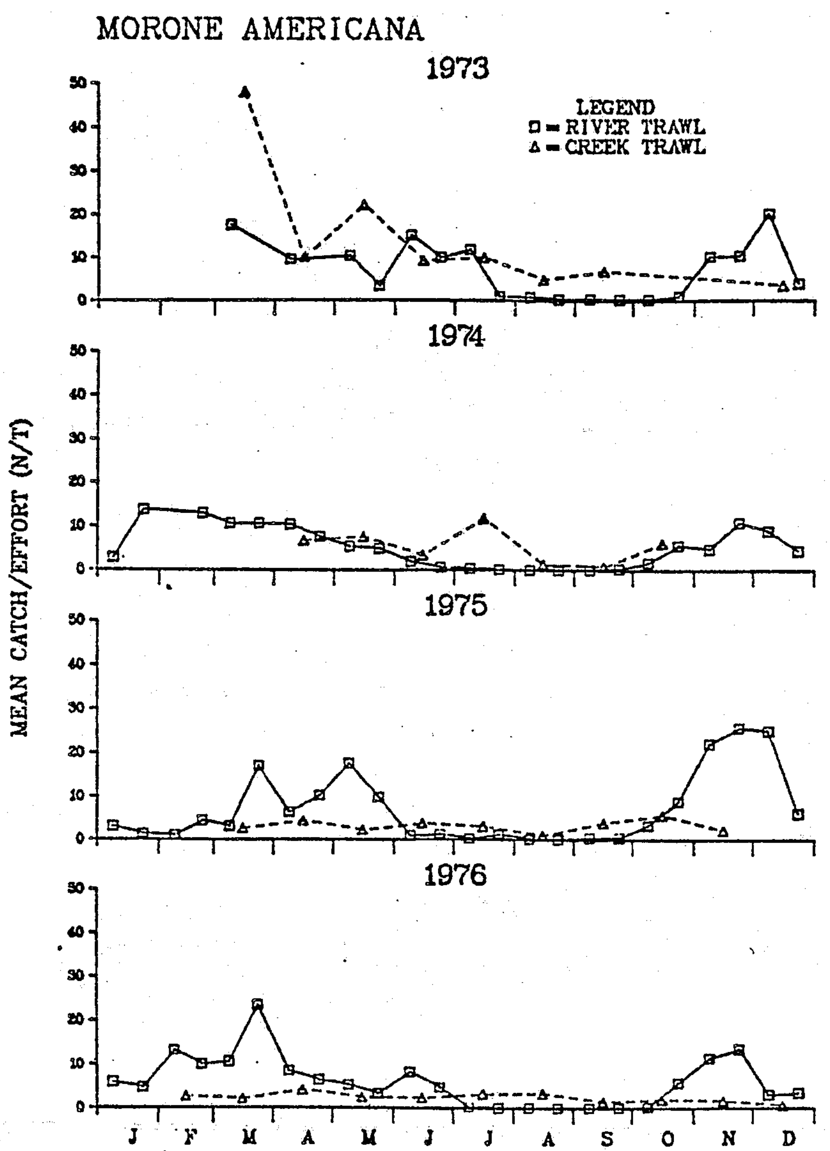
Age and growth was examined by Wallace (1971) early in the present study. By the end of the first growing season (November) age 0+ fish are 65-85 mm FL. Age 1+ fish average 135 mm; age 2+ fish average 155 mm and are about three-quarters the size of an average age 7+ fish (ca. 205 mm). Females grow faster than males to their fifth year. Growth is slower locally than to the south in tributaries of Delaware Bay (Miller, 1963) or the Patuxent River, Virginia (Mansueti, 1961), perhaps because of lower water temperature or a shorter growing season.

Striped bass

The striped bass, Morone saxatilis (Walbaum), of the temperate bass family Percichthyidae, is an anadromous



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Annual and monthly creek trawl and annual and semi-monthly river trawl catch, adjusted for effort (5-min effort creek, 10-min effort river) - white perch.
	Figure 79



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ARTIFICIAL ISLAND STUDIES

Figure 79 - (continued)

species common in the Delaware River Estuary. Although it is typically an important member of mid-Atlantic estuaries (e.g. Chesapeake Bay, Hudson River), it is not abundant in the Delaware River for reasons not totally understood but probably related to lack of suitable spawning habitat. Adults pass through the Artificial Island area from late March through early June during migration to spawning areas in the upper estuary and in the Chesapeake and Delaware Canal. Some eggs and larvae are taken locally from April through June; these are the product of some local spawning and/or the result of transport from more distant spawning areas. Young (age 0+ - 3+) utilize this area as a nursery during summer and fall; some may overwinter here.

The striped bass is a tremendously fast-growing, long-lived species which, on the basis of size and importance, is often called the Queen of the Chesapeake, a water body with which it is especially associated. It may attain a weight of over 50 kg and a length of over 1.8 m (Bigelow and Schroeder, 1953); most are less than 18 kg. Adults occur at salinity of 0-35 ppt (Bigelow and Schroeder, 1953) and water temperature of 0.1-27 C (Merriman, 1941). Larvae occur at temperature of 12-24 C (Murawski, 1969). They occur at salinity of 0-32 ppt, but density is greatest at less than 2 ppt (Magnin and Beaulieu, 1967). Young can tolerate water temperature of 3.5-35 C (Vladykov and Wallace, 1952; Loeber, 1951) and have been reported at salinity of 0.2-16.0 ppt (Dovel, 1971; Merriman, 1937).

The striped bass ranges along the Atlantic coast from the St. Lawrence River, Canada to the St. Johns River, Florida, and in the Gulf of Mexico from Florida to Louisiana (Bigelow and Schroeder, 1953). Large adults (13.5 kg or more) generally frequent the open coast except during spawning runs or during winter (Bigelow and Schroeder, 1953), but are seldom taken farther than 16 km from shore (Raney, 1954). Smaller fish (less than 7 kg) range farther into estuaries and inhabit enclosed bays, small marshes, and river mouths as well as the open coast (Bigelow and Schroeder, 1953). It is an adaptable species, and introduced populations flourish in freshwater lakes, such as the Santee-Cooper Reservoir, South Carolina. It is also common along the Pacific coast where it was introduced in 1879 and 1882.

Along the mid- and north Atlantic coast it is an important (greater than $20 million annually) sport and commercial species (Dovel, 1977). The coastal commercial catch depends heavily on dominant year classes, the latest of which was produced in 1970 (Boone, 1976), and has trended "irregularly upward" since the early 1930's (McHugh, 1977). The species has on occasion ranked first in annual economic value in the Delaware state commercial finfishery. However, this catch is insignificant relative to the commercial catch from

Chesapeake Bay and coastal water of New York, New Jersey, and New England which, in turn, is often exceeded by the sport catch in these waters (McHugh, 1977). The Delaware sport catch is of minor importance, comprising ca. two percent of the state's total landings (Miller, 1978).

Striped bass undertake two different type migrations. One involves northward movement in the spring of fish two years and older to the coast of New York and New England from overwintering grounds in enclosed river mouths and bays, including the Delaware and Chesapeake bays (Raney, 1954; Merriman, 1941, 1952). In October and November these fish retrace the path to the south. The other type migration occurs in spring when adults run up estuaries to spawn.

Spawning takes place at or just above the saltwater-freshwater interface, sometime during February to July (exact timing dependent on latitude), and at water temperature of 10.0-25.0 C (Merriman, 1937; Nichols, 1966). Most spawning occurs within a week after water temperature reaches 12.7-15.6 C (Hollis, 1967). The semi-bouyant eggs are laid near the surface and depend on water currents to keep them off bottom where survival is reduced (Bigelow and Schroeder, 1953). Eggs have been collected at salinity to 12 ppt (Dovel, 1971). Hatching has been reported at 9.7 ppt, but survival decreases above 4.7 ppt (Johnson, 1972).

Chesapeake Bay and its tributaries are reputed to produce more striped bass than all other areas in North America combined (Dovel and Edmonds, 1971). The major spawning grounds have apparently shifted from the lower Susquehanna River to the main navigational channel in the Elk River and in the Chesapeake and Delaware Canal from Turkey Point to Chesapeake City, Maryland (Dovel and Edmonds, 1971). Environmental changes such as reduced flow in the Susquehanna after impoundment (e.g. Conowingo Dam) and increased current from construction and continued deepening of the C & D Canal are probably responsible.

Spawning also takes place in the Hudson River, New York; James River, Virginia; and the upper Delaware estuary. Although the Delaware and Hudson populations are racially distinct, there is probable mixing among populations. For example, the Delaware population may be supplemented by individuals from Chesapeake Bay and James River, Virginia (Lewis, 1957; Murawski, 1958; de Sylva, 1961).

Most age 2+ and all age 3+ males are sexually mature; most females don't mature until age 4+ and all are not mature until age 6+ (Raney, in Horseman and Kernehan, 1976). The simultaneous presence of ripe and immature eggs may account for wide differences in fecundity estimates. Jackson and Tiller (1952) reported that a four-year-old female may produce 65,000 eggs and a 13- or 14-year old may produce 4,5000,000 eggs.

In the Delaware River system spawning occurs in the C & D Canal and in the river between Oakwood Beach (RK 93; RM 58) and Bridgeport, New Jersey (RK 127; RM 79), mostly south of the Delaware Memorial Bridge (RK 111; RM 69) (Murawski, 1969). Spawning typically occurs during mid-April to mid-June (occasionally mid-July) at water temperature of 10-25 C, but peaks at 15-18 C (Wang and Kernehan, 1979).

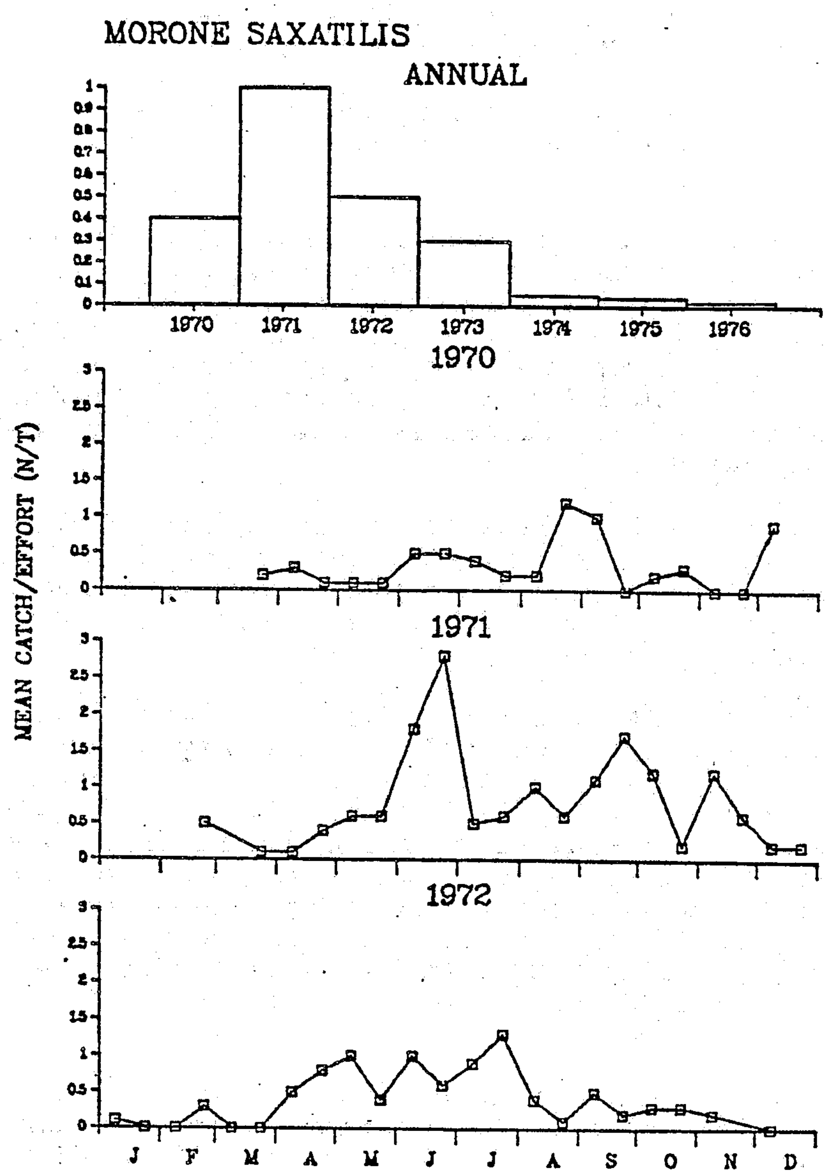
Near Artificial Island migrating adults are taken by gill net from late March through early June, mostly on the east side of the river.

Eggs and larvae of the striped bass have comprised only a minor component of the local ichthyoplankton, e.g. 0.1-0.8 percent of annual samples from 1971 through 1974, and less than 0.1 percent in 1975 and 1976. Eggs were collected in April through June at water temperature of 11.0-22.7 C and salinity of 0.0-5.0 ppt. They were most abundant in April and north of Artificial Island. Generally, less than 50 percent were viable.

Larvae were taken from late April through mid-June, mostly north of Artificial Island, at water temperature of 11.0-22.3 C and salinity of 0.0-2.5 ppt. They were taken more frequently inshore than offshore and were occasionally more abundant at the surface.

Young (ages 0+ - 3+) use the Artificial Island area as a nursery during summer and fall and some may overwinter in the area. They have been taken during all months and at water temperature of 1.0-29.2 C and salinity of 0.0-12.8 ppt, but were generally most abundant in July and August (Fig. 80). Young were generally more abundant north of Artificial Island than south of it. They were common in sheltered areas, e.g. west of Reedy Island Dike, Alloway Creek Cove, and Sunken Ship Cove. Kerr (1953) also observed striped bass sensed and sought out areas of low, uniform current.

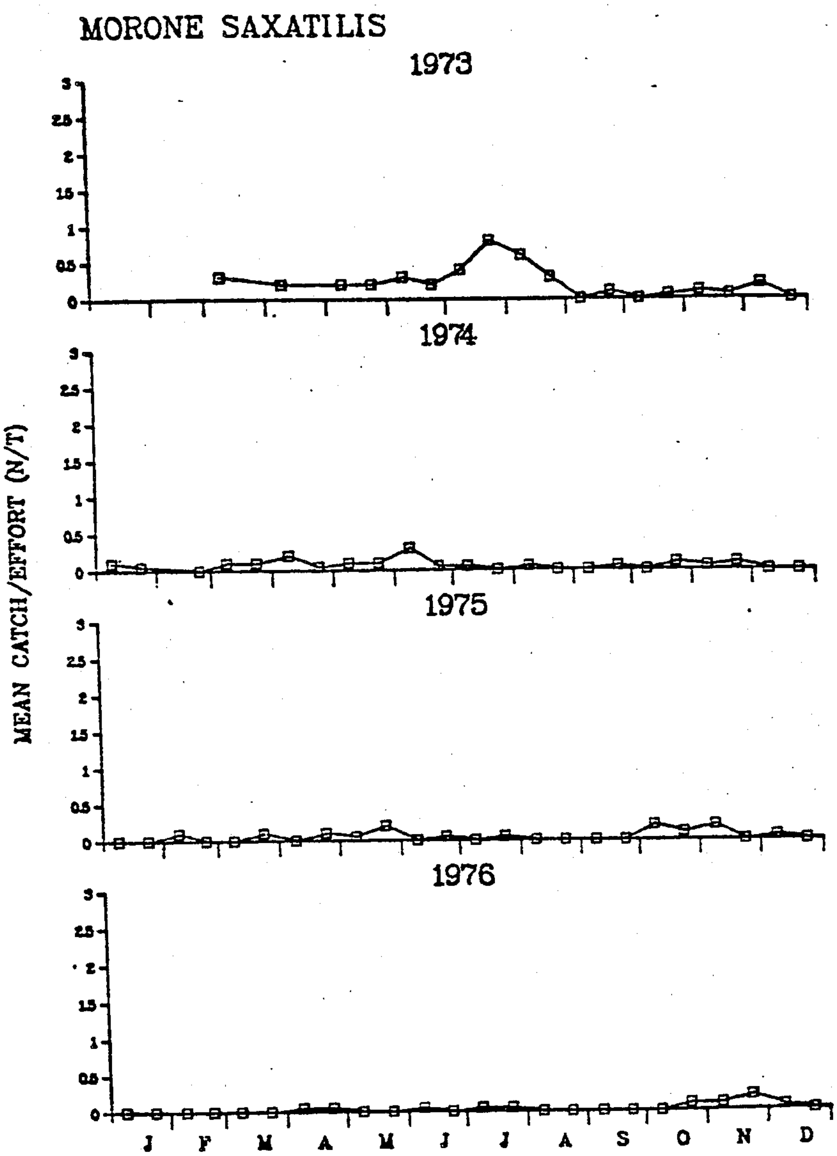
Length-frequency data evidence rapid growth of striped bass near Artificial Island. Age 0+ fish, which are first captured at ca. 4 mm in length, are from 20 to 45 mm FL in July. Growth is ca. 20 mm per month, and by November they range from 70 to 120 mm in length. In spring age 1+ fish are about 85-160 mm in length; age 2+ are about 180-240 mm.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ARTIFICIAL ISLAND STUDIES

Annual and semi-monthly river trawl catch, adjusted for effort - striped bass.

Figure 80



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ARTIFICIAL ISLAND STUDIES

Figure 80 - (continued)

Weakfish

The weakfish, Cynoscion regalis (Bloch and Schneider), of the drum family Sciaenidae, is seasonally abundant in the Delaware River Estuary and is taken in all life stages near Artificial Island. This species, also known as gray seatrout or squeteague, spawns in the Delaware Bay in late spring and summer and utilizes the Artificial Island area primarily as a nursery for larvae and young during summer and fall.

Weakfish is a rapid growing and long-lived species which may attain a weight of 7.9 kg (Thomas, 1971) and an age of nine years (Wilk, 1979). Individuals longer than 900 mm or greater than 5.4 kg are rare (Bigelow and Schroeder, 1953). Young and adults were taken over a temperature range of 6.0-32.0 C in the present study. Larvae have been taken at temperature of 17.0 (Harmic, 1958) to 28.1 C (in the present study). Both larvae and young have been taken at salinity of 0 (in the present study) to over 31 ppt (Harmic, 1958; Richards and Castagna, 1970).

The species ranges along the Atlantic coast from Massachusetts Bay to southern Florida and occasionally to Nova Scotia (Bigelow and Schroeder, 1953) and the Gulf of Mexico (Weinstein and Yerger, 1976). In the mid-Atlantic region it is distributed widely in the Delaware Bay, Chesapeake Bay, and along the coasts of Virginia, Maryland, and New Jersey.

The weakfish is probably the most economically important Sciaenid. During 1930-1949 it was the second most abundant food fish in commercial landings from New York to Virginia (Perlmutter, 1959). In 1955 it ranked first in Delaware commercial food fish landings and second in the sport catch within the Bay (Daiber, 1957). Since 1969 the weakfish has been the most important species in the annually multi-million dollar Delaware marine sport fishery. A recent (since 1967) increase in abundance and specimen size is probably the major reason for the reported (Lesser, 1977) tripling in sport fishing effort in Delaware Bay during the 1970s.

Although of continuing importance, the weakfish population declined from the early 1920s through the mid-1960s (McHugh, 1977), possibly because of overexploitation of age 1+ and 2+ fish by Virginia and North Carolina fisheries (Higgins and Pearson, 1927). Coincident with the late portion of the decline was the increased use of DDT in the 1940s, '50s and '60s, (Joseph, 1972). Whatever the cause, the coastal population decreased by 90 percent between 1944 and 1966. A recent but perhaps temporary population recovery is evidenced in commercial and sport landings which in the mid-Atlantic region have increased over five times since 1967 (McHugh, 1977). The present coastal population features strong 1970, '71, and '75 year classes which were evident in the present study. Boone (1976) reported strong year classes in the Chesapeake Bay in 1969 and 1975.

The population undergoes seasonal coastwise migrations. In the fall young and sub-age 4+ adults leave estuaries and move southward along the coast and overwinter near shore from Virginia to perhaps Florida. Age 4+ and older fish, which move out of estuaries shortly after spawning and summer along the coast, move only as far south as North Carolina and overwinter farther off shore than the younger fish (Wilk, 1979). In the spring, as water temperature increases, fish of all ages move northward and into estuaries where spawning takes place.

Merriner (1976) found that most North Carolina weakfish were sexually mature in their second summer (age 1+) and that all were mature at age 2+. Data from sport and commercial catch indicate a similar age of maturity for Delaware Bay fish. Merriner stated that weight and length of weakfish were better indicators of fecundity than was age. He estimated that a 500-mm SL female (ca. age 5+) would produce about two million eggs and that fecundity of North Carolina weakfish increases 127,900 eggs per 100 grams of body weight. Daiber (1954 and 1956) estimated fecundity of Delaware Bay spawners as 106,000 and 193,000 eggs per 100 gm body weight.

Weakfish spawn in estuaries and inlets and along beaches on the Atlantic coast from March through October (Lippson and Moran, 1974). Spawning period shifts with latitude, e.g., March through May in Georgia (Mahood, 1974), late April through June in North Carolina (Merriner, 1976), late May through August in Delaware Bay (Daiber, 1957), and June through October in Block Island Sound (Merriman and Sclar, 1952). Spawning has been reported to occur at water temperature of 15.5-25.0 C (Herman, 1963; Wang and Kernehan, 1979) and salinity of 12.0-32.5 ppt. (Harmic, 1958).

Eggs hatch after ca. 1000 degree-hours at water temperature between 12.0 and 31.5 C and at salinity of 12.0-32.5 ppt (Harmic, 1958). Dissolved oxygen below 4.3 mg/l and sudden changes in temperature (± 6 C) or salinity (± 5-6 ppt) increase mortality of eggs (Harmic, 1958).

Progeny, through active and passive transport, enter low salinity nursery grounds where they remain through their first summer. In the fall, as water temperature decreases, the then age 0+ young move progressively to warmer waters in the lower estuary and southward to near shore overwintering grounds along the coast.

In spring, adult weakfish moving northward arrive in Delaware Bay as early as April (Daiber and Smith, 1971). Commercial and sport catch and Dingell-Johnson trawl data (Daiber and Smith, 1971) indicate that fish age 3+ and older enter the Bay first. Successive arrivals of younger fish continue into the summer. This progression could suggest that older fish swim faster, or overwinter closer to Delaware Bay, or begin spring migration earlier than do younger fish. After spawning, older fish generally leave the Bay while younger fish may remain through the summer.

In Delaware Bay spawning occurs from late May through August. It has been reported to have two or more peaks in intensity, based on evidence of gonad weight/body weight ratios (Daiber, 1957), abundance of eggs in plankton (Harmic, 1958), and the length-frequency distribution of age 0+ young taken in the present study near Artificial Island during 1969 (Thomas, 1971). The literature disagrees as to the exact timing of these peaks but generally lists the first in June and the second in July. Annual variation in timing may be related to fluctuations in optimum physicochemical conditions which key spawning. Annual length-frequency distribution of young in the study area since 1970 evidence a protracted spawning season in Delaware Bay, but do not consistently evidence multiple peaks. The occurrence of multiple peaks may reflect the sequential movement of progressively younger members of the spawning stock into the Bay (Daiber, 1957), and the presence of more than one dominant year class within this stock.

Welsh and Breder (1923) located the major spawning area as the east side of the Bay between Maurice River Cove and Cape May. Harmic (1958) reported that spawning was most intense in the southwestern region of the Bay. Daiber, et al., (1976) more precisely defined the location as south of the Mispillion River and west of the shipping channel. In July, as salinity increases, spawning activity probably extends into the middle and upper Bay, as evidenced by the commercial capture of ripe adults between Bowers Beach (RK 37; RM 23) and Port Mahon (RK 47; RM 29) and the collection of eggs near Artificial Island during July.

Prior to egg occurrence locally in 1974-1976, the upriver reported limit had been Smyrna River (RK 70; RM 43). During 1974-1976 eggs were collected from late June through July at water temperature of 24.2-27.0 C and salinity of 2.0-13.0 ppt. Annual samples varied from seven specimens in 1975 to ca. 700 in 1974. Most of each year's sample was taken on a single collection date or at one sampling station. Generally, weakfish eggs were most abundant in the downriver portion of the study area, near the shipping channel, and near bottom. Annually, egg viability ranged from 42 to 73 percent.

Eggs taken in the study area are most likely the result of downbay spawning and are transported into the area by upstream subsurface currents. This is evidenced by their advanced stage of development. They are probably the product of the "second" spawn (late June-July), and their occurrence in the area, which has been during years of low freshwater runoff, is dependent on salinity as it affects the proximity of spawning to Artificial Island. During egg occurrence in 1974-1976, biweekly mean salinity ranged from 4.1 to 8.6 ppt; during the same period in 1972 and 1973 it ranged from 0.6 to 3.2 ppt.

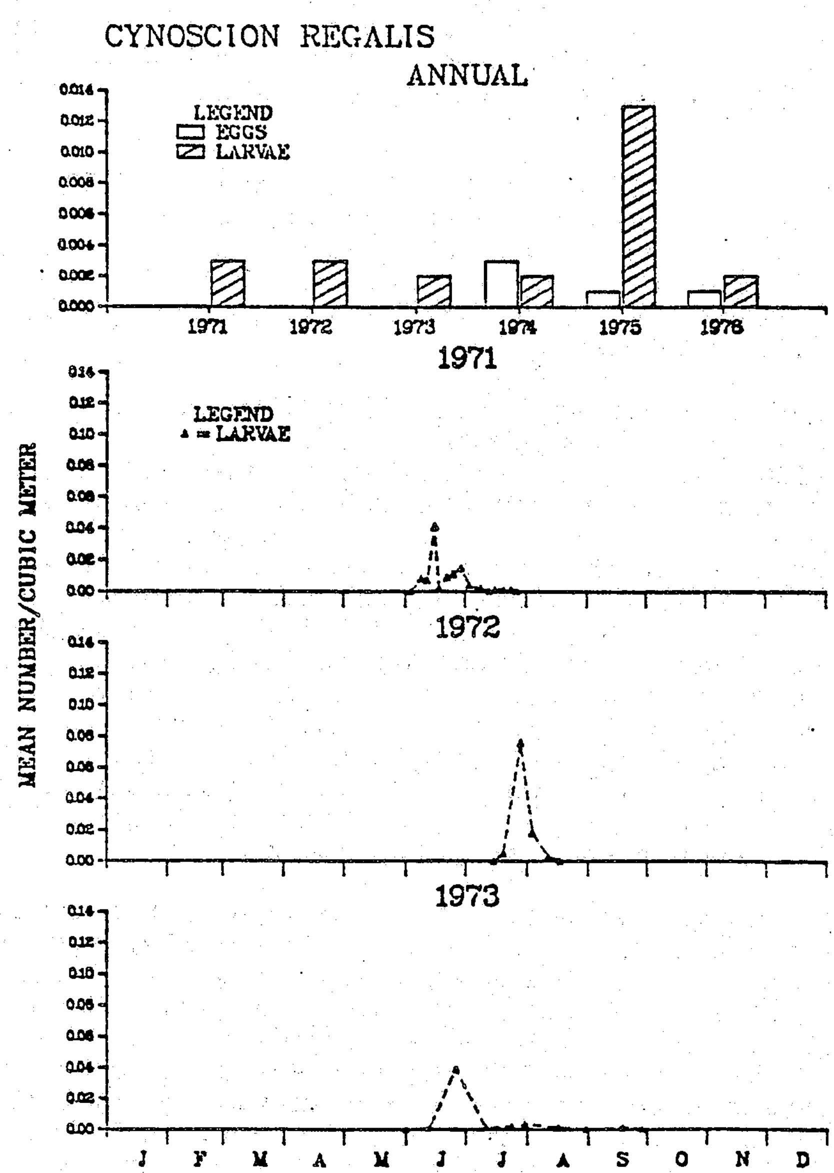
Exploratory sampling near Ship John Shoal (RK 59; RM 36) during 1974 further evidenced the relatively marginal occurrence of eggs in the study area. There, eggs were taken during a longer period and the peak in abundance was earlier and greater by a factor of six than was observed near Artificial Island.

Larvae were taken near Artificial Island from May through September at water temperature of 19.0-28.1 C and salinity of 0.0-13.0 ppt. Their annual abundance varied (Fig. 81) and there was no apparent distributional pattern.

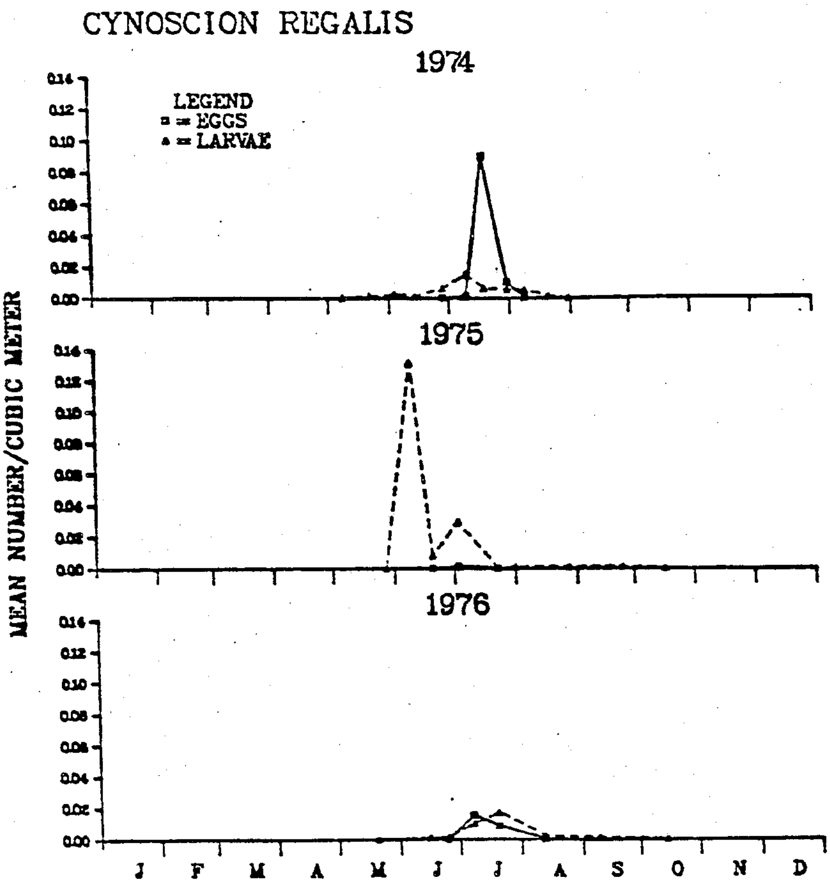
Post-larval weakfish have been taken annually near Artificial Island, typically from April through November, at water temperature of 6.0-32.0 C and salinity of 0.0-20.0 ppt. These were almost exclusively age 0+ young which use the area as a nursery. Annual abundance has fluctuated widely but typically peaked in June or July (Fig. 82). In 1972 (year of Hurricane Agnes) and 1973 heavy runoff depressed salinity in the study area, possibly shifting the nursery area downstream, and delaying peak local abundance until late August and early September.

Weakfish young have been taken throughout the study area, including the tidal tributaries. Typically, age 0+ fish were taken first in the southern portion, indicating recruitment from downbay spawning grounds. As water temperature and salinity have increased in July, distribution has extended further upstream and they remain widely distributed through the summer. Regions of maximum abundance have varied annually; however, weakfish were often abundant in the shallow waters of the extreme up- and downstream portions of the study area.

Length range of fish taken locally has been from 2 mm TL to 690 mm FL. Growth during the first summer is particularly rapid; length-frequency data show that age 0+ specimens may grow from 20 to 35 mm per month during June-September. Although annually variable, modal length typically ranged from 21-35 mm in June, 41-60 mm in July, and 81-95 mm in August. By October, as young leave the area, most are 60 to

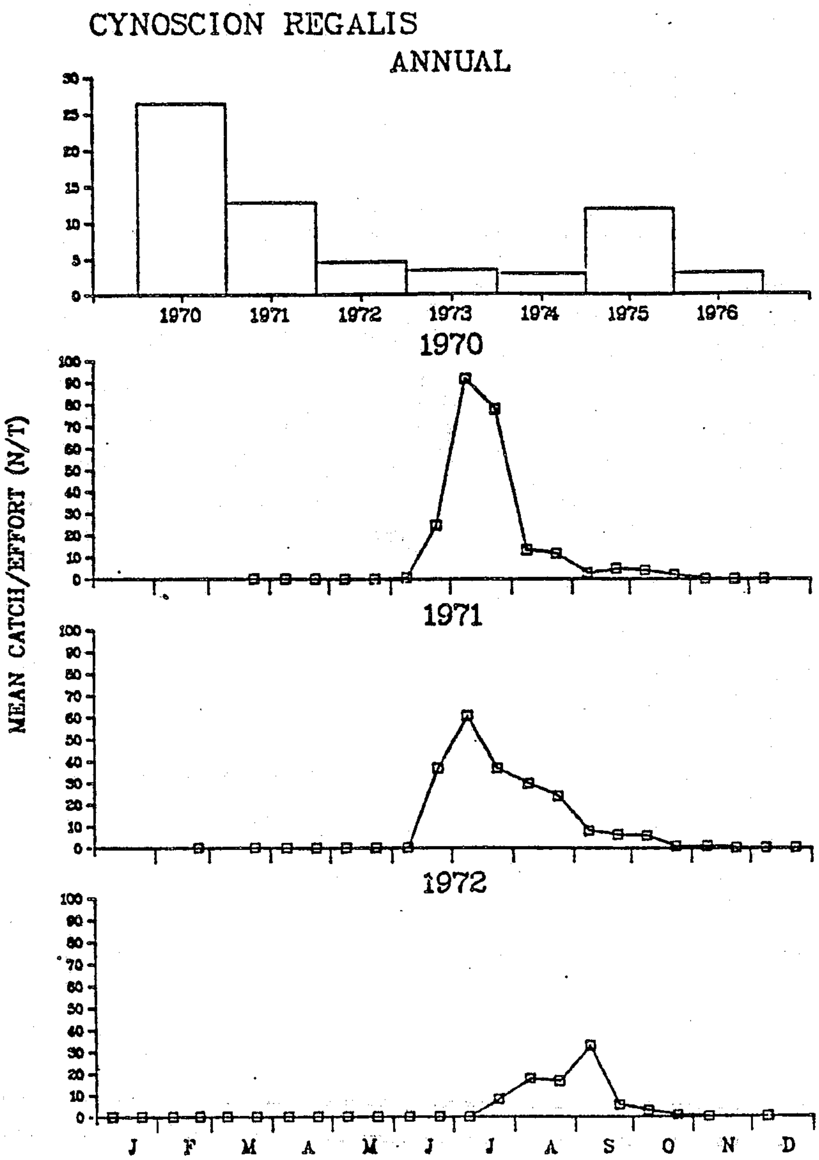


PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Relative annual abundance, and annual patterns of daily mean density, eggs and larvae - weakfish.
	Figure 81

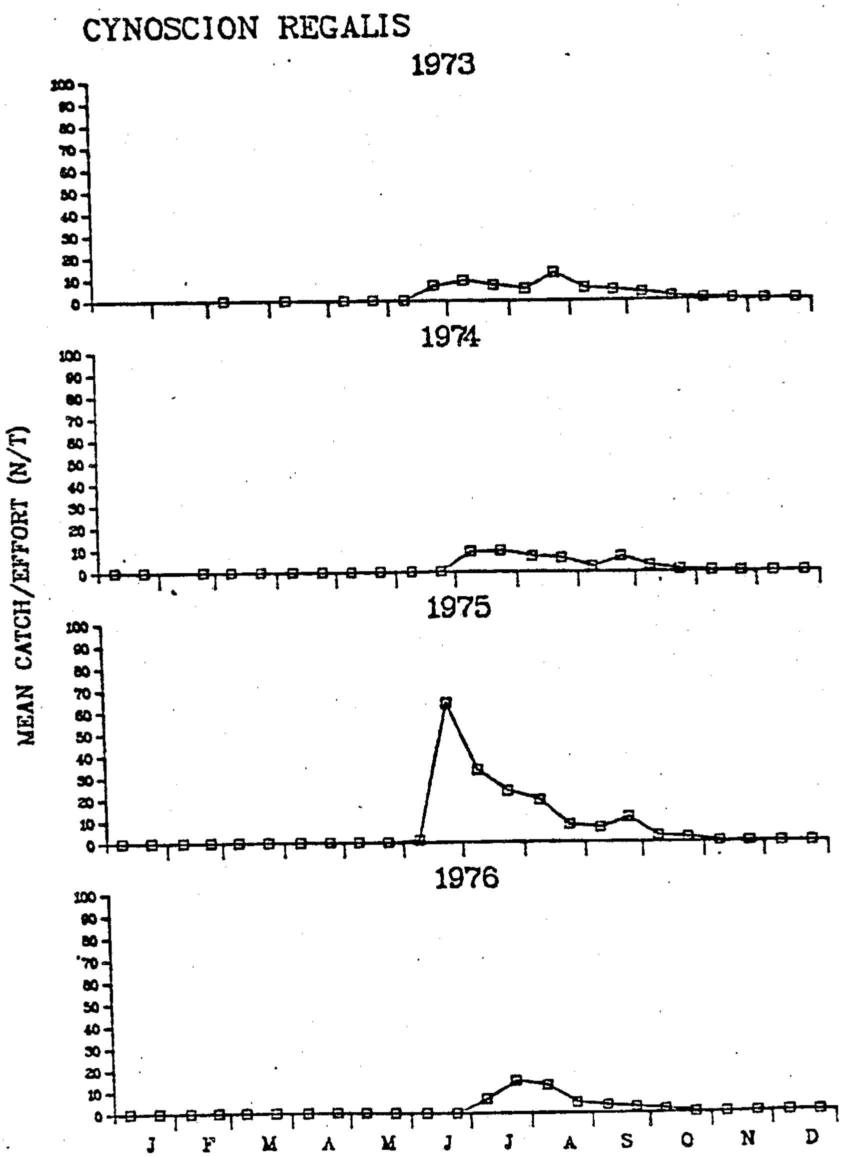


PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ARTIFICIAL ISLAND STUDIES

Figure 81 - (continued)



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Annual and semi-monthly river trawl catch, adjusted for effort - weakfish.
	Figure 82



PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ARTIFICIAL ISLAND STUDIES

Figure 82 - (continued)

150 mm with the mode typically being 110-120 mm. Age 0+ fish average 180 mm when they leave the Bay in fall (Daiber and Smith, 1971). Growth slows during winter, but by June or July of their second year (age 1+) weakfish average about 200 mm. During mid-summer age 2+ fish average 250-260 mm; age 3+ average 310 mm; and age 4+ average 360-370 mm (Daiber and Smith, 1971).

Stomach analysis of locally collected age 0+ weakfish indicate that they feed largely on the opossum shrimp, Neomysis americana, and the grass shrimp, Crangon septemspinosa. Larval weakfish feed on small planktonic organisms such as copepods, but as they grow larger and become young they rely more on opossum and grass shrimp. As young grow larger than 100 mm they feed more heavily on fishes, especially the bay anchovy and Atlantic menhaden. They also prey on smaller members of their own species. Adults are primarily piscivorous.

Spot

The spot, Leiostomus xanthurus Lacepede, of the drum family Sciaenidae, occurs annually in the Delaware River Estuary, and age 0+ young are common in the study area. These young, spawned offshore in ocean waters during winter, appear locally during late spring and remain until fall before moving downbay and offshore ahead of decreasing river temperature. Yearling and older fish occur sporadically in the local area but are more common downbay.

It is a relatively small and short-lived fish. Maximum reported length is 345 mm (Hildebrand and Schroeder, 1928); few grow larger than 255 mm (Dawson, 1958). Maximum recorded age is four and one half years (Welsh and Breder, 1923); few live more than three years (Sundararaj, 1960). It occurs at salinity of 0-60 ppt (Gunter, 1945; Raney and Massman, 1953; Simmons, 1957) and water temperature from 4.8 (present study) to 36.7 C (Dawson, 1958).

The spot ranges along the Atlantic and Gulf coasts from Massachusetts Bay to the Bay of Campeche, Mexico (Dawson, 1958). In the mid-Atlantic region it is distributed widely in the Delaware Bay (de Sylva et al., 1962), Chesapeake Bay (Hildebrand and Schroeder, 1928), and along the coast of Virginia (Richards and Castagna, 1970), Maryland (Schwartz, 1963), and southern New Jersey (Fowler, 1952).

It has both commercial and recreational importance, with the chief fisheries centered in the Chesapeake Bay area and in the Carolinas (Dawson, 1958). It was once but is no longer commercially important north of Chesapeake Bay due to the sporadic catch and low abundance of commercial sized fish. Along the southern Atlantic and Gulf coasts it is, because of its size, considered either a trashfish or an industrial species (Gunter, 1950; Music, 1974).

Spot populations are subject to large apparently random annual fluctuations in abundance typical of a short-lived species. Joseph (1972), reviewing historical catch records along the mid-Atlantic coast dating back to the turn of the century, noted year-to-year fluctuations in excess of 100 percent, but was unable to discern any long-term trends. He further noted that the population depends largely on the strength of recent year classes, and attributed variations in year-class strength to changes in environmental conditions on the spawning grounds.

Spawning along the Atlantic coast occurs largely or entirely offshore. The period is prolonged, occurring anywhere from mid-fall through early spring depending upon geographic region (Dawson, 1958). In the Chesapeake region, spawning takes place during late fall through winter (Hildebrand and Schroeder, 1928). Wang and Kernehan (1979) reported spawning off the Delaware Bay to occur from December to May. Dawson (1958) reported fecundity between ca. 70,000-90,000 eggs. Maturity is reached at the end of the second or early in the third year (Hildebrand and Cable, 1930; Dawson, 1958).

Greatest abundance of young (age 0+) spot along the Atlantic coast occurs south of Delaware Bay (Berrien, 1973a). They enter estuaries from late winter through summer (Dawson, 1958) and remain in these nursery areas for much of their first year. North of the Carolinas, young move out of the estuaries to offshore waters (some may overwinter in deeper bays) during late fall and, as suggested by tagging studies (Pacheco, 1962a), may migrate to waters off North Carolina.

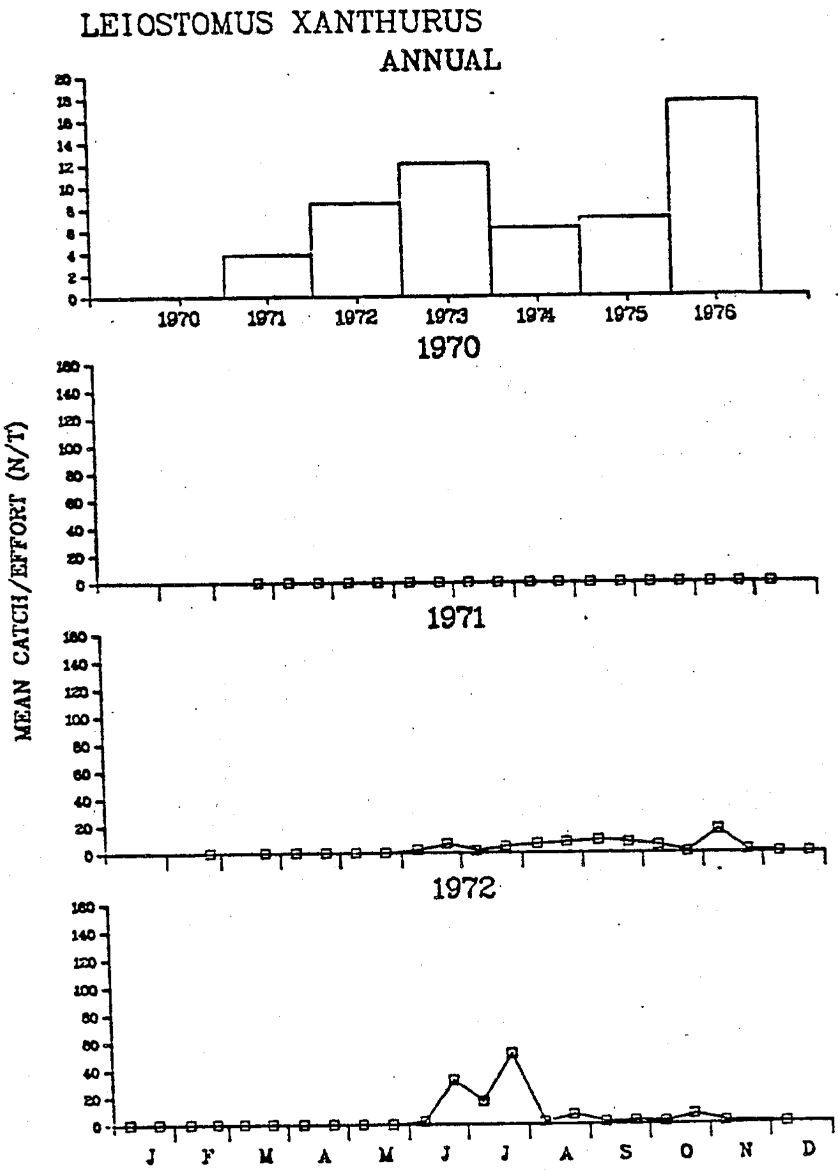
Adult spot migrate seasonally between estuaries and coastal waters. They enter the many bays and sounds during spring, although seldom occur as far up-estuary as do the young. They remain in these areas until late summer or fall before moving offshore to spawn or escape low water temperature. Although the movement into the Delaware River Estuary during spring has not been documented, the abundance and subsequent decrease in catch of age 1+ and 2+ specimens in collections between August-November reported by Daiber and Smith (1971) indicates movement out of the estuary in fall.

Eggs have not been described in the literature and there is no record of their collection in the Delaware River Estuary (Wang and Kernehan, 1979). However, in the present study specimens age 0+ and older have been taken annually. At capture, water temperature ranged from 4.8 to 30.0 C and salinity to 17 ppt. Annual abundance has varied drastically, with annual mean catch per unit effort ranging from 0.002 to 17.6 (Fig. 83). Nearly all specimens collected were age 0+, and annual variation in abundance probably reflects annual production of young offshore of the Delaware Bay, and possibly changes in distribution patterns within the estuary. However, production off Delaware may not be representative of coast wide year-class strength since the spawning potential here is more apt to fluctuate than in the principal spawning grounds further south along the Atlantic coast.

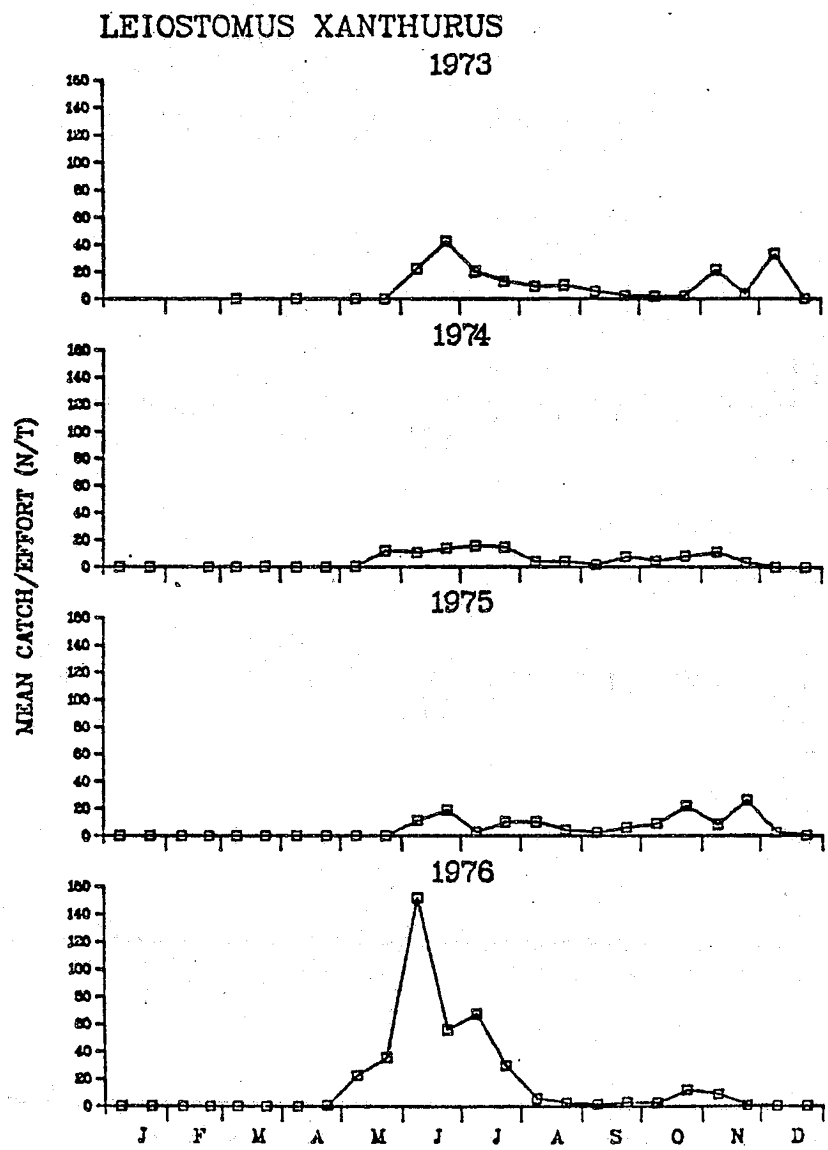
Although age 0+ spot have been taken locally as early as April and as late as December, they typically occur from May through November. Their abundance during this period is seasonal, with peaks occurring in late spring-early summer and mid-fall (Fig. 83). This pattern suggests movements in response to changing salinity and temperature. As salinity increases during summer, young (particularly smaller individuals) apparently migrate still further upriver to areas of preferred salinity. A differential distribution by size with smaller individuals occurring furthest upstream, has been noted in the Chesapeake Bay (Pacheco, 1962b). The local fall peak reflects a progressive movement downstream in advance of decreasing water temperature. It typically occurs at water temperature of 10-13 C. Spot abundance decreases as temperature drops below 10 C, reflecting continued movement downbay. Most have left the study area by the time temperature reaches 5 C. Temperature below 4-5 C is believed lethal (Dawson, 1958). Fewer large and increased numbers of smaller fish in November and December suggest that larger fish emigrate from the area first. Hildebrand and Schroeder (1928) and Pacheco (1962b) noted similar movements in the Chesapeake Bay.

Generally, spot are distributed throughout the study area including the tidal tributaries. During peak abundance, concentrations were found in low current areas with mud or mud/sand bottom, such as occur immediately southeast of Artificial Island, west of Reedy Island Dike, and in Salem Cove.

Spot taken in the present study ranged in length from 13 TL to 250 mm FL. Each annual sample comprised almost exclusively age 0+ specimens. Length varied considerably throughout the year, with range often exceeding 100 mm, probably the result of the protracted spawning season. Length-frequency data indicate two distinct cohorts were annually evident, co-occurring during early summer (June-July). Growth of spot is rapid during their first growing season. Annually, mean length increased from ca. 30 mm in May to some 120-146 mm (range 51-190 mm) in October.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Annual and semi-monthly river trawl catch, adjusted for effort - spot.
	Figure 83



PUBLIC SERVICE ELECTRIC AND GAS COMPANY

ARTIFICIAL ISLAND STUDIES

Figure 83 - (continued)

However, these locally observed lengths at the end of the first growing season may not be representative of the Delaware Bay population since, as noted in the Chesapeake Bay (Pacheco, 1962b), larger fish may be primarily distributed downbay and those few that remain in the study area may not be vulnerable to capture.

Atlantic croaker

The Atlantic croaker, Micropogon undulatus (Linnaeus), of the drum family Sciaenidae, occurs annually in the Delaware River Estuary and is common in the study area during fall with the influx of age 0+ young. These enter the estuary from offshore spawning grounds and utilize the lower river as a nursery before moving downbay, probably to offshore waters, during November and December ahead of decreasing water temperature. Young of the previous year's spawn are occasionally taken during spring through fall. Older fish rarely appear in the lower river.

It is a relatively short-lived species, with a life span of one to four years (White and Chittenden, 1976). Average size is to 250 mm (Haven, 1957; White and Chittenden, 1976) but a 668-mm specimen was reported by Rivas and Roithmayr (1970). It is regularly taken in salinity from 0 to 40 ppt (Haven, 1957) but has been reported at 70 ppt (Simmons, 1957). Generally, the adults and older juveniles are more abundant at higher salinity. Reported temperature at occurrence is from 0.2 (present study) to 35.5 C (Nelson, 1967).

The Atlantic croaker occurs along the Atlantic and Gulf coasts from Cape Cod, Massachusetts to Campeche Bank, Mexico but is seldom found in abundance north of New Jersey (Welsh and Breder, 1923; White and Chittenden, 1976). It is common in the estuaries and along the coast of southern New Jersey (Fowler, 1952), Delaware (de Sylva et al., 1962; Thomas, 1971), and Maryland (Hildebrand and Schroeder, 1928; Schwartz, 1964; Richards and Castagna, 1970). Along the mid-Atlantic coast it supports commercial and recreational fisheries (Joseph, 1972) but is important only as an industrial species through the remainder of its range (Gunter, 1950; Bearden, 1964; Roithmayr, 1965).

The croaker population along the mid-Atlantic coast has demonstrated drastic long-term fluctuations during the past eighty years (Joseph, 1972). Population levels were low at the turn of the century but then increased to a peak in the 1940s. Subsequently, numbers declined precipitously during the 1950s and 1960s (Joseph, 1972), but, based on increased commercial and recreational catches during the '70s, the population appears to be rebounding.

Spawning over much of its Atlantic range occurs principally offshore (Welsh and Breder, 1923; Hildebrand and Cable, 1930; Bearden, 1964). Although unconfirmed, some may occur in larger bays and estuaries including the Delaware and Chesapeake bays (Welsh and Breder, 1923). South of Cape Hatteras the spawning season is protracted, extending from September through at least March (Hildebrand and Cable, 1930). North of Cape Hatteras the season is somewhat more restricted, extending from August through December (Welsh and Breder, 1923; Hildebrand and Schroeder, 1928). Hildebrand and Schroeder (1928) reported the fecundity of a 395-mm specimen at ca. 180,000 eggs. Croaker north of Cape Hatteras mature as they approach two years of age (Welsh and Breder, 1923; Wallace, 1940).

Young (age 0+) occur along the Atlantic coast from New York to Florida but are most abundant from the Chesapeake Bay region south to the Carolinas (Berrien, 1973b). They enter the estuary as larvae (< 15 mm) and are passively transported by subsurface currents to low salinity nursery areas where they spend much of their first year. Haven (1957) and Bearden (1964) noted that growth is accompanied by a net seaward movement of larger individuals.

North of the Carolinas adult croaker undertake seasonal migrations, apparently in response to changing water temperature (Bearden, 1964). During spring, they move up the coast from overwintering grounds off North Carolina. By summer they are found along the coast and in estuaries as far north as New Jersey. However, with the onset of spawning in late summer, they begin to congregate offshore. After spawning and as water temperature decreases through fall and winter they migrate down the coast to the offshore waters of North Carolina.

The occurrence of adult croaker in the recreational fishery in the lower Delaware Bay and adjacent ocean waters during late summer and early fall, together with the occurrence of larval specimens in the upper Bay and lower Delaware River during the same period, suggests that some spawning occurs in waters offshore of the Delaware Bay. The incidence of very small larvae (< 10 mm TL) in the study area (ca. RK 61-97; RM 40-RM 60) in 1974 and 1975 suggests that, at least in those years, some spawning may even have occurred in the Bay.

Spawning off the Delaware coast may occur all year, but at least from late August through February (Thomas, 1971; Wang and Kernehan, 1979). The incidence of age 0+ specimens between 21-30 mm in length in the present study during

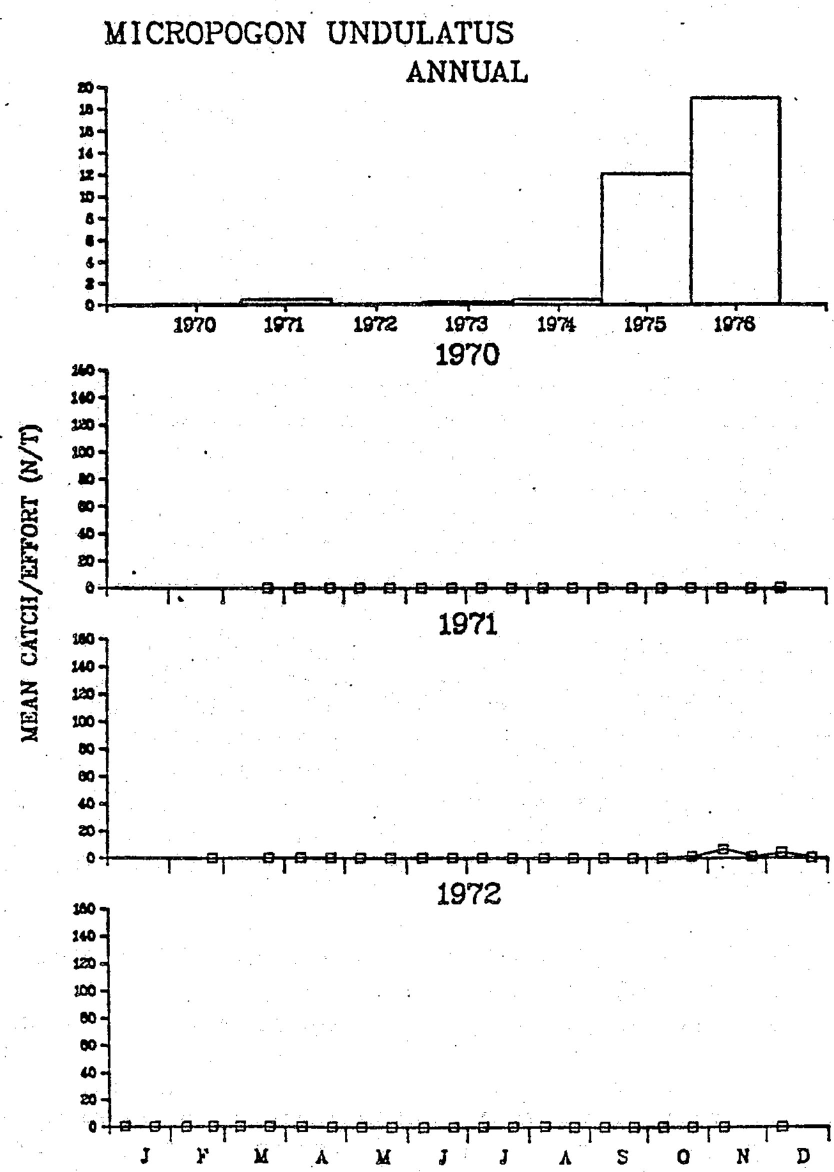
August 1975 suggests that spawning occurred as early as July. In addition, the occurrence of specimens smaller than 15 mm through December indicates continued spawning at least through November.

No eggs were taken in the study area; none can be expected to occur here because of the distant location of the spawning grounds. However, specimens age 0+ and older have been taken annually since 1970 at water temperature of 0.2-30.0 C and salinity to 17.0 ppt. Annual abundance from 1970 through 1974 was low (n/T < 0.5) but increased sharply in 1975 (12.1) and 1976 (19.0) (Fig. 84). Nearly all specimens collected were age 0+, and annual variation in abundance probably reflects the annual production of young offshore of the Delaware Bay, and possibly changes in distributional patterns within the estuary. However, production off Delaware may not be representative of coast wide year-class strength since the spawning potential here is more apt to fluctuate than in the principal spawning grounds further south along the Atlantic coast.

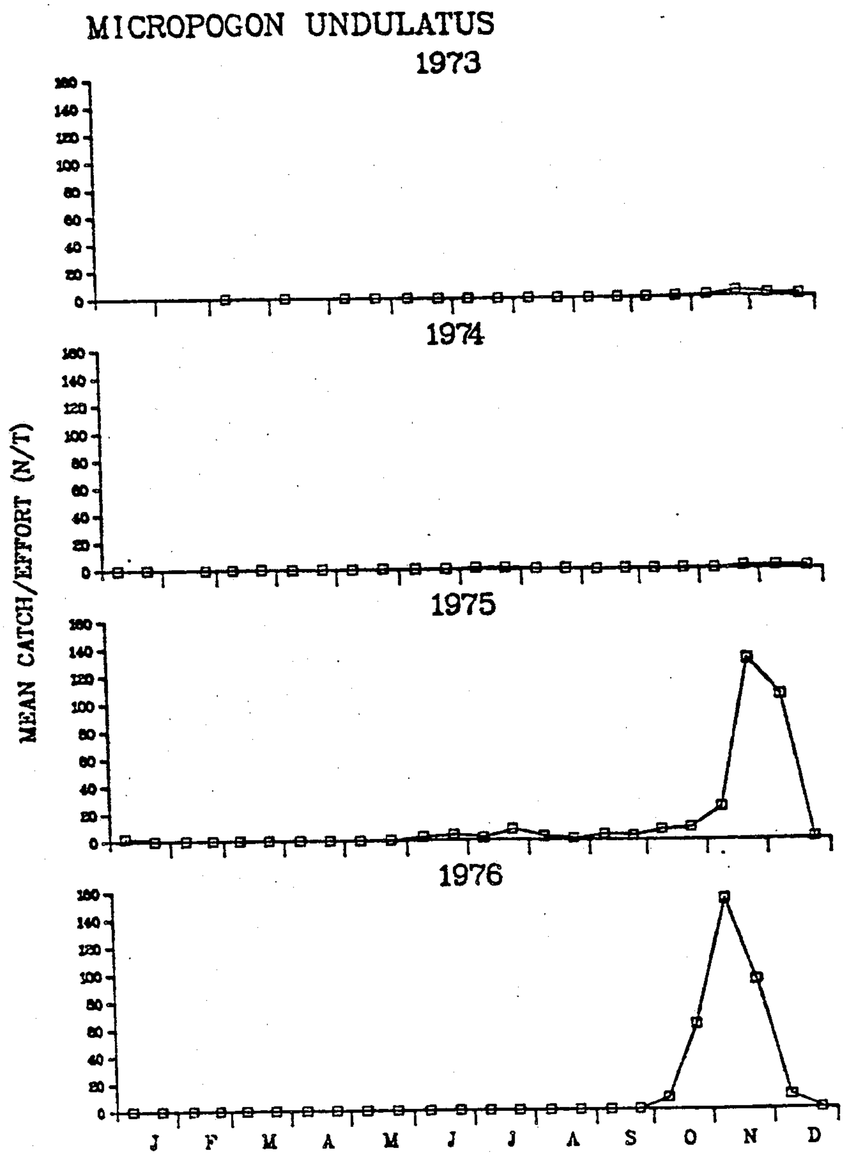
Croaker have annually demonstrated a fall peak in local abundance, reflecting recruitment of age 0+ specimens (Fig. 84). Typically, early age 0+ (< 30mm) were first taken in September or October, but they have arrived as early as August and as late as November. In all years peak abundance occurred in November. After November, abundance declined drastically as water temperature decreased. In several years, age 1+ specimens, the progeny of the previous year's spawn, appeared in the study area during early spring and often remained through summer or fall. Their occurrence usually followed mild winters, suggesting that if water temperature remains high enough some overwintering in the bay or near ocean waters may occur. However, local abundance during spring was generally less than 10 percent of that of the previous fall. This indicates that probably only a small proportion of the year class overwintered in this system.

The concentration of larval croaker south of Artificial Island (RK 80; RM 50) and near bottom indicates their downbay origin and utilization of subsurface estuarine transport to low salinity nursery areas. Larger age 0+ croaker during most years were more widely distributed throughout the river, with concentrations in deep water. Few were taken in the shore zone or tidal tributaries. During years of high relative abundance, many were taken in the deeper waters off Artificial Island, north and east of Reedy Island, and in the channel. During years of low abundance the distribution was patchy with no apparent areas of concentration.

Croaker ranged in length from 6 to 301 mm TL. Although older fish were taken, age 0+ specimens were predominant.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Annual and semi-monthly river trawl catch, adjusted for effort - Atlantic croaker.
	Figure 84



PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ARTIFICIAL ISLAND STUDIES

Figure 84 - (continued)

Growth of young is apparently slow during fall since specimens collected in the study area attained a mean length of only about 30-35 mm by December. Growth continues slowly during winter as indicated by the length of specimens collected in March (41-59 mm). Although based on only a small number of fish, it appears that rapid growth begins in spring, and by September specimens reach a model length of approximately 150 mm. Similar growth at the end of one year has been reported throughout the croaker's range (Welsh and Breder, 1923; Pearson, 1929; Hildebrand and Cable, 1930; Suttkus, 1954).

Naked goby

The naked goby, Gobiosoma bosci (Lacepede), of the goby family Gobiidae, is a demersal resident of the Delaware River Estuary which, in larval stages, has occurred annually in the study area from June through October with peak abundance in July. Locally, adults are relatively uncommon. The principal importance of this region to the species is as a nursery.

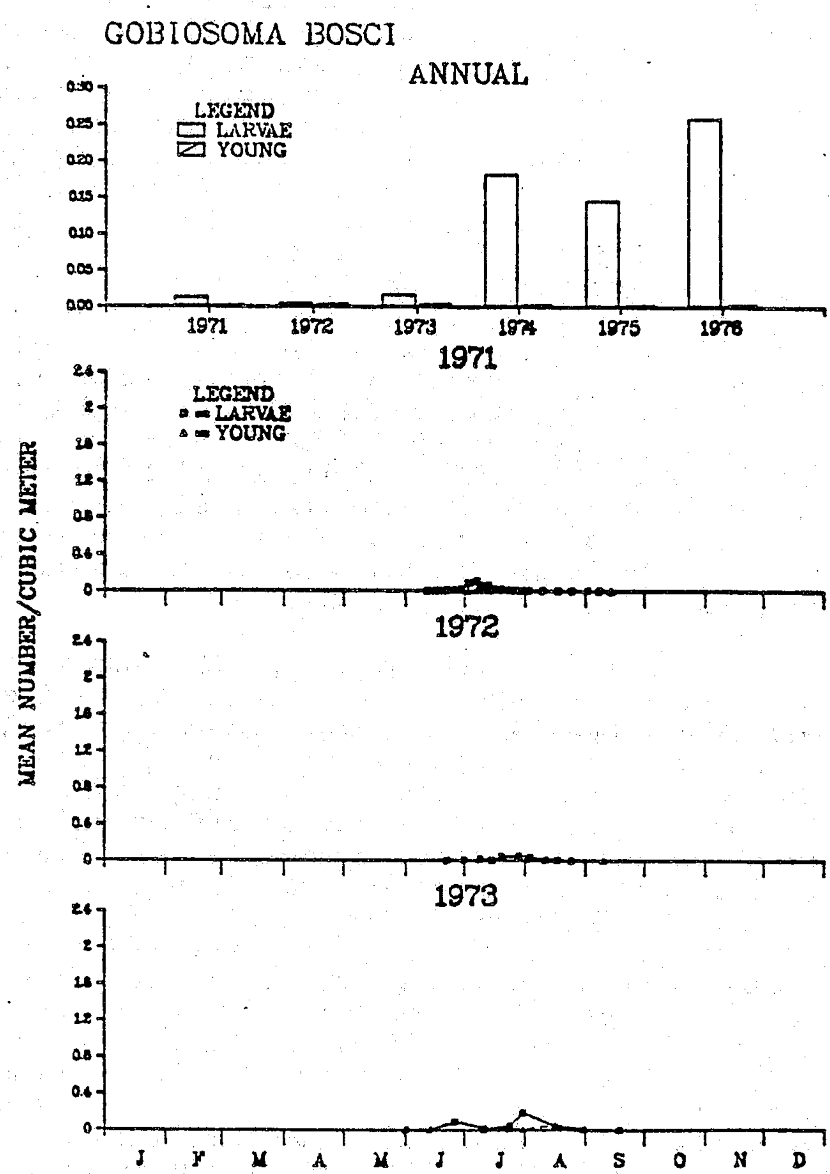
The naked goby is a small, short-lived species seldom larger than 60 mm TL or older than two years (Hildebrand and Schroeder, 1928; Nero, 1976). The literature contain little life history information specific to the northern portion of its range, which includes the Delaware River Estuary. Inference must be drawn primarily from data collected in estuaries along the Georgia, Florida, and Gulf coasts. Although resident populations have been documented in freshwater (Tagatz, 1968) and at salinity as high as 45 ppt (Simmons, 1957), the species is most common in less than 20-25 ppt (Gunter, 1945; Springer and Woodburn, 1960; Christmas and Waller, 1973; Dahlberg and Conyers, 1973).

It occurs in bays and estuaries along the Atlantic and Gulf coasts from Connecticut (Pearcy and Richards, 1962) to Campeche, Mexico (Dawson, 1969), and it is an important forage fish for such sport and commercial species as Atlantic croaker, white perch, weakfish, bluefish, summer flounder, and striped bass (Dawson, 1966; Wass and Wright, 1969).

Adults seldom occur at depths greater than 12 m (Dahlberg and Conyers, 1973), preferring shallow inshore areas with aquatic vegetation or shell substrate (Wang and Kernehan, 1979). Musick (1972) indicated that in the Chesapeake Bay naked goby were most common in the near shore shallows in spring and summer and may move to deep channels in winter. In Georgia estuaries, Dahlberg and Conyers (1973) collected them in mud-bottom marsh pools at water temperature below 20 C, and they speculated, as did Hildebrand and Cable (1938), that they may burrow during the coldest part of the winter.

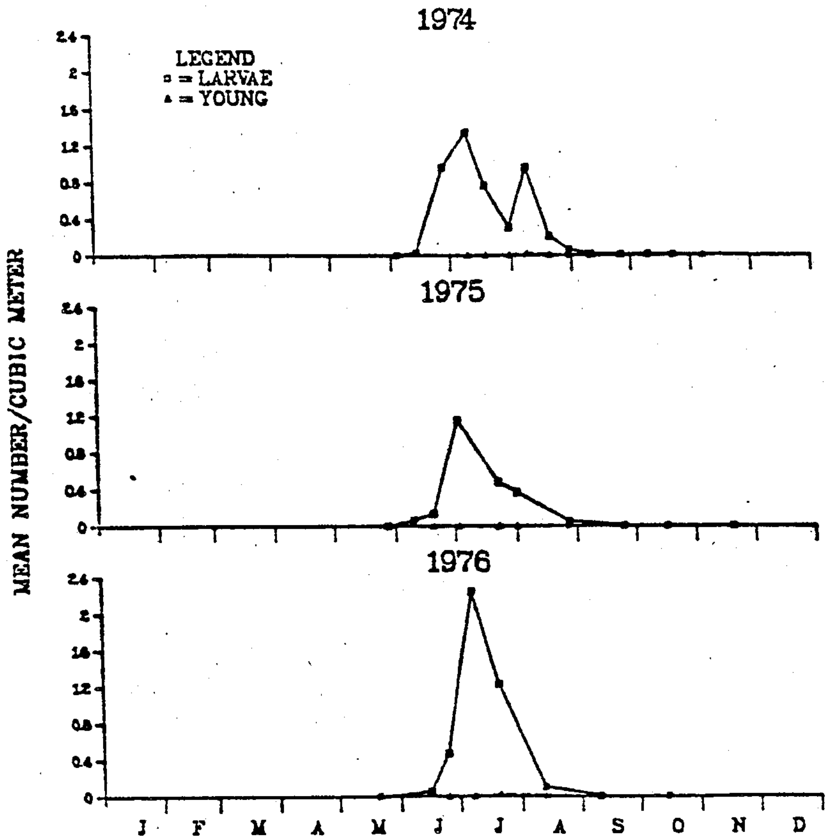
The naked goby spawns at salinity of 10-20 ppt in the Delaware and Indian river estuaries (Wang and Kernehan, 1979). It occurs from May through September, beginning at water temperature of 15-20 C and continuing through the summer maximum (Dahlberg and Conyers, 1973; Wang and Kernehan, 1979). The preferred spawning substrate appears to be oyster and clam beds where egg deposition occurs inside dead, gaping shells (Dahlberg and Conyers, 1973). Eggs, which are adhesive, attach to the shell substrate and hatch in 4-5 days at water temperature of 24-28 C (Lippson and Moran, 1974; Hildebrand and Cable, 1938). Available literature contain no fecundity estimates. The larvae are pelagic and are passively transported by tidal currents into the upper parts of estuaries (Massman et al., 1963) where they are most abundant at salinity less than 12 ppt (Dovel, 1971). Larvae are most common in deeper channel waters and exhibit a diel vertical migration indicative of a negative phototaxis, i.e. typically more common in subsurface waters during the day and in surface waters at night (Massman et al., 1963; Wang and Kernehan, 1979). Their occurrence in channel waters may be related to the utilization of the faster tidal currents in these areas for their up-estuary migration (Wang and Kernehan, 1979).

It is unlikely that spawning occurs in the study area because of unsuitable substrate and salinity, and eggs have never been taken locally. Too, the absence of prolarval specimens is further evidence of no local spawning and of the downbay origin of the larvae and young collected in this area. Although larvae have ranked second or third in each annual ichthyoplankton sample, abundance was relatively low during 1971-1973, with annual mean density from 0.004 to $0.016/m^3$ (Fig. 85). However, during 1974-1976 abundance increased nearly ten fold. This increase may have been to more typical levels. Low abundance in early years of study, except for 1971, could have reflected unsuccessful spawning or a displacement of progeny from the study area as a result of the recorded heavy freshwater runoff and depressed salinity during spawning seasons. Larvae typically occur from June through September but have been taken as late as October (1974, 1975) (Fig. 85). The occurrence of larvae smaller than 5.0 mm TL in October indicates continued spawning and a protracted spawning season. Larvae were typically most abundant during early July when biweekly mean salinity was greater than 5.0 ppt. However, in 1972 and 1973, when salinity levels were depressed in early July, their abundance peaked in late July as salinity increased.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Relative annual abundance, and annual patterns of daily mean density, larvae and young - naked goby.
	Figure 85

GOBIOSOMA BOSCI



PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ARTIFICIAL ISLAND STUDIES

Figure 85 - (continued)

The spatial distribution of naked goby larvae in the study area reflects a downbay origin. Although taken throughout the study area and as far upstream as Killcohook Wildlife Refuge (RK 102; RM 63), larvae have been typically most abundant in areas south of Artificial Island and in deeper mid-channel waters. Larvae were most abundant in surface waters at night and in mid- and bottom waters during the day, indicating their negative phototaxis.

Young and adult naked goby have been taken annually in the study area since 1970, but relative abundance has been consistently low. Annual samples ranged from 9 to 145 specimens and were typically less than 50. This low abundance reflects lack of preferred substrate in the area and the species low vulnerability to capture due to its small size. Although taken in all months except February and March, young adults were most common in late summer and fall. No further delineation of temporal and spatial distribution can be made.

Naked goby in the vicinity of Artificial Island have ranged from 2 to 49 mm TL. Adults were typically less than 50 mm, and the mean length of larvae, by collection date, ranged from 4.1 mm in early June to 9.8 mm in early September. However, this 5 mm increase in mean length is an underestimate of larval growth since it also includes the smaller specimens continually recruited into the area throughout the protracted spawning season. Larvae less than 5.0 mm TL were commonly taken as late as mid-October. In the Artificial Island area specimens 20-25 mm have been commonly taken in late fall. Nero (1976) indicated that growth rate of young naked goby is perhaps as great as 3.0 mm per month but slows after the first year, when mean length is from 18-24 mm. He stated further that age 1+ naked goby may be as large as 44 mm, that fish larger than 46 mm were age 2+, and that specimens greater than 50 mm were rare.

Hogchoker

The hogchoker, *Trinectes maculatus* (Bloch and Schneider), of the sole family Soleidae, is a resident flatfish of the Delaware River Estuary, and all life stages occur near Artificial Island. Although some local spawning does occur, the area is primarily a nursery for larvae and young. Hogchoker occurs throughout the year and is typically most abundant from May through early June and September through October.

The hogchoker has been reported at salinity of 0 to 50 ppt (Massman, 1954; Simmons, 1957). Young prefer lower salinity than do adults and may occur in freshwater (Dover et al., 1969). It had been reported at temperature of 1.1 to 31.1 C (de Sylva et al., 1962; Dovel et al., 1969); in the present study specimens were collected at 0.6 C. It lives to at least seven years and although maximum reported length is 202 mm (Hildebrand and Schroeder, 1928), specimens to 253 mm TL have been collected in the present study.

The species is primarily estuarine although it does range as far offshore as 80-104 KM (Bullis and Thompson, 1965). Its range is along the Atlantic and Gulf coasts from Maine to Venezuela (Bigelow and Schroeder, 1953), but primary abundance is south of the Chesapeake Bay (Wang and Kernehan, 1979). Its flavor is described as delicious but its small size precludes any commercial importance except to an industrial fishery along the southern Atlantic and Gulf coasts (Dawson, 1962). It is of no economic importance in the Delaware River Estuary.

Hogchoker migration and distribution have been described in detail for only the Patuxent River Estuary, Maryland, although similar patterns are probable throughout its range (Dovel et al., 1969). Spawning and hatching occurs in downbay mesohaline waters and the ensuing age 0+ specimens move upstream to areas of low salinity where they remain through the winter. After winter these individuals begin an annual cycle of downstream movement in spring and upstream in fall which continues till at least their fourth year. Successive annual movements bring them to areas of higher salinity and more optimum spawning conditions (Dovel et al., 1969). Few specimens return to low salinity upstream areas after reaching age 4.

Spawning occurs throughout the range, primarily in estuaries (some may occur in ocean waters) and typically at night (Mansueti and Pauly, 1956). Spawning occurs at temperature of 14.7-30.1 C with a peak at 20.0-27.5 C, and salinity of 0-24 ppt with a peak at 10-16 ppt (Dovel et al., 1969). Eggs are pelagic with an incubation period of 26-36 hrs at 23.3-24.5 C (Hildebrand and Cable, 1938). Dovel et al. (1969) suggested that sexual maturity may not be attained until the fourth year; however Koski (1978) found that at least some Hudson River hogchoker are mature in their second year. Fecundity estimates for specimens 87-165 mm (SL) are ca. 11,000-54,000 eggs (Castagna, 1955).

Spawning in the Delaware River Estuary occurs from May through September. Most occurs at water temperature greater than 25 C and salinity of 10-20 ppt and in the river reach between Kitts Hummock and Woodland Beach (RK 39-66; RM 24-41) (Wang and Kernehan, 1979). Some spawning may occur in the river near Artificial Island, but low annual density of eggs and larvae evidences marginal importance of the area.

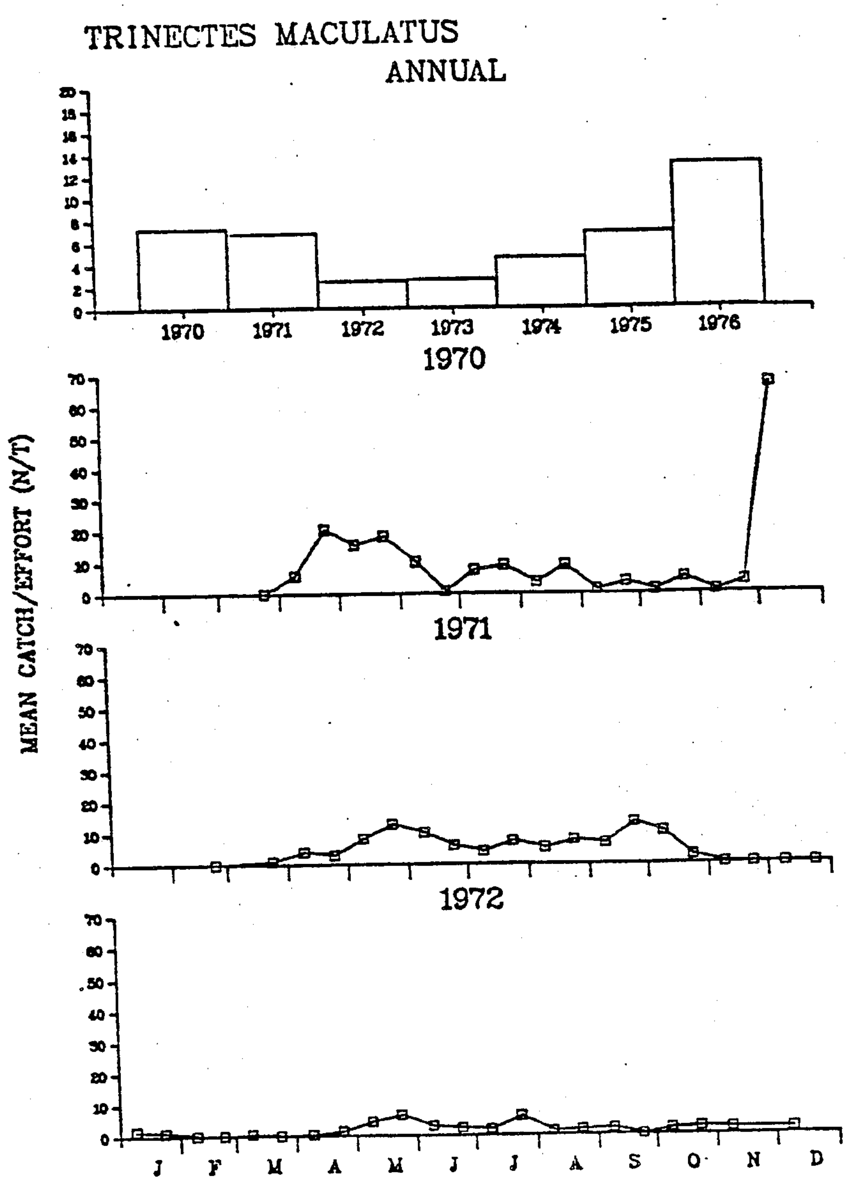
Near Artificial Island, almost all eggs and larvae were taken in July at temperature of 22.0-25.0 C and salinity of 4.0-12.0 ppt. Eggs were characteristically most abundant at night and in sub-surface waters. Larvae were most abundant in the region north and west of Artificial Island, reflecting their upstream migration from higher salinity downstream regions.

Age 0+ young were present in the study area from July through December. Largest numbers were consistently taken in fall (September-October), indicating movement into and utilization of this area as a nursery and overwintering ground.

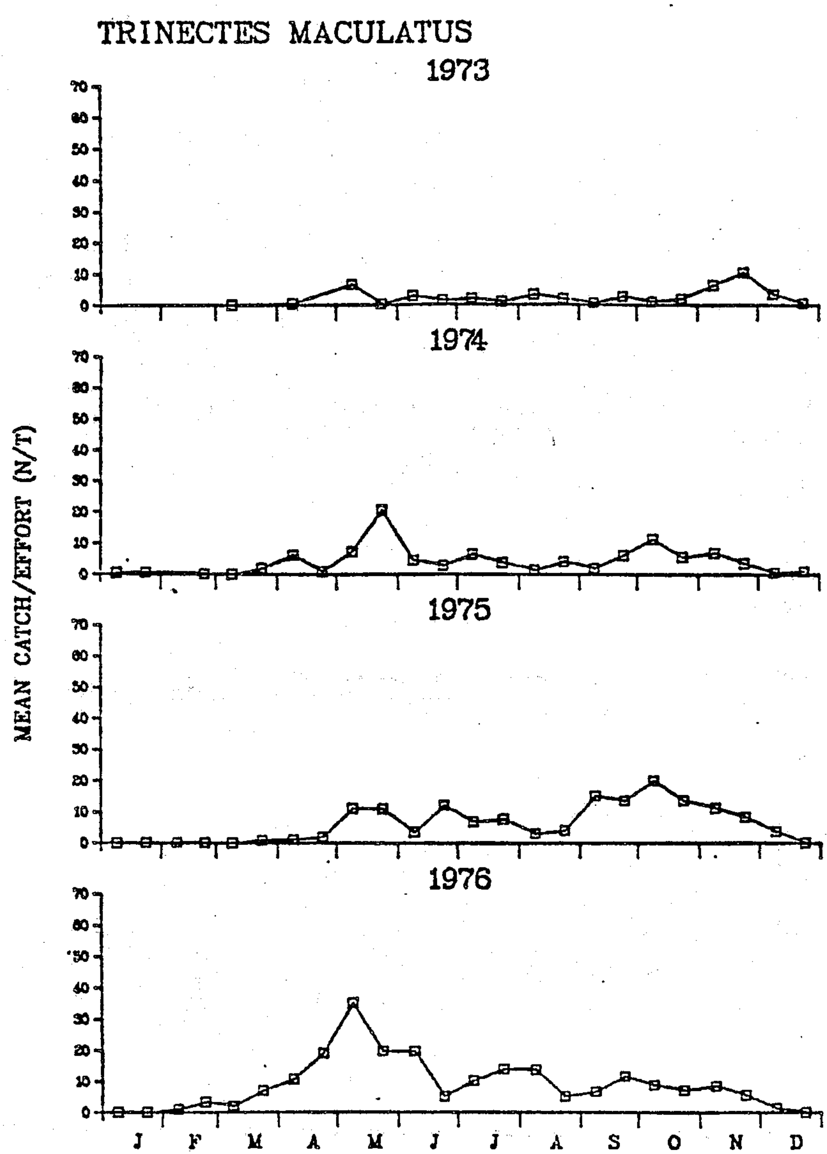
Variation in annual abundance within and over the seven-year period was slight (Fig. 86). In 1972 and 1973 unusually large freshwater discharge in late spring and summer apparently resulted in reduced survival of age 0+ specimens. This was evident in the low numbers of juveniles migrating into this area during the fall and the low annual mean catch in these years (Fig. 86). Hogchoker have been taken each month over the full local range of temperature and salinity. Two peaks in abundance are evident, during May through early June and during September through early October. Spring abundance reflects juvenile migration and adult pre-spawning movements into the area. Recruitment of age 0+ young and migration of adults towards local overwintering areas results in abundance during fall.

Hogchoker occur throughout the river and local tributaries but few were taken in the shore zone. They were generally more abundant in areas with mud or mud/sand bottom. Abundance west of the channel was at least 1.5 times greater than east, probably due to predominance of preferred bottom type on the west.

Hogchoker taken in the study area ranged from 2 to 253 mm TL. Growth is rapid during the first two years of life and then slows gradually. Specimens of the 1974 year class (a particularly large year class) ranged from 21-55 mm in October. This year class was still 21-55 mm in April 1975, indicating essentially no growth during winter. Their range was 51-90 mm in October 1975 (age 1+) and 75-115 mm (age 2+) by October 1976. Age 3+ individuals were 91-125 mm. Koski (1978) reported length range of hogchoker in the Hudson River was 59-82 mm TL at age 1+, 75-112 mm at age 2+, and 96-122 mm at age 3+.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Annual and semi-monthly river trawl catch, adjusted for effort - hogchoker.
	Figure 86



PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ARTIFICIAL ISLAND STUDIES

Figure 86 - (continued)

Threatened and Endangered Species

The shortnose sturgeon (Acipenser brevirostrum) is the only threatened or endangered species listed in the Federal Register that is known to occur within the Delaware River Estuary. However, no specimens of the shortnose sturgeon were taken during the present study.

Based on their abundance and/or commercial and recreational importance both within the Artificial Island area and throughout the estuary, blueback herring, alewife, American shad, bay anchovy, white perch, striped bass, weakfish, spot, and Atlantic croaker were selected as target species for further study during operation of SNGS. Future studies will attempt to estimate population levels, determine distribution and movement patterns, and assess involvement of each species with Salem.

Community Discussion

The ichthyofaunal community of the Delaware River near Artificial Island is a diverse assemblage of 92 species, which on the basis of life strategy can be divided into two distinct groups of 41 resident and 51 migratory forms. Residents can be further classified by general salinity preference as tidal-freshwater or estuarine residents. The migratory group can be divided on the basis of extent or type of movements into three groups of 10 diadromous species, 10 estuarine-dependent marine types, and 31 marine visitors. The dominant resident species have been estuarine residents, namely bay anchovy, hogchoker, Atlantic and tidewater silversides, naked goby, and mummichog; the tidal-freshwater resident silvery minnow also has been common. Dominant migratory species have been the estuarine-dependent weakfish, spot, Atlantic croaker, and Atlantic menhaden and the diadromous eel, white perch, blueback herring, and alewife.

Large seasonal variation in physicochemical conditions, most notably water temperature and salinity, and productivity at lower trophic levels are paralleled by changes in composition, abundance, and distribution of the region's ichthyofauna. Within the community mechanisms have evolved which allow the efficient, and obviously scheduled, utilization of habitat and resources. These are manifested through differences in timing and location of spawning and the subsequent recruitment to this area of early life stages, and habitat and feeding behavior of all stages.

Within each season, but to a perhaps lesser extent in winter, constant patterns of immigration and emigration are apparent, all keyed to optimal utilization of available resources. This cyclic pattern of community transition is perhaps the key to an overall stability and harmony which is reflected in annual similarity. During spring and fall major changes in water temperature and salinity prompt shifts in community composition as species adjust their distributions to seek preferred reproductive, nursery or overwintering conditions. As temperature and salinity stabilize so does the community, with many species utilizing the warm, highly productive summer period for reproduction and growth; only a few reside in this area during the cold period.

In spring, species variety increases with water temperature; estuarine residents move from downbay overwintering areas, anadromous species migrating from offshore waters, move through this region to freshwater spawning grounds, and progeny of several estuarine-dependent marine fish migrate or are transported to the local low salinity nursery areas. Adult bay anchovy, Atlantic silverside, hogchoker, and white perch typically arrive in the study area from downbay in March and April to feed in preparation for spawning later. Mummichog, among the few fish to overwinter locally, become active in the shore zone as they too prepare for spawning. The anadromous striped bass, American shad, blueback herring, and alewife pass through the study area enroute to spawn grounds upstream and/or in local tributaries, and only remain in the vicinity of the salt-freshwater interface only during final in osmoregulation. Larvae and young of the ocean spawning, but estuarine-dependent Atlantic menhaden and spot, which have been entering the lower estuary through winter, appear locally as early as March as temperature rises above lower lethal levels and local productivity increases to levels necessary for larval and juvenile growth.

During May, as the locally feeding adult bay anchovy and hogchoker reach spawning condition they begin to move back downbay to higher salinity spawning grounds; this continues through summer as younger specimens progressively mature in local waters. Adults of the estuarine-dependent weakfish, which have entered the Bay from offshore, and of the resident naked goby, also begin spawning downbay. By mid-June progeny of all these species typically have moved into the low salinity nursery grounds near Artificial Island. Their local abundance increases concurrent with salinity and remain high through summer. However young of the spot and Atlantic menhaden prefer less saline water, and their local abundance decreases as they follow the movement of the oligohaline portion of the nursery (0.5-5 ppt) upstream.

By early to mid-July eggs and larvae recently spawned near Artificial Island or transported from downbay peak in number, and together with older cohorts produced earlier and downbay comprise most of the local ichthyofaunal community. Year-class strength is evidenced during July through September as spawning activity slows and young of the dominant species of the summer community reach peaks in annual abundance.

Abundance declines during late September, October, and November as decreasing water temperature and productivity initiate emigration to overwintering areas downbay and/or off shore. Lowering water temperature also prompts the gradual movement of spot, Atlantic menhaden, and river herrings through the area from upriver nursery grounds to oceanic overwintering areas. Perhaps more in response to lowering salinity than temperature, white perch also move into the area from upriver in the fall. Conversely, progeny of the ocean-spawning, but estuarine-dependent Atlantic croaker migrate into the area during the fall and utilize it as a nursery until minimum water temperature (January or February) prompt their return to downbay and warmer water. During winter, variety within the local ichthyofaunal community is low; only white perch, hogchoker, and silvery minnow are common. Low water temperature limits activity as metabolism slows and restricts the distribution of these fish to the deeper waters.

Just as patterns of immigration and emigration partition resources temporally for species which occupy similar niches, the efficient allocation for species which occur simultaneously is accomplished by species specific preferences for habitat type and food. During spring and summer, for example, the community consists of demersal species, i.e., spot, hogchoker and weakfish; shore zone inhabitants, i.e., Atlantic silverside and mummichog; and open water pelagic forms, i.e., Atlantic menhaden and bay anchovy. Among species with generally similar habitat preferences, partitioning may be effected through their food selectivity. For example, although spot and hogchoker are both bottom feeders, spot feed principally on epifaunal crustaceans while hogchoker feed primarily on infaunal annelids. Bay anchovy and Atlantic menhaden are both pelagic planktivores; however, the difference in coincident life stages may limit direct competition for food organisms. Partitioning also may be accomplished through subtle preferences within general habitat types. For example, both Atlantic silverside and mummichog occur within the shore zone habitat, but exhibit preferences to sand and mud substrates, respectively.

THE OLIGO-MESOHALINE REACH OF THE DELAWARE RIVER ESTUARY, A SYNOPSIS

The dynamic nature of the physicochemical conditions that characterize the oligo-mesohaline reach of the Delaware River Estuary, of which the study area is part, result in a variable and demanding aquatic environment. However, they also result in an abundance of food resources because, in this zone of transition between freshwater and the sea, the back-and-forth tidal activity enhances productivity by supplying food, nutrients, and oxygen. In addition, the attendant vertical mixing recycles and traps nutrients, sediments, detritus, and planktonic organisms. This great productive potential is utilized by a variety of animals which have adapted either through resilience or behavior to the physical stresses and which develop high population levels. The floral communities too, both the extensive marshland which lines the shore and the phytoplankton, form a food base suitable to a wide variety of animal life. As the previous pages evidence, large populations of planktonic and benthic invertebrates, and forage and predatory fishes thrive in this reach.

The effect of continuing but regular change in salinity, temperature, etc. on local biological structure is reflected in the seasonality of each major community composition, i.e., phytoplankton, zooplankton, benthos, and fishes. Within each year, many species utilize this reach of the Estuary. During seasons of high flow the local water mass has many freshwater characteristics, and the flora and fauna are typical of those found in the lower part of freshwater rivers. When flow is low and salinity relatively high the biota are generally brackish-water types with a few marine species.

Phytoplankton are the principal primary producers in this reach of the Estuary. The periphyton and submerged aquatic vascular plants, so often important in other aquatic systems, are not abundant in this highly turbid system and add little to local energetics. Plant detritus, the other major local source of primary energy, is transferred from the surrounding brackish tidal marsh to the river. The absolute value of phytoplankton versus detritus in the study area is not precisely known but seasonal importance can be inferred especially during winter when phytoplankton populations are low. The net result is that energy sources are abundantly available to a variety of particle consumers such as molluscs, zooplankton, larval and juvenile fish and invertebrates, and adult filter-feeding fish.

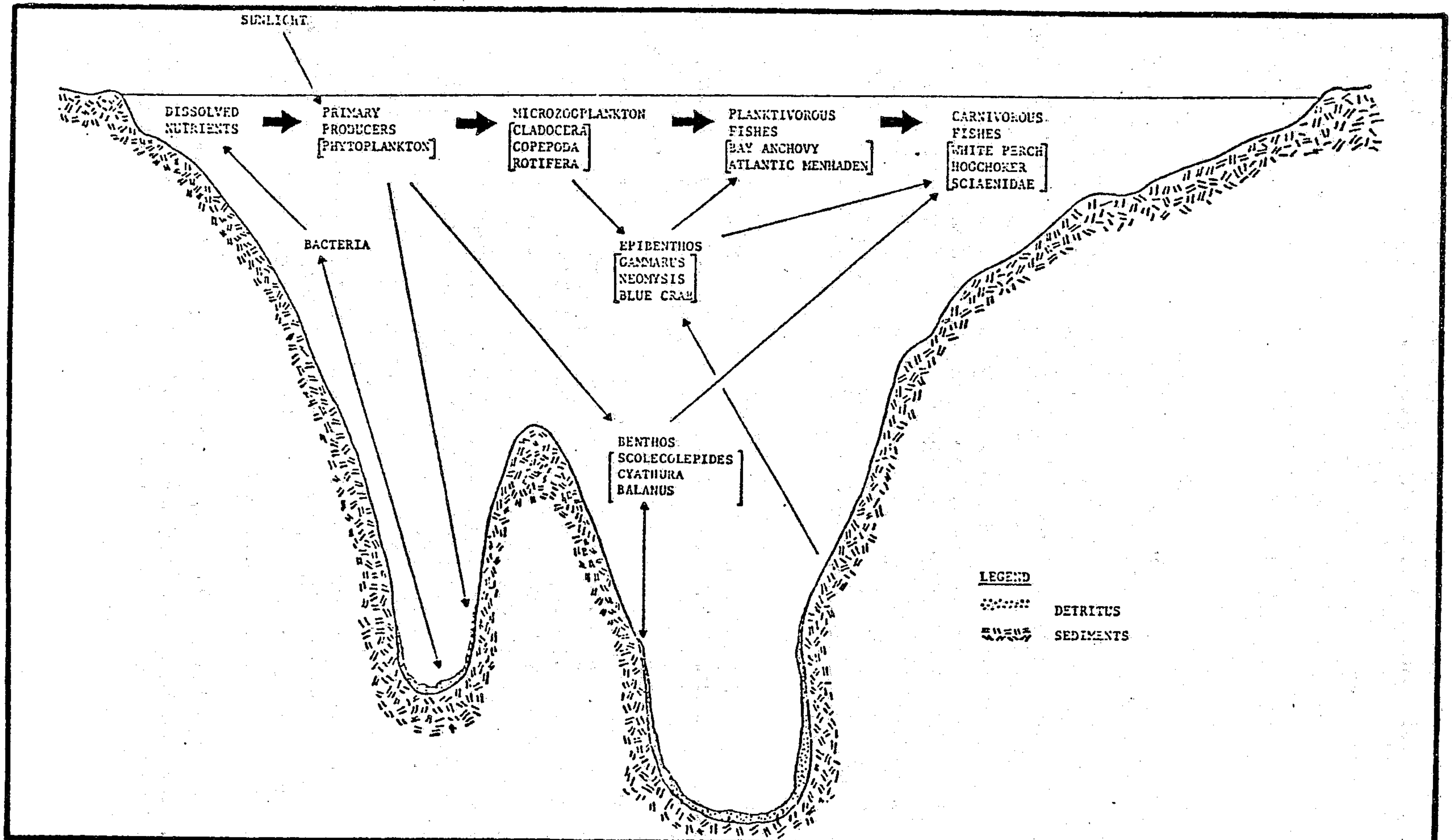
Most of the consumers in this low salinity reach of the Estuary are opportunistic, as opposed to selective, feeders.

Their feeding habits vary with life stage, season, locality and changing abundance of the major food species. This adaptability is essential to success since the types and numbers of prey available fluctuate greatly with season and salinity. Many consumer species function at more than one trophic level and local food web relationships are quite complex. For illustrative purposes, a simplified food web highlighting the major food pathways for the Delaware River near Artificial Island is presented in Figure 87. In addition to its function as a source of food for fishes and invertebrates, this reach is also important as a passageway for migratory fishes.

Perhaps the most conspicuous biotal feature of an oligo-mesohaline environment such as the study area is the large populations of a few highly productive species within each trophic level. Generally it is the euryhaline, eurythermal species, i.e., the most tolerant of change, which are annually dominant, account for the bulk of the biomass, and transfer the most energy. Species well adapted to the rigors of this environment, especially to abrupt changes in salinity, and representative of the major trophic levels include the diatom, Skeletonema costatum; the copepods, Eurytemora affinis and Acartia tonsa; the mysid shrimp, Neomysis americana; the polychaete, Scolecolepides viridis; and the fishes, Anchoa mitchilli, Morone americana, and Cynosion regalis.

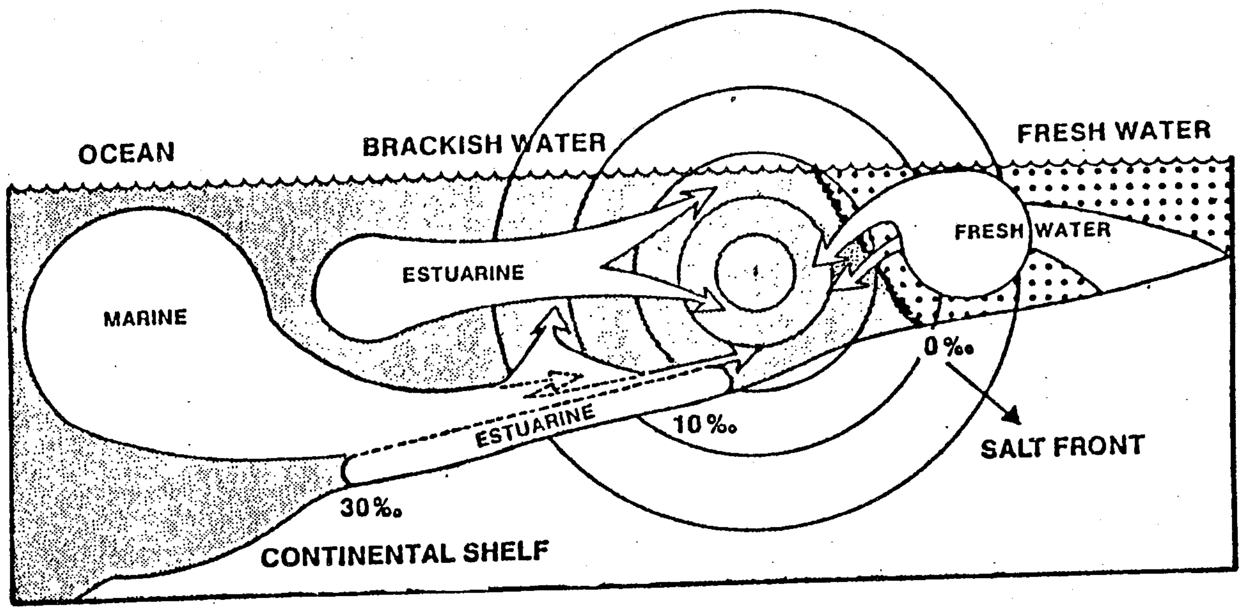
The highly productive low salinity reach of the Delaware River Estuary is important to the fisheries resources, particularly as a feeding and nursery area for the young of many species. Into this region come the eggs and larvae from fresh, estuarine, and marine spawners (Fig. 88). The low salinity waters are accepted as an amalgam of essential conditions for early development of a wide variety of fishes. Since relatively few species are resident in the low salinity estuary throughout the year vacant niches become available to a succession of young fishes. The arrival of these in this area coincide with periods of maximum food production (late spring and summer). Higher water temperature during spring and summer than in areas further south in the Bay probably results in faster local growth. The relatively high turbidity of this reach can only offer greater protection to these vulnerable young, at least from sight-orienting predators. Also, there are fewer predatory species in the low salinity nursery area than in higher salinity regions downbay.

In summary, the plentiful food resources, available habitats, and nursery and passage functions of this reach make the oligo-mesohaline zone a most vital component of the total estuarine system.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Simplified food web for the Delaware River Estuary - RK 80, RM 50. Figure 87

216



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Movement of estuarine-dependent fish larvae toward a common low salinity nursery ground. (After Cronin and Mansueti, 1971). Figure 88

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APPENDIX A

AN ANNOTATED CHECKLIST OF THE ESTUARINE INVERTEBRATES OF THE DELAWARE RIVER NEAR ARTIFICIAL ISLAND, NEW JERSEY

The invertebrate community of the lower Delaware Bay area has been extensively studied, inventoried, and described (Deevey, 1960; Cronin et al., 1962; Watling and Maurer, 1972; Watling et al., 1974; Kinner et al., 1975; etc.). The purpose of this checklist is to record occurrence, period of abundance, physicochemical range, and, where data permit, length range of invertebrate taxa taken in the low salinity (oligo-mesohaline) reach of the Delaware River Estuary between RK 68 (RM 42) and RK 97 (RM 60) during 1971 through 1976. This checklist is a compilation of data reported in the Artificial Island Ecological Study annual Progress Reports (Schuler, 1974-1977).

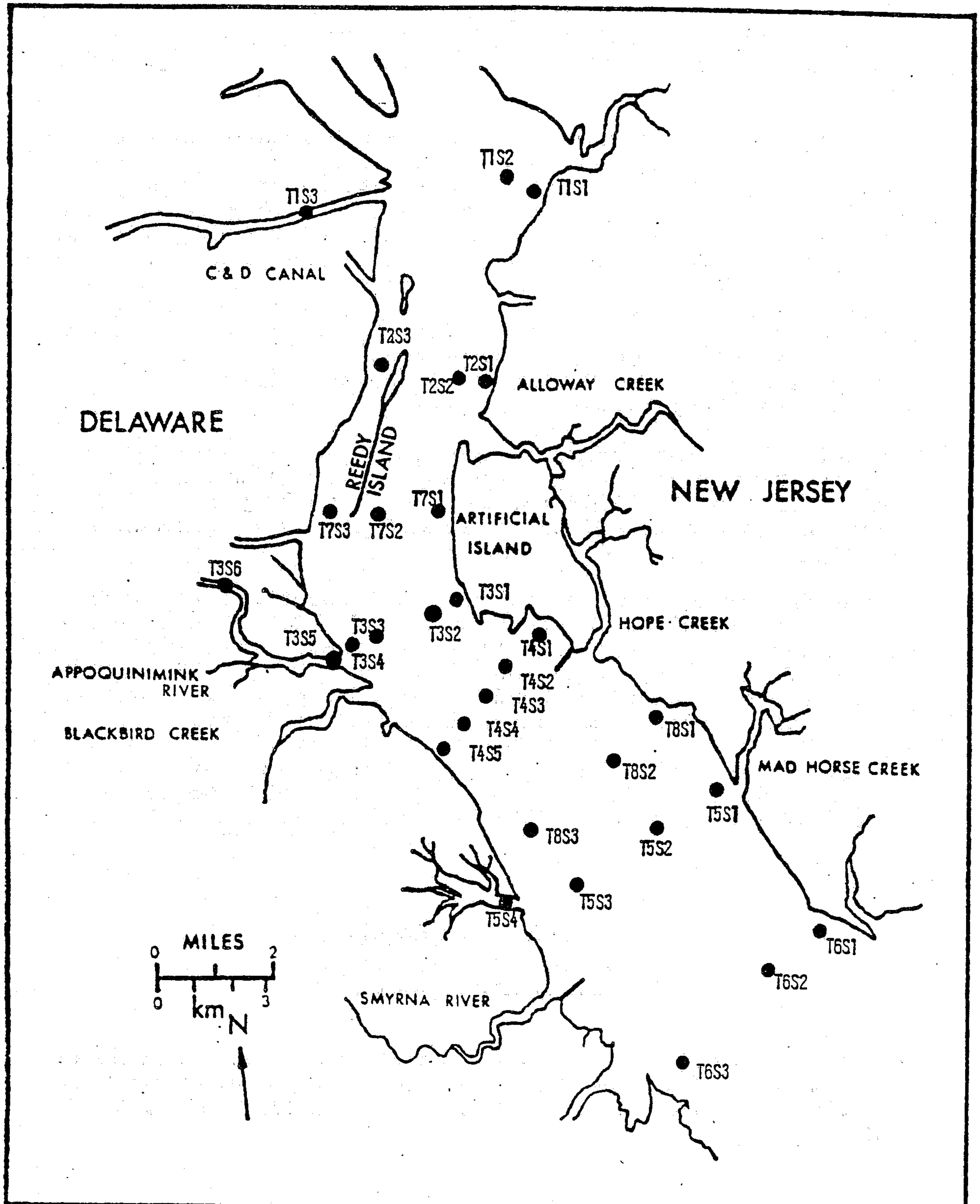
A total of 203 invertebrate taxa were identified in 6,931 samples taken from 1971 through 1976. Of the total sample, crustaceans comprised 43 percent, rotifers 22 percent, molluscs 7 percent, and polychaetes 6 percent. Sixteen major groups comprised 22 percent.

In the following, taxa are listed phylogenetically and data (where available) are given in order of: Scientific name - Common name. Life habit; temperature range; salinity range; months of occurrence; station occurrence (Figs. 1-3); and length range. Relative abundance is defined and, as data permit, the inferred period of abundance is listed.

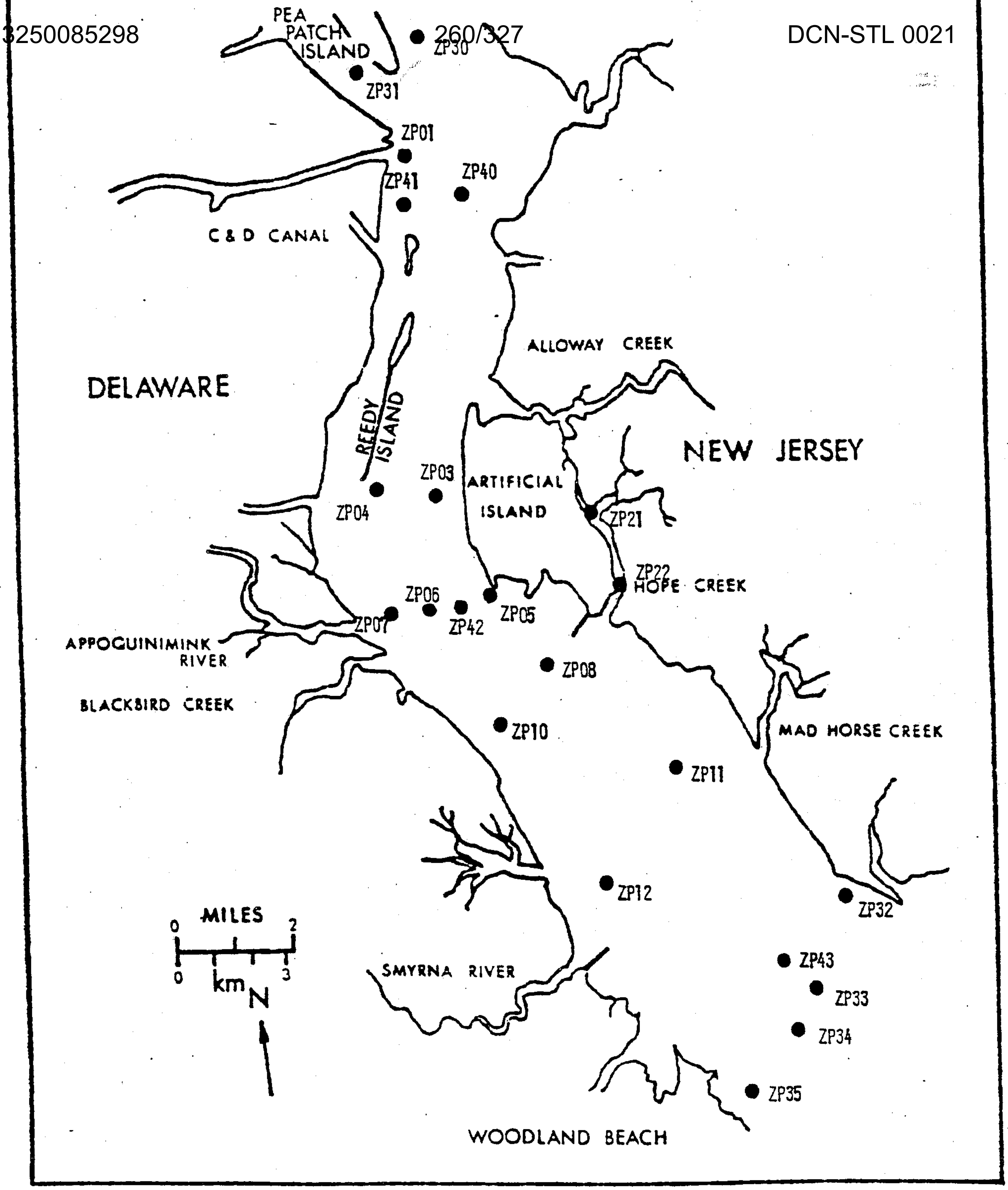
Principal references consulted for phylogenetic arrangement include: Wilson, 1932; Ward and Whipple, 1959; Gosner, 1971, 1979; Wass et al., 1972; and Ruttner-Kolisko, 1974.

PHYLUM PORIFERA
Order Poecilosclerida
Family Microcionidae

Microciona prolifera (Ellis and Solander, 1786) - Red beard sponge. Benthic; 2.0-28.0 C; 0.0-16.5 ppt; Jan.-Dec.; T1S2, T2S2, T3S1-3, T4S1-5, T5S2, T5S3, T6S1, T6S2, T7S1-3, T8S2, T8S3. Uncommon.

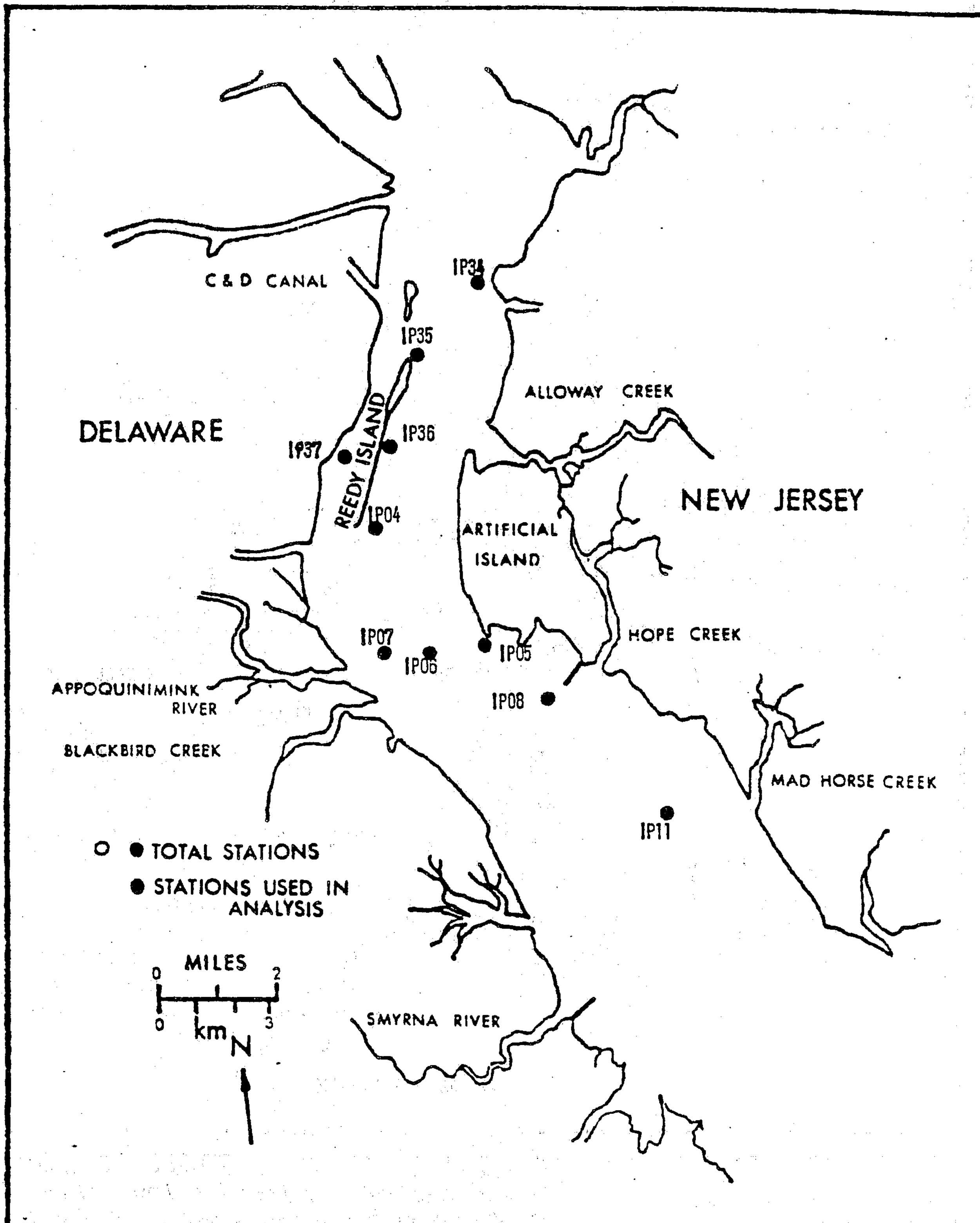


PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Stations at which benthos was sampled, 1971-1976 (not all stations sampled in each year).
	Figure A1



Station at which microzooplankton was sampled, 1973-1976 (not all stations sampled in each year).

Figure A2



PUBLIC SERVICE ELECTRIC AND GAS COMPANY ARTIFICIAL ISLAND STUDIES	Station at which macroinvertebrate plankton was sampled, 1973-1976 (not all stations sampled in each year).
	Figure A3

PHYLUM CNIDARIA
Class Hydrozoa

Hydroid. Benthic; 2.1-6.2 C; 5.0-9.0 ppt; Nov., Dec.; T5S1, T5S2. Four specimens during 1976.

Order Athecata
Family Moerisiidae

Moerisia lyonsi Boulenger, 1908 - Hydromedusa. Planktonic; 20.0-23.0 C; 7.7-10.2 ppt; Aug.-Oct.; IP06, 11. Uncommon.Oligo- and mesohaline (Wass et al., 1972).

Family Clavidae

Cordylophora caspia (Pallas, 1771) - Hydroid. Benthic; 3.5-27.9 C; 0.0-6.0 ppt; Feb., April-Sept., Nov.; T1S2, T2S2, T3S1, T3S2, T3S5, T3S6, T8S2. Rare to uncommon.

Family Bougainvilliidae

Bougainvillia spp. - Hydromedusa. Planktonic; 20.0-25.2 C; 1.0-9.0 ppt; June-Sept.; IP05, 06, 11, 34. Probably rare, identified only during 1974. Meso- to polyhaline (Wass et al., 1972).

Garveia franciscana (Torrey, 1902) - Hydroid. Benthic; 1.8-29.9 C; 0.0-17.0 ppt; Jan.-Dec.; T1S1-3, T2S1-3, T3S1-6, T4S1-5, T5S1-4, T6S1-3, T7S1-3, T8S1-3. Common.

Nemopsis bachei L. Agassiz, 1849 - Hydromedusa. Planktonic; 17.2-30.0 C; 1.0-12.0 ppt; May-Oct.; IP04-06, 11, 34; 1-9 mm. Rare to uncommon. Very euryhaline (Wass et al., 1972).

Order Thecata
Family Campanulariidae

Hartlaubella gelatinosa (Pallas, 1766) - Hydroid. Benthic; 2.0-28.5 C; 0.0-16.5 ppt; Jan.-Dec.; T1S1-3, T2S1-3, T3S1-3, T4S1-5, T5S2-4, T6S1-3, T7S1-3, T8S1-3. Uncommon.

Phialidium spp. - Hydromedusa. Planktonic; 11.8-29.0 C; 2.0-12.0 ppt; July-Oct.; IP05, 06, 08, 11, 34, 35. Probably uncommon, identified only during 1974.

Family Lovenellidae

Blackfordia virginica Mayer, 1910 - Hydromedusa. Planktonic; 2.0-30.2 C; 2.0-12.0 ppt; July-Oct., Dec.; IP04-07, 11, 34, 37; 1-21 mm. Common to very abundant. Greatest density during August-September. Typically the dominant hydromedusa near Artificial Island, it may be an important local copepod predator. It was often observed below the 7.6 ppt salinity minimum reported by Cronin et al. (1962).

Family Sertulariidae

Sertularia argentea Linnaeus, 1758 - Hydroid. Benthic; 1.8-29.9 C; 0.0-17.0 ppt; Jan.-Dec.; T1S1-3, T2S1-3, T3S1-6, T4S1-5, T5S1-4, T6S1-3, T7S1-3, T8S1-3. Common.

Order Trachymedusae
Family Geryonidae

Liriope sp. - Hydromedusa. Planktonic; 20.0 C; 5.0 ppt; Sept.; IP05. One specimen during 1974.

Class Scyphozoa
Order Semaeostomae
Family Ulmaridae

Aurelia aurita (Linnaeus, 1758) - Moon Jelly. Planktonic; 21.5 C; 6.0 ppt; Sept.; IP34. One specimen during 1973. Typically at above 16 ppt salinity (Gosner, 1979).

Class Anthozoa
Order Actiniaria
Family Diadumenidae

Diadumene leucolena (Verrill, 1866) - Ghost anemone. Benthic; 2.0-26.6 C; 0.0-10.7; Jan., Feb., April, Aug.-Dec.; T3S3, T4S2, T4S3, T5S1-3, T6S3, T8S2. Rare to uncommon. More abundant near Ship John Shoal (Annual Progress Report, 1974) and further south in Delaware Bay (Maurer and Watling, 1973).

PHYLUM CTENOPHORA

Although observed annually in substantial numbers during late summer-early fall, quantitative measurement of abundance and range of physicochemical parameters was limited due to specimen fragility. Voracious predators, ctenophores may be important in the reduction of copepod and larval fish populations (Gosner, 1971; 1979).

Class Tentaculata
Order Cydippida
Family Pleurobrachiidae

Pleurobrachia pileus Vanhoffen - Sea gooseberry. Planktonic; 7.1-7.5 C; 11.9-14.0 ppt; Nov.; ZP43. Rare. Taken only during 1971. Typically marine, it serves as a food source for several fishes (Gosner 1971; 1979).

Order Lobata
Family Mnemiidae

Mnemiopsis leidyi A. Agassiz, 1865 - Comb jelly. Planktonic; 24.8-29.0 C; 4.0-11.5 ppt; July-Aug; IP05, 06, 11, 35. Subject to predation by Beroe. Meso- to euhaline (Wass et al., 1972).

Class Nuda
Order Beroida
Family Beroidae

Beroe ovata Chamisso and Eysenhardt, 1821 - Comb jelly. Planktonic; 18.9-25.0 C; 4.0-11.0 ppt; Sept.-Oct.; IP05-07, 11. Upper meso- to polyhaline (Wass et al., 1972).

PHYLUM PLATYHELMINTHES
Class Turbellaria

Flatworms. Benthic, planktonic; 1.8-28.2 C; 0.0-12.0 ppt; Jan.-Dec.; T2S1, T2S2, T3S1-4, T4S1-3, T5S1, T5S2 T7S1, T7S2, T8S1-3, ZP05, 11, 12; 1-2 mm. Abundant among benthos in sand substrate; uncommon in others. Rare in microzooplankton. Greatest density in May, in benthos. They are lower order turbellarians (Gosner, 1971).

Order Polycladida
Family Stylochidae

Stylochus ellipticus (Girard, 1850) - Oyster flatworm. Benthic; 2.0-27.2 C; 0.0-13.1 ppt; Jan, May-Dec.; T2S2, T3S5, T4S1-5, T5S2, T5S3, T6S3, T7S3, T8S1-3; 0.5-8.0 mm. Uncommon. Greatest density during June-November. Often found in empty barnacle shells.

Family Leptoplanidae

Euplana gracilis (Girard, 1850) - Slender flatworm. Benthic; 2.0-22.6 C; 5.0-12.0 ppt; Sept.,Oct.,Dec.; 0.4-2.0 mm; T3S5, T4S2, T5S2. Rare.

PHYLUM RHYNCHOCOELA

Nemertean Worms. Benthic, planktonic; 1.8-29.0 C; 0.0-12.0 ppt; Jan.-Dec.; T1S1, T1S2, T2S1-3, T3S1-6, T4S1-5, T5S1-4, T6S1-3, T7S1-3, T8S1-3, IP05, 07; 2.0-72.0 mm. Common in benthos; rare in macroinvertebrate plankton. Greatest density during August-October, in benthos.

PHYLUM ASCHELMINTHES
Class Rotifera

"Rotifer" spp. - Wheel animals. Planktonic; 0.1-29.5 C; 0.0-17.8 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Very abundant. Greatest density during December-May. An artificial taxon describing rotifers that contract upon preservation. Detailed information in species discussion section.

Rotifer "A". Planktonic; 1.8-30.0 C; 0.0-11.0 ppt; Feb., May-Dec.; ZP01, 03-08, 10-12, 21, 22, 30, 31, 34, 35, 40, 41, 43. Abundant. Greatest density during May-June.

Order Bdelloidea

Planktonic; 1.5-20.0 C; 0.0-11.5 ppt; May, Oct., Dec.; ZP01, 03, 05, 07, 11, 33. Uncommon. Primarily benthic (Ruttner-Kolisko, 1974).

Family Philodinidae

Rotaria sp. Scopoli. Planktonic; 0.1-27.9 C; 0.0-5.5 ppt; Jan.-May, Aug.-Dec.; ZP01, 05-07, 10, 31, 35, 40. Uncommon.

Order Monogononta

Planktonic; 0.7-9.6 C; 0.0-10.0 ppt; Feb.-April, Nov.; ZP01, 03-08, 12. Uncommon.

Family Brachionidae

<u>Notholca</u> spp. (Gosse, 1886). Planktonic; 0.0-28.4 C; 0.0-14.0 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Abundant. Greatest density during January-May.

<u>Keratella</u> spp. (Bory de St. Vincent, 1822). Planktonic; 0.0-31.0 C; 0.0-14.0 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-32, 34, 35, 40, 41, 43. Common. Greatest density in May.

<u>Keratella valga</u> (Carlin). Planktonic; 1.2-30.0 C; 0.0-17.8 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30, 31, 35, 40, 41, 43. Common. Greatest density during May-July.

<u>Keratella serrulata</u> (Ehrenberg, 1838). Planktonic; 2.0-26.6 C; 0.0-8.8 ppt; Jan., Mar., Aug., Dec.; ZP05-07, 10. Uncommon.

<u>Keratella quadrata</u> (Muller, 1786). Planktonic; 0.0-27.3 C; 0.0-13.0 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Common. Greatest density in May.

<u>Brachionus</u> spp. (Pallas, 1776). Planktonic; 1.7-21.2 C; 0.0-6.0 ppt; Feb.-April, Aug.-Oct.; ZP01, 03-06, 11, 31, 40, 41.

<u>Brachionus calyciflorus</u> (Pallas, 1766). Planktonic; 0.0-29.5 C; 0.0-17.8 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Abundant. Greatest density during March-May.

<u>Brachionus angularis</u> (Gosse, 1851). Planktonic; 0.1-31.0 C; 0.0-14.0 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Abundant. Greatest density during May-July.

<u>Brachionus variabilis</u> (Hempel, 1896). Planktonic; 3.0-26.4 C; 0.0-8.5 ppt; Jan.-June, Aug., Oct.-Dec.; ZP03-07, 10-12, 21, 30, 31, 40, 41. Common. Greatest density during April-May. Most in surface samples.

<u>Brachionus rubens</u> (Ehrenberg, 1838). Planktonic; 4.1-5.8 C; 0.0 ppt; Feb.; ZP05, 06. Probably rare, identified only during 1975.

<u>Brachionus bidentatas</u> (Andersen, 1889). Planktonic; 21.2-24.5 C; 0.0-4.0 ppt; May-June; ZP01, 07. Uncommon.

<u>Brachionus caudatus</u> (Barrois, 1894). Planktonic; 1.5-31.0 C; 0.0-12.3 ppt; Feb.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-32, 34, 35, 40, 41, 43. Common. Greatest density during May-July. In 1976, greatest density in September.

Brachionus urceolaris (Muller, 1773). Planktonic; 1.9-29.0 C; 0.0-9.0 ppt; Feb.-Aug., Oct.-Dec.; ZP01, 03-08, 10, 12, 21, 31, 40. Common. Greatest density during April-May.

Brachionus budapestinensis (Daday, 1885). Planktonic; 22.8-25.6 C; 0.0-2.5 ppt; Feb., July-Aug.; ZP04, 06, 07, 30, 31. Rare to uncommon. Most in bottom samples.

Brachionus diversicornis (Daday, 1883). Planktonic; 17.0-27.0 C; 0.0-4.2 ppt; May-Aug.; ZP06, 07, 30, 31, 40. Rare to uncommon.

Brachionus havanaensis (Rousselet, 1911). Planktonic; 8.4-31.0 C; 0.0-7.8 ppt; May-Nov.; ZP01, 04-07, 30, 31, 40, 41. Uncommon. Greatest density in May, June, or July. Most in surface samples.

Brachionus plicatilis (Muller, 1786). Planktonic; 3.0-25.6 C; 0.0-12.0 ppt; Jan., April-Aug., Oct.; ZP01, 05-07, 30, 31, 35, 41. Uncommon to Rare.

Brachionus pterodinoides (Rousselet, 1913). Planktonic; 2.5-16.2 C; 0.0-2.0 ppt; Mar., Oct., Dec.; ZP01, 04-06, 11. Rare.

Brachionus quadridentatus (Hermann, 1783). Planktonic; 3.0-26.8 C; 0.0-5.5 ppt; Jan.-Dec.; ZP01, 03-07, 10, 30, 32, 40, 41. Common. Greatest density during May-July and September-October.

Brachionus leydigii (Cohn, 1862). Planktonic; 8.5-9.0 C; 0.0 ppt; Oct.; ZP05. Probably rare, identified only during 1976.

Brachionus patulus (Wulfert, 1965). Planktonic; 3.5-28.5 C; 0.0-3.0 ppt; Jan., Feb., June-July; ZP01, 03, 05-07, 40, 41, 43. Uncommon. Most in surface samples.

Kellicottia spp. (Ahlstrom, 1938). Planktonic; 4.5-9.0 C; 0.0-3.0 ppt; Jan., May; ZP07. Rare.

Kellicottia bostoniensis (Rousselet, 1908). Planktonic; 0.1-28.5 C; 0.0-12.0 ppt; Jan.-Dec.; ZP01, ZP03-08, 10-12, 21, 22, 30-35, 40, 41. Common. Greatest density during April-May.

Kellicottia longispina (Kellicott, 1879). Planktonic; 1.6-24.5 C; 0.0-6.0 ppt; Feb.-June, Oct.-Dec.; ZP01, 03-08, 10-12, 21, 30-35, 40, 41. Uncommon to common. Greatest density during March-May.

Platyias sp. (Harring, 1913). Planktonic; 25.6 C; 1.2 ppt; June; ZP05. Rare.

Platyias quadricornis (Ehrenberg, 1832). Planktonic; 6.0 C; 2.0 ppt; March; ZP11. Probably rare, identified only during 1975.

Trichotria sp. (Bory de St. Vincent, 1827). Planktonic; 2.6-27.3 C; 0.0 ppt; June, Dec.; ZP03, 07, 30. Rare.

Colurella sp. (Bory de St. Vincent, 1824). Planktonic; 21.0 C; 1.0 ppt; May; ZP05. Probably rare, identified only during 1974.

Family Synchaetidae

Polyarthra spp. (Ehrenberg, 1834). Planktonic; 0.1-28.0 C; 0.0-9.0 ppt; Jan.-July, Sept.-Dec.; ZP01, 03-08, 11, 12, 21, 30, 31, 35, 40, 41, 43. Uncommon. Greatest density during April-June.

Synchaeta spp. (Ehrenberg, 1832). Planktonic; 7.8-23.5 C; 0.0-6.0 ppt; May, Nov.-Dec.; ZP04-07, 21. Uncommon. Most in bottom samples.

Ploesoma spp. (Herrick, 1885). Planktonic; 9.1-29.5 C; 0.0-5.0 ppt; May-July, Oct.-Dec.; ZP01, 03-08, 10, 12, 22, 30, 31, 40, 41. Uncommon to common. Greatest density during May-June. Most in surface samples.

Family Lecanidae

Lecane spp. (Nitzsch, 1827). Planktonic; 2.4-27.2 C; 0.0-8.0 ppt; Jan., Feb., Aug.-Sept., Dec.; ZP01, 05-07, 32. Rare.

Monostyla sp. (Ehrenberg). Planktonic; 2.5-8.7 C; 0.0-7.0 ppt; Mar., Dec.; ZP05, 31. Rare.

Monostyla bulla. Planktonic; 1.9 C; 7.0 ppt; Dec.; ZP08. Probably rare, identified only during 1976.

Family Asplanchnidae

Asplanchna spp. (Gosse, 1850). Planktonic; 0.5-27.0 C; 0.0-8.0 ppt; Jan., April-July, Sept.-Oct.; ZP01, 03-08, 10-12, 22, 30-35, 40, 41, 43. Common. Greatest density during April-May.

Family Testudinellidae

Filinia sp. (Bory de St. Vincent, 1824). Planktonic; 0.1 C; 0.0 ppt; Jan.; ZP01. Rare.

Filinia longiseta (Ehrenberg, 1834). Planktonic; 0.1-28.0 C; 0.0-9.0 ppt; Jan.-Aug., Oct.-Dec.; ZP01, 03-08, 10, 11, 21, 22, 30, 31, 33, 34, 40, 41, 43. Common. Greatest density during April-June.

Family Dicranophoridae

Planktonic; 0.1-6.1 C; 0.0-2.0 ppt; Jan.-March; ZP01, 03, 05-07, 12. Rare.

Family Trichocercidae

Trichocerca spp. (Lamarck, 1801). Planktonic; 2.5-31.0 C; 0.0-5.0 ppt; May-July, Sept.-Oct., Dec.; ZP01, 03-07, 10. Uncommon. Most in surface samples.

Family Hexarthridae

Hexartha spp. (Schmarda, 1854). Planktonic; 14.9-27.3 C; 0.0-2.0 ppt; May-July, Nov.; ZP05-07. Rare.

PHYLUM GASTROTRICHA
Class Chaetenidea
Order Chaetonotoida
Family Chaetonotidae

Chaetonotus sp. (Ehrenberg, 1830). Planktonic; 2.5 C; 0.0 ppt; Dec.; ZP31. Probably rare, identified only during 1973.

PHYLUM NEMATODA

Roundworms. Planktonic; 0.2-28.0 C; 0.0-14.0 ppt; Jan.-Dec.; ZP01, 03-08, 10, 11, 21, 22, 30-35, 40, 41, 43. Common. Density variable, generally greatest February-June. Most in bottom samples.

PHYLUM ANNELIDA
Class Polychaeta

Bristleworms (adults). Planktonic; 1.4-30.0 C; 0.0-10.0 ppt; Jan.-Dec.; IP04-07, 11, 34-36. Common. Variable abundance throughout the year.

Bristleworms (eggs and larvae). Planktonic; 0.0-31.0 C; 0.0-17.2 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Abundant. Greatest density during September-December.

Order Phyllodocida
Family Phyllodocidae

Eteone heteropoda Hartman, 1951. Benthic; 2.3-27.0 C; 4.0-12.0 ppt; June-Dec.; T4S1-4, T5S1-3, T6S2, T6S3, T7S2, T8S1, T8S2; 2.0-10.0 mm. Rare to uncommon.

Family Nereidae

Laeonereis culveri (Webster, 1879). Benthic; 2.3-28.1 C; 0.0-13.0 ppt; Jan-April, June, July, Sept.-Dec.; 12.0-73.0 mm; T2S1, T4S1, T4S4, T8S1. Rare to uncommon. Generally taken only at shallow stations.

Nereis succinea (Frey and Leuckart, 1847). Benthic; 1.8-28.2 C; 0.0-13.0 ppt; Jan.-Dec.; T2S1-3, T3S1-6, T4S1-5, T5S1-4, T6S1, T6S3, T7S1-3, T8S1-3; 1.3-55.0 mm. Abundant. Greatest density at station with gravel shell substrate (T4S2).

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APPENDIX B

ANNOTATED CHECKLIST OF THE FISHES OF THE DELAWARE RIVER AND TIDAL TRIBUTARIES NEAR ARTIFICIAL ISLAND, NEW JERSEY

The fish community of the Delaware River Estuary has been studied and inventoried (Fowler, 1952; Daiber, 1954; de Sylva et al., 1962, Daiber and Smith, 1971; Wang and Kernehan, 1979), but much of this work was restricted to the Delaware Bay. This checklist enumerates the fishes taken by plankton net, seine, trawl, and gill net in the lower Delaware River and upper Bay (RK 61-97; RM 38-60) and local tidal tributaries (Appoquinimink Creek, Delaware; Alloway and Hope creeks, New Jersey). It presents data which characterize the occurrence of these fishes in this region with respect to seasonality, relative abundance, and habitat utilization. This checklist is a compilation of data previously reported in Annual Progress Reports of the Artificial Island Ecological Study (Schuler et al., 1971-1977).

This list includes 93 taxa (92 to species) of marine, estuarine, and freshwater fishes, most of which either occur as residents or utilize the region seasonally for nursery, feeding, and/or spawning activities. Several are anadromous and pass through the area to spawning grounds upriver. Others are strays which appear only during or after unusual environmental conditions.

Fishes are listed phylogenetically. The order and the scientific and common names are those found in "A list of common and scientific names of fishes from the United States and Canada" American Fisheries Society Special Publication No. 6, 1970. Each species account includes (when available) the following information: Scientific name - Common name. Basic habitat. Primary activity in area. Length range. By life stage - relative abundance; period of occurrence; temperature range at capture; salinity range at capture; general distribution (offshore (river), shore zone (river), tributaries). In certain cases, early life stages were not identified to species because of the absence of descriptive taxonomic information in the literature; these are listed by genus. Species discussed in the Fisheries Section within the main body of the report are indicated by "(see text)".

Order Petromyzontiformes
Family Petromyzontidae

Petromyzon marinus Linnaeus - Sea lamprey. Anadromous. Migratory. 130-914 mm. Young and adult - rare; March, April, June, December; 4.8-26.0 C; 0.0-3.0 ppt; offshore, tributaries.

Order Rajiformes
Family Myliobatidae

Rhinoptera bonasus (Mitchill) - Cownose ray. Marine, brackish. Stray. 600, 766 mm. Adult - rare; 26.0 C; 9.5 ppt; offshore.

Order Acipenseriformes
Family Acipenseridae

Acipenser oxyrhynchus Mitchill - Atlantic sturgeon. Anadromous. Migratory, nursery. 340-765 mm. Young - rare; March, May, June, September; 8.1-23.0 C; 0.0-6.0 ppt; offshore.

Order Anguilliformes
Family Anguillidae

Anguilla rostrata (Lesueur) - American eel. Catadromous. Migratory, summer feeder, nursery. 40-760 mm. Young and adult - common; January-December; 0.5-31.0 C; 0.0-15.0 ppt; offshore, shore zone, tributaries. (See text).

Family Congridae

Conger oceanicus (Mitchill) - Conger eel. Marine. Stray. 85 mm. Young - rare; June; 19.5 C; 4.0 ppt; shore zone.

Order Clupeiformes
Family Clupeidae

Alosa spp. Eggs - rare; April; 11.5-12.5 C; 0.0 ppt. Larvae - uncommon; April-July; 9.0-29.0 C; 0.0-12.0 ppt; 4-34 mm.

Alosa aestivalis (Mitchill) - Blueback herring. Anadromous. Migratory, spawning, nursery. 12-300 mm. Young and adult - common to abundant; January-December; 1.0-32.8 C; 0.0-12.0 ppt; offshore, shore zone, tributaries. (See Text).

Alosa mediocris (Mitchill) - Hickory shad. Anadromous. Migratory. 12-498 mm. Young and adult - rare to uncommon; March-August, October, November; 6.0-29.9 C; 0.0-9.5 ppt; offshore, shore zone, tributaries. (See Text).

Alosa pseudoharengus (Wilson) - Alewife. Anadromous. Migratory, spawning, nursery. 16-310 mm. Young and adult - common to abundant; January-December; 0.2-30.0 C; 0.0-14.0 ppt; offshore, shore zone, tributaries. (See Text).

Alosa sapidissima (Wilson) - American shad. Anadromous. Migratory. 39-580 mm. Young and adult - uncommon; March-June, October-December; 2.9-23.0 C; 0.0-12.0 ppt; offshore, shore zone, tributaries. (See Text).

Brevoortia tyrannus (Latrobe) - Atlantic menhaden. Marine, brackish, freshwater. Nursery, summer feeder. 19-365 mm. Larvae - common; March-June; 1.5-26.5 C; 0.0-8.0 ppt. Young and adult - abundant to very abundant; January, March-December; 4.9-32.0 C; 0.0-15.0 ppt; offshore, shore zone, tributaries. (See Text).

Clupea harengus harengus Linnaeus - Atlantic herring. Marine, brackish. Stray. 22-325 mm. Young and adult - rare; March-August; 3.0-26.4 C; 0.0-12.0 ppt; offshore.

Dorosoma cepedianum (Lesueur) - Gizzard shad. Freshwater, brackish. Resident. 5-337 mm. Larvae - rare; June; 22.2 C; 0.5 ppt. Young and adult - uncommon to common; January-December; 0.2-29.9 C; 0.0-10.5 ppt; offshore, shore zone, tributaries.

Family Engraulidae

Anchoa hepsetus (Linnaeus) - Striped anchovy. Marine, brackish. Stray. 55-105 mm. Young and adult - rare; August-October; 5.0-28.2 C; 5.0-10.0 ppt; offshore, shore zone.

Anchoa mitchilli (Valenciennes) - Bay anchovy. Estuarine. Summer feeder, spawning, nursery. 2-107 mm. Eggs - very abundant; May-October; 17.0-30.0 C; 0.0-13.0 ppt. Larvae - very abundant; May-December; 6.0-30.2 C; 0.0-15.0 ppt. Young and adult - very abundant; January-December; 0.6-32.0 C; 0.0-20.0 ppt; offshore, shore zone, tributaries. (See Text).

Order Salmoniformes
Family Umbridae

Umbra pygmaea (DeKay) - Eastern mudminnow. Freshwater. Stray. 64-89 mm. Adult - rare; February-April; 4.0-6.0 C; 0.0-4.0 ppt; shore zone.

Family Esocidae

Esox americanus americanus Gmelin - Redfin pickerel. Freshwater. Resident. 50-151 mm. Young and adult - rare; January, May-July, September; 4.3-27.1 C; 0.0-3.0 ppt; shore zone, tributaries.

Esox niger Lesueur - Chain pickerel. Freshwater. Resident. 40-457 mm. Young and adult - rare; May-September; 16.5-28.3 C; 0.0 ppt; tributaries.

Order Myctophiformes
Family Synodontidae

Synodus foetens (Linnaeus) - Inshore lizardfish. Marine, brackish. Stray. 32-195 mm. Young and adult - rare; June, August, September; 19.0-27.0 C; 6.0-12.0 ppt; offshore, shore zone.

Order Cypriniformes
Family Cyprinidae

Cyprinid spp. Larvae - uncommon; May-July; 19.1-29.0 C; 0.0-5.0 ppt; 3-9 mm.

Carassius auratus (Linnaeus) - Goldfish. Freshwater, brackish. Resident (introduced). 106-315 mm. Young and adult - rare; January-July, September, December; 4.6-29.4 C; 0.0-4.5 ppt; offshore, shore zone, tributaries.

Cyprinus carpio Linnaeus - Carp. Freshwater, brackish. Resident (introduced). 80-900 mm. Young and adult - common; January-December; 1.5-30.8 C; 0.0-10.5 ppt; offshore, shore zone, tributaries.

Hybognathus nuchalis Agassiz - Silvery minnow. Freshwater, brackish. Resident. 8-158 mm. Young and adult - common; January-December; 0.2-31.5 C; 0.0-9.5 ppt; offshore, shore zone, tributaries.

Notemigonus crysoleucas (Mitchill) - Golden shiner. Freshwater, brackish. Resident. 9-203 mm. Young and adult - rare to abundant; March-December; 0.9-31.5 C; 0.0-2.0 ppt; offshore, shore zone, tributaries.

Notropis analostanus (Girard) - Satinfin shiner. Freshwater. Resident. 19-81 mm. Young and adult - uncommon; February-December; 3.0-31.0 C; 0.0-2.0 ppt; tributaries.

Notropis hudsonius (Clinton) - Spottail shiner. Freshwater, brackish. Resident. 9-125 mm. Young and adult - rare to uncommon; March-November; 4.5-31.5 C; 0.0-10.0 ppt; shore zone, tributaries.

Semotilus atromaculatus (Mitchill) - Creek chub. Freshwater. Stray. 51 mm. Adult - rare (one specimen); February; 18.0 C; 0.0 ppt; tributaries.

Family Catostomidae

Catostomus commersoni (Lacépède) - White sucker. Freshwater. Resident. 157, 158 mm. Adult - rare; June, July; 21.0-25.7 C; 0.0-2.0 ppt; tributaries.

Erimyzon oblongus (Mitchill) - Creek chubsucker. Freshwater. Resident. 21 mm. Young - rare to uncommon; June, July; 21.0-26.0 C; 0.0 ppt; tributaries.

Order Siluriformes
Family Ictaluridae

Ictalurus catus (Linnaeus) - White catfish. Freshwater, brackish. Resident. 19-480 mm. Young and adult - uncommon to common; February-December; 2.1-31.5 C; 0.0-10.0 ppt; offshore, shore zone, tributaries.

Ictalurus nebulosus (Lesueur) - Brown bullhead. Freshwater, brackish. Resident. 32-375 mm. Larvae - rare; June; 18.6 C; 0.0 ppt. Young and adult - common; January-December; 0.5-30.0 C; 0.0-12.0 ppt; offshore, shore zone, tributaries.

Ictalurus punctatus (Rafinesque) - Channel catfish. Freshwater, brackish. Resident. 19-515 mm. Young and adult - uncommon to common; January-December; 2.5-30.0 C; 0.0-11.0 ppt; offshore, shore zone, tributaries.

Order Batrachoidiformes
Family Batrachoididae

Opsanus tau (Linnaeus) - Oyster toadfish. Estuarine. Summer feeder. 12-261 mm. Larvae - rare; October; 13.0-14.0 C; 5.5-8.5 ppt. Young and adult - uncommon; May-October; 17.0-29.5 C; 5.0-15.5 ppt; offshore.

Order Gadiformes
Family Gadidae

Merluccius bilinearis (Mitchill) - Silver hake. Marine, brackish. Stray. 45-99 mm. Young - rare; April, November; 4.8-12.5 C; 2.0-8.0 ppt; offshore.

Urophycis chuss (Walbaum) - Red hake. Marine, brackish. Nursery, spring feeder. 37-160 mm. Young - rare to uncommon; March-June; 3.0-19.8 C; 0.0-12.0 ppt; offshore.

Urophycis regius (Walbaum) - potted hake. Marine, brackish. Nursery, spring feeder. 38-196 mm. Young - rare to common; January, March-July, November; 1.3-26.0 C; 0.0-12.0 ppt; offshore, shore zone.

Family Ophidiidae

Rissola marginata (DeKay) - Striped cusk-eel. Marine, brackish. Summer feeder. 24-227 mm. Young and adult - rare to common; April-November; 3.0-30.0 C; 1.0-15.5 ppt; offshore, shore zone, tributaries.

Order Atheriniformes
Family Exocoetidae

Hyporhamphus unifasciatus (Ranzani) - Halfbeak. Marine, brackish. Stray. 38-44 mm. Young - rare; June; 24.7-25.0 C; 4.0-7.0 ppt; shore zone.

Family Belonidae

Strongylura marina (Walbaum) - Atlantic needlefish. Marine, brackish, freshwater. Summer feeder. 48-390 mm. Young and adult - rare to uncommon; June-September; 20.0-31.5 C; 0.0-11.0 ppt; offshore, shore zone, tributaries.

Family Cyprinodontidae

Cyprinodon variegatus Lacépède - Sheepshead minnow. Estuarine. Summer feeder. 28-49 mm. Young and adult - rare; April, June, October-December; 4.1-20.0 C; 0.0-9.5 ppt; shore zone, tributaries.

Fundulus spp. Eggs - rare; May; 16.9 C; 1.0 ppt. Larvae - rare to common; May-August; 16.1-29.0 C; 0.0-8.0 ppt; 7.0 mm.

Fundulus diaphanus (Lesueur) - Banded killifish. Brackish, freshwater. Resident. 9-108 mm. Young and adult - common to abundant; January-December; 1.0-31.0 C; 0.0-10.0 ppt; shore zone, tributaries.

Fundulus heteroclitus (Linnaeus) - Mummichog. Estuarine. Resident. 9-108 mm. Young and adult - common to abundant; January-December; 0.2-32.0 C; 0.0-15.0 ppt; offshore, shore zone, tributaries. (See Text).

Fundulus majalis (Walbaum) - Striped killifish. Estuarine. Summer feeder. 17-182 mm. Young and adult - rare to uncommon; March-December; 4.0-32.8 C; 0.0-10.5 ppt; offshore, shore zone, tributaries.

Lucania parva (Baird) - Rainwater killifish. Estuarine. Summer feeder. 26-29 mm. Young and adult - rare; July, October; 13.3-26.7 C; 0.0-8.5 ppt; shore zone.

Family Poeciliidae

Gambusia affinis (Baird and Girard) - Mosquitofish. Brackish, freshwater. Resident. 20-22 mm. Adult - rare; July, October; 15.0-31.0 C; 0.0 ppt; tributaries.

Family Atherinidae

Membras sp./Menidia spp. Eggs - uncommon; May-August; 18.0-27.8 C; 0.0-8.0 ppt. Larvae - common; May-September; 17.2-30.0 C; 0.0-13.0 ppt; 3-18 mm.

Membras martinica (Valenciennes) - Rough silverside. Estuarine. Summer feeder. 14-105 mm. Young and adult - uncommon to common; May-October; 12.8-32.8 C; 0.0-9.5 ppt; offshore, shore zone, tributaries. (See Text).

Menidia beryllina (Cope) - Tidewater silverside. Estuarine. Resident. 10-100 mm. Young and adult - common to abundant; January, March-December; 0.2-31.0 C; 0.0-20.0 ppt; offshore, shore zone, tributaries. (See Text).

Menidia menidia (Linnaeus) - Atlantic silverside. Estuarine. Resident. 10-125 mm. Young and adult - very abundant; January-December; 0.2-32.8 C; 0.0-15.0 ppt; offshore, shore zone, tributaries. (See Text).

Order Gasterosteiformes
Family Gasterosteidae

Apeltes quadracus (Mitchill) - Fourspine stickleback. Estuarine. Winter feeder. 34-48 mm. Adult - rare; February-May; 6.0-22.5 C; 0.0-2.0 ppt; shore zone, tributaries.

Gasterosteus aculeatus Linnaeus - Threespine stickleback. Anadromous. Winter feeder. 21-70 mm. Larvae - rare; May; 16.1 C; 2.0 ppt. Young and adult - rare to uncommon; January-May; 2.0-19.1 C; 0.0-6.0 ppt; offshore, shore zone, tributaries.

Family Syngnathidae

Hippocampus erectus Perry - Lined seahorse. Marine, brackish. Stray. Adult - rare (one specimen); April; 5.5 C; 8.0 ppt; offshore.

Syngnathus fuscus Storer - Northern pipefish. Estuarine. Nursery, summer feeder. 11-220 mm. Larvae - uncommon; June - August; 21.0-27.3 C; 4.0-12.0 ppt. Young and adult - uncommon to common; April-December; 5.9-29.5 C; 0.0-17.0 ppt; offshore, shore zone, tributaries.

Order Perciformes
Family Percichthyidae

Morone americana (Gmelin) - White perch. Anadromous - estuarine. Resident. 3-325 mm. Eggs - uncommon; April-May; 11.0-20.0 C; 0.0-5.0 ppt. Larvae - uncommon; April-July; 11.0-28.7 C; 0.0-6.0 ppt. Young and adult - abundant to very abundant; January-December; 0.2-31.3 C; 0.0-20.0 ppt; offshore, shore zone, tributaries. (See Text).

Morone saxatilis (Walbaum) - Striped bass. Anadromous - marine. Migratory, nursery, summer feeder. 4-950 mm. Eggs - uncommon; April-June; 11.0-22.7 C; 0.0-5.0 ppt. Larvae - uncommon; April-June; 11.0-22.3 C; 0.0-2.5 ppt. Young and adult - common to abundant; January-December; 1.0-29.8 C; 0.0-14.5 ppt; offshore, shore zone, tributaries. (See Text).

Family Serranidae

Centropristis striata (Linnaeus) - Black sea bass. Marine, brackish. Stray. 52-141 mm. Young - rare; April, May, August, October; 12.5-24.2 C; 0.0-12.0 ppt; offshore.

Family Centrarchidae

Enneacanthus gloriosus (Holbrook) - Bluespotted sunfish. Freshwater, brackish. Stray. 20-76 mm. Young and adult - rare; July-September; 24.0-27.8 C; 0.0 ppt; tributaries.

Lepomis spp. Larvae - rare; June; 26.0-29.0 C; 1.0 ppt; 12 mm.

Lepomis gibbosus (Linnaeus) - Pumpkinseed. Freshwater, brackish. Resident. 10-164 mm. Young and adult - uncommon to common; January-December; 1.8-31.0 C; 0.0-8.0 ppt; offshore, shore zone, tributaries.

Lepomis macrochirus Rafinesque - Bluegill. Freshwater, brackish. Resident. 8-189 mm. Young and adult - uncommon to abundant; January-December; 3.0-31.0 C; 0.0-8.5 ppt; offshore, shore zone, tributaries.

Micropterus dolomieui Lacépède - Smallmouth bass. Freshwater, brackish. Stray. 93-111 mm. Young - rare; August; 29.9 C; 1.0 ppt; tributaries.

Micropterus salmoides (Lacépède) - Largemouth bass. Freshwater, brackish. Resident. 18-330 mm. Young and adult - rare to uncommon; March-December; 4.9-29.1 C; 0.0-2.5 ppt; offshore, shore zone, tributaries.

Pomoxis annularis Rafinesque - White crappie. Freshwater, brackish. Resident. 20-209 mm. Young and adult - rare to uncommon; April-October, December; 4.8-28.8 C; 0.0-5.0 ppt; offshore, shore zone, tributaries.

Pomoxis nigromaculatus (Lesueur) - Black crappie. Freshwater, brackish. Resident. 10-255 mm. Young and adult - uncommon to common; January, March-December; 3.0-31.5 C; 0.0-6.5 ppt; offshore, shore zone, tributaries.

Family Percidae

Etheostoma olmstedi Storer - Tessellated darter. Freshwater, brackish. Resident. 0-97 mm. Young and adult - uncommon to common; January-December; 4.3-29.9 C; 0.0-8.0 ppt; shore zone, tributaries.

Perca flavescens (Mitchill) - Yellow perch. Freshwater, brackish. Resident. 7-310 mm. Larvae - rare; April; 7.0-12.0 C; 0.0-2.0 ppt. Young and adult - uncommon to common; January-December; 0.2-30.0 C; 0.0-10.0 ppt; offshore, shore zone, tributaries.

Family Pomatomidae

Pomatomus saltatrix (Linnaeus) - Bluefish. Marine, brackish. Nursery, summer feeder. 24-725 mm. Young and adult - common; May-November; 11.5-32.8 C; 0.0-15.0 ppt; offshore, shore zone, tributaries.

Family Carangidae

Caranx hippos (Linnaeus) - Crevalle jack. Marine, brackish. Nursery, summer feeder. 34-165 mm. Young - uncommon to common; June-November; 11.9-30.0 C; 0.0-1.5 ppt; offshore, shore zone.

Selene vomer (Linnaeus) - Lookdown. Marine, brackish. Stray. 22-78 mm. Young - rare; July-September; 20.0-28.1 C; 5.0-15.0 ppt; offshore, shore zone.

Family Sparidae

Lagodon rhomboides (Linnaeus) - Pinfish. Marine, brackish. Stray. 93 mm. Young - rare; August; 25.5 C; 5.0 ppt; shore zone.

Family Sciaenidae

Bairdiella chrysura (Lacépède) - Silver perch. Marine, brackish, freshwater. Nursery, summer feeder. 2-210 mm. Larvae - rare; June-August; 17.5-27.5 C; 2.0-8.0 ppt. Young and adult - rare to common; June-November; 10.3-29.5 C; 0.0-15.0 ppt; offshore, shore zone, tributaries.

Cynoscion regalis (Bloch and Schneider) - Weakfish. Marine, brackish, freshwater. Nursery, summer feeder. 2-690 mm. Eggs - uncommon to common; June, July; 24.2-27.0 C; 2.0-13.0 ppt. Larvae - common; May-September; 19.0-28.1 C; 0.0-13.0 ppt. Young and adult - abundant to very abundant, April-November; 6.0-32.0 C; 0.0-20.0 ppt; offshore, shore zone, tributaries. (See Text).

Leiostomus xanthurus Lacépède - Spot. Marine, brackish, freshwater. Nursery, summer feeder. 13-250 mm. Larvae - uncommon; April-June; 10.3-27.8 C; 0.0-11.0 ppt. Young and adult - rare to very abundant; March-December; 4.8-30.0 C; 0.0-17.0 ppt; offshore, shore zone, tributaries. (See Text).

Menticirrhus saxatilis (Bloch and Schneider) - Northern kingfish. Marine, brackish. Stray. Young - rare (one specimen); November.

Micropogon undulatus (Linnaeus) - Atlantic croaker. Marine, brackish, freshwater. Nursery, fall feeder. 6-301 mm. Larvae - uncommon; September-December; 2.3-28.5 C; 0.0-10.0 ppt. Young and adult - rare to very abundant; January, March-December; 0.2-30.0 C; 0.0-17.0 ppt; offshore, shore zone, tributaries. (See text).

Pogonias cromis (Linnaeus) - Black drum. Marine, brackish, freshwater. Nursery. 7-201 mm. Larvae - rare; June; 28.5 C; 1.0 ppt. Young - rare to common; June-December; 7.0-32.8 C; 0.0-13.0 ppt; offshore, shore zone, tributaries.

Family Chaetodontidae

Chaetodon ocellatus Bloch - Spotfin butterflyfish. Marine. Stray. 20 mm. Young - rare (one specimen); August; 27.0 C; 5.0 ppt; offshore.

Family Mugilidae

Mugil cephalus Linnaeus - Striped mullet. Marine, brackish. Summer feeder. 25-318 mm. Young and adult - rare; March, April, June, August-October; December; 5.0-27.1 C; 0.0-7.5 ppt; shore zone.

Mugil curema Valenciennes - White mullet. Marine, brackish. Stray. 29 mm. Young - rare; April, June, July, November; 12.5-29.6 C; 0.0-8.0 ppt; shore zone.

Family Uranoscopidae

Astroscopus guttatus Abbott - Northern stargazer. Marine, brackish. Stray. 14-106 mm. Young - rare to uncommon; 10.0-28.0 C; 5.0-15.0 ppt; offshore, shore zone.

Family Ammodytidae

Ammodytes sp. - Sand lance. Larvae - rare; March, April; 5.5-8.5 C; 1.0-7.0 ppt; 9-17 mm.

Family Gobiidae

Gobiosoma bosci (Lacépède) - Naked goby. Estuarine. Resident. 2-49 mm. Larvae - abundant; June-October; 13.0-30.2 C; 0.0-13.0 ppt. Young and adult - rare to common; January-March, June-December; 0.6-30.0 C; 0.0-12.0 ppt; offshore, shore zone, tributaries. (See Text).

Gobiosoma ginsburgi Hildebrand and Schroeder - Seaboard goby. Marine, brackish. Stray. 48 mm. Adult - rare; April; 6.0 C; 4.0 ppt; offshore.

Family Glyceridae

Glycera dibranchiata Ehlers, 1868. Benthic; 3.9-23.8 C; 2.0-12.0 ppt; Jan., June, Sept.-Dec.; T4S2, T5S1-3, T6S1, T8S1, T8S2; 4.0-23.0 mm. Rare to uncommon. More abundant near Ship John Shoal (Annual Progress Report, 1974) and further south in Delaware Bay (Kinner & Maurer, 1978).

Family Goniadidae

Glycinde solitaria Webster, 1879. Benthic; 6.0-26.0 C; 2.0-16.1 ppt; Aug.-Dec.; T5S1, T5S2, T6S1, T6S2, T8S1, T8S2; 2.9-7.5 mm. Rare. More abundant downbay (Kinner & Maurer, 1978).

Order Spionida
Family Spionidae

Polydora sp. Benthic; 1.9-28.0 C; 0.0-13.0 ppt; Jan.-Dec.; T2S1, T2S3, T3S1-6, T4S2-5, T5S1-4, T6S1, T6S2, T7S2, T7S3, T8S1-3; 4.0-13.8 mm. Very abundant. Detailed information in species discussion section.

Scolecolepides viridis (Verrill, 1873). Benthic; 1.8-29.9 C; 0.0-13.0 ppt; Jan.-Dec.; T1S1-3, T2S1-3, T3S1-4, T3S6, T4S1-5, T5S1-3, T6S1, T6S2, T7S1-3, T8S1-3; 1.3-65.0 mm. Very abundant. Greatest density during January-April. Detailed information in species discussion section.

Streblospio benedicti Webster, 1879. Benthic; 2.0-27.4 C; 0.0-12.0 ppt; Jan.-Dec.; T3S1, T3S3, T3S4, T4S1-5, T5S1, T5S2, T6S1-3, T7S3, T8S1-3; 1.4-18.0 mm. Uncommon to common. More abundant downbay (Kinner & Maurer, 1978).

Family Sabellariidae

Sabellaria vulgaris Verrill, 1873. Benthic; 2.1-12.9 C; 7.0-12.0 ppt; Oct., Dec.; T5S2; 1.0-4.5 mm. Rare. Very abundant near Ship John Shoal (Annual Progress Report, 1974) and further south in Delaware Bay (Kinner & Maurer, 1978).

Order Terebellida
Family Ampharetidae

Hypaniola grayi (=florida Pettibone, 1977). Benthic; 11.2-20.0 C; 8.0 ppt; April, Sept.; T8S1. Rare.

Class Oligochaeta

Aquatic earthworms. Benthic; planktonic; 1.0-30.0 C; 0.0-15.8 ppt; Jan.-Dec.; T1S1-3, T2S1-3, T3S1-6, T4S1-5, T5S1-4, T6S1-3, T7S1-3, T8S1-3, ZP01, 03, 05-07, 21, 22, 30, 31, 32, 34, 35, 40, 41, IP04-07, 11, 34-36. Uncommon to common in benthos; rare to uncommon in the microzooplankton and macroinvertebrate plankton.

Oligochaeta "#1". Benthic, planktonic; 1.8-29.0 C; 0.0-12.0 ppt; Jan.-Dec.; T3S1, T3S3W H4E6W HOEb-3, T5S1, T5S2, T6S1-3, T7S1, T8S1-3, IP11. Common in benthos; rare in macroinvertebrate plankton.

Family Naididae

Paranais litoralis (Muller, 1784) - Benthic; 1.8-29.9 C; 0.0-17.0 ppt; Jan.-Dec.; T1S1-3, T2S1-3, T3S1-6, T4S1-5, T5S1-4, T6S1-3, T7S1-3, T8S1-3; 3.0-21.0 mm. Very abundant. Detailed information in species discussion section.

Class Hirudinea

Leeches. Benthic, planktonic; 4.0-28.0 C; 0.0-10.4 ppt; Feb.-Sept., Nov.; T3S5, T3S6, T4S4, T5S2, T8S1, IP04-07, 11. Rare to uncommon in benthos; rare in macroinvertebrate plankton.

PHYLUM MOLLUSCA
Class Gastropoda

Univalve molluscs (adults). Benthic, planktonic; 4.9-27.0 C; 0.0-13.2 ppt; March, May, July-Oct.; T5S1, T8S2, IP05. Rare in benthos and macroinvertebrate plankton.

Univalve molluscs (veligers). Planktonic; 1.8-31.0 C; 0.0-14.0 ppt; Jan., April-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40. Common to abundant. Greatest density during June-September. Most in bottom samples.

Order Tectibranchia
Family Pyramidellidae

Pyramidellid snails. Benthic; 2.3-27.2 C; 1.0-8.0 ppt; July, Nov., Dec.; T3S2, T5S1, T5S2. Rare. Seven specimens during 1975 and 1976.

Turbonilla sp. Benthic; 17.6-23.7 C; 2.0-7.0 ppt; May, June; T5S1, T5S2. Rare. Three specimens during 1975 and 1976.

Order Nudibranchia

Shell-less gastropods. Benthic, planktonic; 12.8-26.0 C; 2.0-8.0 ppt; May-Sept., Nov.; T2S3, T5S2, T7S2, T7S3, IP05, 06, 11; 1.0-3.0 mm. Rare, in benthos and macroinvertebrate plankton.

Family Corambidae

Doridella obscura (Verrill, 1870). Benthic; 12.9-25.0 C; 6.0-12.0 ppt; Aug.-Oct.; T4S2, T5S2; 1.0-2.0 mm. Rare. Three specimens during 1976 on gravel shell substrate.

Class Pelecypoda

Bivalve molluscs (veligers). Planktonic; 0.1-29.0 C; 0.0-17.2 ppt; Jan., March-Dec.; ZP01, 03, 05-08, 10-12, 21, 22, 30-35, 40, 41. Uncommon to common. Density variable, but greatest September-November.

Order Pteroconchida
Family Mytilidae

Modiolus demissus (Dillwyn, 1817) - Ribbed mussel. Benthic; 2.0-27.5 C; 0.0-16.4 ppt; Jan.-Dec.; T4S2, T5S1, T5S2, T6S3, T8S2; 3.0-35.0 mm. Uncommon, but most on gravel-shell substrate.

Family Ostreidae

Crassostrea virginica (Gmelin, 1792) - Common oyster. Benthic; 2.0-28.0 C; 0.0-13.2 ppt; Jan., Mar.-Dec.; T4S2, T4S3, T5S1, T5S2, T6S3, T8S2; 2.5-74.8 mm. Rare to uncommon, with most on gravel-shell substrate.

Order Heterodontida
Family Dreissenidae

Congeria leucophaeta (Conrad, 1831). Benthic; 4.3-24.9 C; 2.1-8.0 ppt; Mar., July, Oct., Nov.; T3S5, T3S6, T4S2. Rare. Most taken at Appoquinimink River stations (T3S5, T3S6).

Family Tellinidae

Macoma balthica (Linnaeus, 1758). Benthic; 1.8-28.2 C; 0.0-16.0 ppt; Jan.-Dec.; T1S2, T2S1, T2S2, T3S1, T3S3-6, T4S1-5, T5S1-4, T6S1-3, T7S1-3, T8S1-3; 1.0-33.0 mm. Uncommon to common.

Macoma tenta (Say, 1834). Benthic; 1.8-24.5 C; 2.0-12.0 ppt; May, July, Sept., Oct., Dec.; T5S2, T8S1, T8S2; 3.7-11.0 mm. Rare.

Family Mactridae

Mulinia lateralis (Say, 1822) - Coot or little surf clam. Benthic; 6.2-25.6 C; 6.0-10.0 ppt; July-Sept., Nov.; T4S2, T5S1, T5S2, T8S2; 1.0-10.0 mm. Rare. Much more abundant downbay (Maurer et al., 1974).

Rangia cuneata (Gray, 1831) - Brackish water clam. Benthic; 3.5-27.6 C; 0.0-12.0 ppt; Jan.-April, June-Dec.; T1S1, T2S1, T3S4, T3S6, T4S1, T5S1, T5S2, T7S3, T8S1, T8S3; 2.0-58.0 mm. Rare-uncommon. Very high numbers in upper Chesapeake Bay (Pfitzenmeyer, 1970). This reach of the Delaware River Estuary appears to be the northernmost extent of its range on the east coast (*see discussion at the end of this section).

Family Myacidae

Mya arenaria (Linnaeus, 1758) - Soft-shelled clam. Benthic; 2.0-24.7 C; 0.0-10.0 ppt; May, July, Sept.-Dec.; T4S2, T5S1, T5S2, T8S1, T8S2; 1.0-5.2 mm. Rare to uncommon.

PHYLUM ARTHROPODA

Class Merostomata
Order Xiphosurida
Family Limulidae

Limulus polyphemus (Linnaeus, 1758) - Horseshoe crab. Planktonic; 24.3-27.0 C; 2.0-10.0 ppt; July-Aug.; IP04-07, 11; 3-4 mm. Rare. Reproduction occurs at higher salinity downbay.

Class Arachnida
Order Acarina

Water mites. Planktonic, benthic; 1.8-25.0 C; 0.0-9.0 ppt; April-June, Sept.-Dec.; ZP01, 03, 05-08, 12, 21, 22, 32, IP05, 06, 34, 35, T3S1. Uncommon in microzooplankton; rare in macroinvertebrate plankton and benthos.

Class Crustacea
Subclass Branchiopoda

Water fleas. Planktonic; 3.0-26.3 C; 2.0-8.0 ppt; Feb.-June, Aug., Oct., Dec.; ZP05-07, 11, 30, 31, 32, 34. Uncommon.

Order Cladocera
Family Leptodoridae

Leptodora kindtii (Focke, 1884). Planktonic; 12.0-28.0 C; 0.0-7.0 ppt; May-Aug., Oct.; IP04-07, 11; 2-7 mm. Rare to uncommon. Greatest density during May-July. Probably more abundant upriver of Artificial Island. Oligohaline (Wass et al., 1972).

Family Bosminidae

Bosmina spp. (Baird, 1845). Planktonic; 0.1-31.0 C; 0.0-17.8 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Common. Greatest density during June-September.

Family Daphnidae

Daphnia spp. (Muller, 1785). Planktonic; 0.1-25.6 C; 0.0-11.0 ppt; Jan., March-July, Nov.-Dec.; ZP01, 03, 05-07, 10, 30, 31, 33, 40, 41, 43. Rare to uncommon. Most in bottom samples.

Daphnia rosea (Richard, 1896). Planktonic; 0.5 C; 2.0 ppt; Jan.; ZP12. Probably rare, identified only during 1976.

Daphnia parvula Fordyce, 1901. Planktonic; 17.0-27.3 C; 0.0-2.0 ppt; May-June, Aug.,; ZP03, 05-07, 30-31, 40-41. Uncommon.

Scapheloberis sp. Schodler, 1858. Planktonic; 14.9-28.0 C; 0.0-2.0 ppt; June-July, Nov.; ZP05, 07. Probably rare, identified only during 1975.

Simocephalus sp. Schodler, 1858. Planktonic; 2.8 C; 0.0 ppt; Feb.; ZP01. Probably rare, identified only during 1976.

Moina spp. Baird, 1850. Planktonic; 4.3-31.0 C; 0.0-10.0 ppt; Feb.-Nov.; ZP01, 03-08, 10, 11, 22, 30, 31, 40, 41. Uncommon to common. Greatest density during June-September.

Ilyocryptus spp. Sars, 1861. Planktonic; 7.0-28.0 C; 0.0-3.0 ppt; Feb., Aug., Nov.-Dec.; ZP01, 05, 07, 10. Rare.

Ilyocryptus sordidus (Lieven, 1848). Planktonic; 0.2 C; 2.0 ppt; Jan.; ZP04. Probably rare, identified only during 1976.

Family Polyphemidae

Podon sp. - Planktonic; 2.5 C; 2.0 ppt; Feb.; ZP05. Probably rare, identified only during 1974.

Family Chydoridae

Alona sp. Baird, 1850. Planktonic; 5.5-12.0 C; 0.0-3.0 ppt; Feb.-April; ZP05, 07, 31. Rare.

Chydorus sp. Leach, 1843. Planktonic; 2.0-20.5 C; 0.0-8.0 ppt; Jan.-May, Dec.; ZP01, 03, 05-07, 12, 30, 31, 35, 40, 41. Uncommon.

Alonella sp. Sars, 1862. Planktonic; 4.2-12.1 C; 0.0-2.0 ppt; Feb.-April; ZP03, 05-07, 12. Rare. Most in bottom samples.

Subclass Ostracoda

Seed shrimp. Planktonic; 0.1-28.0 C; 0.0-14.0 ppt; Jan.-Dec.; ZP01, 03-08, 11, 21, 22, 30, 32, 33, 40, 43. Uncommon.

Subclass Copepoda

Adults. Planktonic; 3.0-31.0 C; 0.0-12.0 ppt; Feb.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30, 31-33, 35, 40, 41, 43. Uncommon.

Nauplii. Planktonic; 0.0-28.7 C; 0.0-17.8 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Very abundant. Greatest density during April-June. Most in surface samples. Detailed information in species discussion section.

Order Calanoida
Family Calanidae

Calanus finmarchicus (Gunnerus, 1765). Planktonic; 17.9-18.2 C; 3.5-5.5 ppt; Oct.; ZP07. Probably rare, identified only during 1975. Oceanic species (Wass et al., 1972).

Family Paracalanidae

Paracalanus crassirostris Dahl, 1894. Planktonic; 0.0-28.2 C; 2.0-14.0 ppt; Feb.-May, July-Oct.; Dec.; ZP03-08, 10-12, 21, 22, 32-35. Uncommon.

Family Pseudocalanidae

Pseudocalanus minutus (Kroyer, 1840). Planktonic; 0.2-12.9 C; 8.0-14.0 ppt; Feb.-March, May; ZP33, 34. Probably rare, identified only during 1974.

Family Temoridae

Temora longicornis (Muller, 1792). Planktonic; 0.0-18.6 C; 0.0-14.0 ppt; Feb.-May; ZP03, 05-07, 10-12, 22, 30, 32-34. Rare to uncommon. Most in bottom samples.

Eurytemora affinis (Poppe, 1880). Planktonic; 0.0-31.0 C; 0.0-17.8 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Very abundant. Greatest density during March-June. Most in bottom samples. Detailed information in species discussion section.

Family Centropagidae

Centropages hamatus (Lilljeborg, 1853). Planktonic; 0.0-25.0 C; 0.0-17.8 ppt; Jan.-March, May, Oct.-Nov.; ZP03, 05-08, 10-12, 31-34, 43. Rare to uncommon. Most adults in bottom samples.

Centropages typicus Kroyer, 1849. Planktonic; 12.9 C; 10.0 ppt; May; ZP33. Probably rare, identified only during 1974.

Family Diaptomidae

Diaptomus spp. Westwood, 1836. Planktonic; 0.0-27.0 C; 0.0-13.0 ppt; Jan.-April, July-Dec.; ZP01, 04-07, 12, 30, 34, 35. Uncommon.

Pseudodiaptomus coronatus Williams, 1906. Planktonic; 0.0-28.7 C; 0.0-17.8 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 43. Common. Very abundant mid-estuary (Cronin et al., 1962). Greatest density during June-October. Most in bottom samples.

Family Pontellidae

Labidocera aestiva Wheeler, 1889. Planktonic; 11.8-25.6 C; 1.0-12.0 ppt; July, Sept.-Nov.; IP05, 06, 11, 34, 35; 2-3 mm. Rare to uncommon. Greatest density in July. Typically oceanic, abundance increased downriver of Artificial Island (Cronin, et al., 1962).

Family Acartiidae

Acartia tonsa Giesbrecht, 1892. Planktonic; 0.0-30.0 C; 0.0-17.8 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Very abundant. Greatest density during June-September. Most in bottom samples. Detailed information in species discussion section.

Order Harpacticoida

Planktonic; 0.0-29.0 C; 0.0-17.8 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Uncommon to common. Greatest density during June-August. Most in bottom samples.

Harpacticoid "C". Planktonic; 1.2-25.0 C; 0.0-17.8 ppt; Feb.-July; ZP03, 05-07, 11, 40, 41, 43. Probably uncommon, identified only during 1973. Most in bottom samples.

Family Canthocamptidae

Canthocamptus sp. Westwood, 1836. Planktonic; 4.3-4.5 C; 0.0 ppt; Feb.; ZP06. Probably rare, identified only during 1975.

Leptastacus sp. T. Scott, 1906. Planktonic; 1.9-25.4 C; 0.0-9.0 ppt; Mar., June-July, Sept.-Dec.; ZP01, 05, 07, 12. Rare. Most in bottom samples.

Family Longipediidae

Scottolana sp. Planktonic; 1.5-30.0 C; 0.0-12.5 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41. Common. Greatest density during April-June. Most in bottom samples.

Scottolana canadensis (Willey, 1923). Planktonic; 19.6 C; 0.0 ppt; May; ZP31. Rare.

Family Ectinosomidae

Ectinosoma spp. Boeck, 1864. Planktonic; 0.7-29.5 C; 0.0-14.0 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 32-35. Common. Most in bottom samples.

Family Laophontidae

Planktonic; 14.5-22.1 C; 0.0-8.0 ppt; March-June; ZP05, 06, 30, 34. Probably rare, identified only during 1974. Most in bottom samples.

Paralaophonte spp. Planktonic; 19.2-19.4 C; 4.0 ppt; May. ZP05. Probably rare, identified only during 1976.

Laophonte spp. Philippi, 1840. Planktonic; 0.5-28.7 C; 0.0-12.5 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 32, 33. Uncommon to common. Most in bottom samples.

Order Cyclopoida
Family Oithonidae

Oithona sp. Baird, 1843. Planktonic; 1.0-28.0 C; 0.8-17.8 ppt; Feb.-Mar., July-Oct.; ZP03, 05-07, 11, 30, 32-35, 43. Uncommon.

Oithona colcarva (Bowman, 1975). Planktonic; 0.0-29.0 C; 0.0-14.0 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30, 32-35. Uncommon to common. Greatest density during August-September. Most in bottom samples.

Family Cyclopidae

Halicyclops sp. Norman, 1903. Planktonic; 24.8-25.0 C; 0.0-3.1 ppt; June; ZP06, 07. Probably rare, identified only during 1973.

Halicyclops fosteri M. Wilson, 1958. Planktonic; 0.0-31.0 C; 0.0-14.0 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Common to abundant. Density variable. Most in bottom samples.

Cyclops spp. Muller, 1776. Planktonic; 0.1-29.5 C; 0.0-13.0 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Common. Greatest density during February-July.

Cyclops vernalis Fischer, 1853. Planktonic; 0.1-31.0 C; 0.0-14.0 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Uncommon.

Cyclops bicuspidatus thomasi Claus, 1857. Planktonic; 0.0-26.5 C; 0.0-13.0 ppt; Jan.-June, Oct.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Uncommon to common. Greatest density during March-April.

Eucyclops sp. Claus, 1893. Planktonic; 1.8-24.0 C; 0.0-12.0 ppt; Jan.-Mar., July; ZP05-07. Probably rare, identified only during 1974.

Eucyclops agilis Koch, 1838. Planktonic; 1.9-14.5 C; 0.0-7.0 ppt; Jan.-May, Oct.-Dec.; ZP05-07, 11, 30. Rare to uncommon.

Eucyclops speratus (Lilljeborg, 1901). Planktonic; 4.3-4.5 C; 0.0 ppt; Feb.; ZP06. Probably rare, identified only during 1975.

Tropocyclops spp. Planktonic; 0.1-14.8 C; 0.0-5.0 ppt; Jan.-April, Nov.-Dec.; ZP01, 03-07, 10, 21, 30. Rare.

Tropocyclops prasinus (Fischer, 1860). Planktonic; 17.3-26.0 C; 0.4-4.0 ppt; July, Oct.; ZP06, 07. Probably rare, identified only during 1975.

Paracyclops fimbriatus (Fischer, 1853). Planktonic; 7.6-19.5 C; 0.0-2.5 ppt; May, Nov.; ZP03, 07, 12. Rare.

Family Lichomolgidae

Leptinogaster major (Williams, 1907) - Fish parasite. Planktonic; 8.1-27.0 C; 0.0-10.0 ppt; May, July, Sept.-Nov.; ZP05-07. Rare.

Family Ergasilidae

Ergasilus spp. Nordmann, 1832 - Fish parasite. Planktonic; 3.0-19.0 C; 0.0-4.0 ppt; Jan., May; ZP05, 06, 31, 41. Rare.

Subclass Branchiura
Order Argulidea
Family Argulidae

Argulus spp. Muller, 1785 - Fish lice. Planktonic; 10.5-30.0 C; 0.0-12.0 ppt; May-Nov.; IP04-08, 11, 34, 35, 37; 1-9 mm. Common to abundant. Greatest density during July-September. The dominant fish parasite in macroinvertebrate plankton.

Subclass Cirripedia

Nauplii and cypris larvae. Planktonic; 0.1-30.0 C; 0.0-14.0 ppt; Jan.-Dec.; ZP01, 03-08, 10-12, 21, 22, 30-35, 40, 41, 43. Abundant. Greatest density during May-September. Most cypris larvae in bottom samples.

Order Thoracica
Family Balanidae

Balanus improvisus Darwin, 1854 - Bay barnacle. Benthic; 2.0-28.2 C; 0.0-17.0 ppt; Jan.-Dec.; T2S2, T3S1-6, T4S2-4, T5S1-3, T6S1-3, T7S1-3, T8S1, T8S2. Very abundant. Detailed information in species discussion section.

Subclass Malacostraca
Order Mysidacea
Family Mysidae

Neomysis americana (Smith, 1873) - Opossum shrimp. Planktonic, benthic; 0.0-30.2 C; 0.0-17.0 ppt; Jan.-Dec.; IP04-08, 11, 34-37, T1S1-3, T2S1-3, T3S1-6, T4S1-5, T5S1-4, T6S1-3, T7S1-3, T8S1-3; 1-18 mm. Very abundant in macroinvertebrate plankton; common in benthos. Greatest density from June-November, December. Detailed information in species discussion section.

Order Cumacea
Family Leuconidae

Leucon americanus Zimmer, 1943. Planktonic, benthic; 5.5-29.9 C; 0.0-16.5 ppt; Mar.-Dec.; IP04, 05, 07, 11, 34, 35; T1S3, T2S2, T2S3, T3S1-6, T4S1-5, T5S1-4, T6S1-3, T7S1-3, T8S1-3; 2-5 mm. Uncommon to common in macroinvertebrate plankton and benthos. Greatest density during July-August in macroinvertebrate plankton and August-November in benthos. Meso- to euhaline (Wass et al., 1972); lowest density upriver of Artificial Island.

Order Isopoda
Family Idoteidae

Chiridotea almyra Bowman, 1855. Benthic, planktonic; 0.0-30.0 C; 0.0-16.5 ppt; Jan.-Dec.; T1S1-3, T2S1-3, T3S1-6, T4S1-5, T5S1-4, T7S1-3, T8S1-3, IP04-07, 11, 34-37; 1-9 mm. Common in benthos and macroinvertebrate plankton. Benthic abundance greatest in sand substrate. Greatest abundance during March-July, September, November in macroinvertebrate plankton, and May-September in benthos. An obligate brackish water species (Watling et al., 1974).

Edotea triloba (Say, 1818). Planktonic, benthic; 2.6-30.0 C; 0.0-17.0 ppt; Jan.-Dec.; IP04-08, 11, 34, 35, T1S1, T1S3, T2S1-3, T3S1-6, T4S1-5, T5S1-4, T6S1-3, T7S1-3, T8S1-3; 0.5-7 mm. Common to abundant in macroinvertebrate plankton; uncommon to common in benthos. Greatest density during August-September in macroinvertebrate plankton, and August-October in benthos. Detailed information in species discussion section.

Family Anthuridae

Cyathura polita (Stimpson, 1855). Benthic, planktonic; 1.8-29.9 C; 0.0-17.0 ppt; Jan.-Dec.; T1S1-3, T2S1-3, T3S1-6, T4S1-5, T5S1-4, T6S1-3, T7S1-3, T8S1-3, IP04-08, 11, 34, 35; 0.4-27.0 mm. Very abundant in benthos; uncommon in macroinvertebrate plankton. Greatest density occurred during May-September in macroinvertebrate plankton. Detailed information in species discussion section.

Family Sphaeromidae

Cassidinidea lunifrons (Richardson, 1900). Planktonic, benthic; 5.5-30.0 C; 0.2-8.0 ppt; IP04-07, 11, T3S5, T4S2, T7S1; Feb., Apr., May-Aug., Nov.-Dec.; 2-4 mm. Rare in macroinvertebrate plankton and benthos. An obligate brackish water species (Watling et al., 1974).

Family Cymothoidae

Aegathoa medialis Richardson, 1900. Planktonic; 13.6-30.0 C; 0.0-11.0 ppt; IP04-08, 11, 34-37; May-Oct.; 2-22 mm. Uncommon. Greatest density during June-September. External parasite on a wide variety of fish, including white perch, weakfish, spot, and Atlantic menhaden (Watling et al., 1974). Probably a juvenile form of another cymothoid (Schultz, 1969).

Lironeca ovalis (Say, 1818). Planktonic. Parasitic, occurs ie the gill cavity of many fishes (Watling, et al., 1974), possibly favoring bluefish (Lindsay and Moran, 1976).

Olencira praegustator (Latrobe, 1802). Planktonic. Parasitic, occurs chiefly in the buccal cavity of Atlantic menhaden (Watling, et al., 1974; Lindsay and Moran, 1976).

Order Bopyridae

Probopyrus pandalicola (Packard, 1879). Planktonic; 3.0-28.7 C; 0.0-12.2 ppt; Jan., Mar., May-Nov.; ZP01, 03-08, 10, 11, 22, 30, 32-35. Larvae uncommon in microzooplankton. Adult is a branchial parasite of Palaemonetes (Schultz, 1969).

Order Amphipoda
Family Photidae

Leptocheirus plumulosus Shoemaker, 1932. Benthic, planktonic; 1.8-28.2 C; 0.0-14.9 ppt; Jan.-Dec.; T1S1, T1S2, T2S1-3, T3S1-6, T4S1, T4S2, T4S4, T4S5, T5S1, T5S2, T5S4, T7S1, T7S3, T8S1-3, IP04-07, 11, 34, 36; 1.0-11.0 mm. Abundant in benthos; rare to uncommon in macroinvertebrate plankton.

Family Corophiidae

Corophium acherusicum Costa, 1857. Planktonic; 25.2 C; 7.0 ppt; Aug.; IP05; 1-3 mm. Probably rare, identified only during 1976. Poly- to euhaline (Wass et al., 1972).

Corophium lacustre Vanhoffen, 1911. Benthic, planktonic; 1.0-30.0 C; 0.0-17.0 ppt; Jan.-Dec.; T1S1-3, T2S1-3, T3S1-6, T4S1-5, T5S1-4, T6S1-3, T7S1-3, T8S1-3, IP04-08, 11, 34-37; 1.0-10.0 mm. Abundant to very abundant in benthos; abundant in macroinvertebrate plankton. Greatest density during June-November in macroinvertebrate plankton. Detailed information in species discussion section.

Family Gammaridae

Gammarus spp. - Scud. Planktonic, benthic; 0.0-30.0 C; 0.0-17.0 ppt; Jan.-Dec.; IP04-08, 11, 34-37, T1S1-3, T2S1-3, T3S1-6, T4S1-5, T5S1-4, T6S1-3, T7S1-3, T8S1-3; 1-18 mm. Very abundant in macroinvertebrate plankton; common to very abundant in benthos. Greatest density during April-September in macroinvertebrate plankton. Detailed information in species discussion section.

Melita nitida Smith, 1873. Planktonic, benthic; 2.0-30.0 C; 0.0-13.2 ppt; Jan.-Mar., May-Dec.; IP04-07, 11, T1S1, T2S1-2, T3S1-2, T3S5-6, T4S2-4, T5S1-2, T6S1, T6S3, T7S1-2, T8S1-2; 1-8 mm. Uncommon in macroinvertebrate plankton and benthos. Greatest density during August-September in macroinvertebrate plankton, and July-November in benthos. Dominant on downbay oyster beds (Watling and Maurer, 1974).

Family Haustoriidae

Planktonic; 2.0-29.5 C; 2.0-8.0 ppt; June-Aug., Nov.-Dec.; IP04-07, 11; 2-9 mm. Rare. Typically occur at higher salinity downbay (Watling and Maurer, 1972).

Haustorius sp. Planktonic; 16.8 C; 3.0 ppt; May; IP05; 4 mm. One specimen during 1975.

Parahaustorius sp. Benthic; 1.9-29.0 C; 0.0-10.0 ppt; Jan.-May, July-Dec.; 2.5-12.0 mm; T3S1, T3S2, T7S1. Rare to uncommon. Only at stations with sand substrate.

Family Oedicerotidae

Monoculodes edwardsi Holmes, 1903. Planktonic, benthic; 0.0-30.0 C; 0.0-13.0 ppt; Jan.-Dec.; IP04-7, 11, 34-36, T1S1-3, T2S1-3, T3S1-4, T3S6, T4S1-5, T5S1-3, T6S1-2, T7S1-3, T8S1-3; 1-8 mm. Uncommon to abundant in macroinvertebrate plankton; uncommon in benthos. Scattered occurrence throughout the year. Euryhaline (Wass et al., 1972).

Family Pleustidae

Parapleustes sp. Planktonic, benthic; 12.9-27.0 C; 6.0-12.0 ppt; May-Oct.; IP04-7, 11, T5S2; 1-5 mm. Taken only during 1976, when uncommon in macroinvertebrate plankton and rare in benthos. Found downbay on hydroids (Watling and Maurer, 1972).

Family Talitridae

Orchestia sp. Planktonic; 6.0-26.0 C; 0.0-6.0 ppt; Mar., June-Aug.; IP05-7, 36; 3 mm. Rare.

Family Caprellidae

Planktonic, benthic; 15.3-21.5 C; 7.0-13.1 ppt; June, Oct.; IP11, T4S3, T8S2. Rare. One specimen in macroinvertebrate plankton, two in benthos. Meso- to euhaline (Wass et al., 1972).

Order Decapoda
Family Penaeidae

Penaeus aztecus aztecus Ives, 1891 - Prawn. Probably rare, taken periodically with fisheries gear. Meso- to euhaline (Wass, et al., 1972).

Family Palaemonidae

Palaemonetes pugio Holthius, 1949 - Grass shrimp. Planktonic, benthic; 3.0-30.2 C; 0.0-15.2 ppt; Feb., May-Dec.; IP04-08, 11, 34, 35, 37, T3S3, T3S6, T4S2, T4S5, T5S2, T6S1, T7S1, T7S3, T8S3; 2-38 mm. Abundant in macroinvertebrate plankton, rare to uncommon in benthos. Greatest density during June-August or early September in macroinvertebrate plankton. Detailed information in species discussion section.

Family Crangonidae

Crangon septemspinosa (Say, 1818) - Sand shrimp. Planktonic, benthic; 2.6-30.0 C; 1.0-16.5 ppt; Feb.-Dec.; IP04-7, 11, 34-37, T1S3, T2S1-3, T3S1-6, T4S1-5, T5S1-4, T6S1-3, T7S1-3, T8S1-3; 2-50 mm. Common to abundant in macroinvertebrate plankton; uncommon in benthos. Greatest density during May-November in macroinvertebrate plankton. Detailed information in species discussion section.

Family Portunidae

Callinectes sapidus Rathbun, 1896 - Blue crab. Nektonic, planktonic, benthic; 0.5-30.2 C; 0.0-21.0 ppt; all 22 trawl zones, IP04-08, 11, 34, 35, 37, T2S1, T4S2, T7S2-3, T8S1; 2-228 mm. Abundant in nekton (juveniles and adults); uncommon in macroinvertebrate plankton (megalopae and juveniles); rare in benthos (juveniles). Zoeae never taken. Greatest density during May-November in nekton and August-September in macroinvertebrate plankton. Detailed information in species discussion section.

Family Xanthidae

Panopeus herbstii H. Milne-Edwards, 1834 - Large mud crab. Benthic; 22.0 C; 4.0 ppt; June; T3S6. One specimen during 1971. Meso- to euhaline (Wass et al., 1972).

Rhithropanopeus harrisii (Gould, 1841) - Brackish water mud crab. Planktonic, benthic; 1.9-30.2 C; 0.0-17.0 ppt; Jan.-Dec.; IP04-08, 11, 34, 35, T1S2-3, T2S1-3, T3S1, T3S3-6, T4S1-4, T5S1-2, T6S1, T6S3, T7S2-3, T8S1-3; 1.3-13.5 mm.

Very abundant (larvae) in macroinvertebrate plankton; uncommon to common (juveniles and adults) in benthos. Greatest density during July-August in macroinvertebrate plankton. Detailed information in species discussion.

Family Grapsidae

Sesarma reticulatum (Say, 1817) - Saltmarsh mud crab. Planktonic. Probably uncommon, identified only during 1972. Meso- and polyhaline marshes (Wass et al., 1972).

Family Ocypodidae

Uca minax (LeConte, 1855) - Red-jointed fiddler crab. Planktonic; 17.0-29.5 C; 0.0-12.0 ppt; June-Sept.; IP04-07, 11, 34, 35. Very abundant (larvae) in macroinvertebrate plankton. Greatest density during mid-June-July. Detailed information in species discussion section.

Class Insecta

Insect larvae. Planktonic; 2.0-30.0 C; 1.0-6.0 ppt; Feb. May-Aug.; IP04-07, 34, 35, 2-3 mm. Rare to uncommon.

Order Collembola

Springtails. Planktonic; 11.0 C; 0.0 ppt; Feb., Apr.; ZP06, 07. Rare.

Order Diptera

Fly larvae. Benthic, planktonic; 3.5-22.0 C; 0.0-15.9 ppt; Mar.-June, Sept, Oct.; T1S3, T2S1, T3S2, T3S3, T4S4, T7S1, T8S3, ZP05, 34. Rare in benthos and macroinvertebrate plankton.

Family Tipulidae

Crane fly larvae. Benthic; 2.8-6.1 C; 1.0-4.6 ppt; Feb., Mar.; T3S1, T3S6. One specimen during 1972 and 1976.

Family Ceratopogonidae

Culicoides sp. Latreille - Biting midge larvae. Benthic; 2.5 C; 8.0 ppt; Dec.; T8S1. One specimen during 1975.

Family Culicidae

Chaoborus sp. Lichtenstein - Phantom midge larvae. Planktonic; 1.2-30.0 C; 0.0-5.0 ppt; Jan.-Feb., Apr., June-July; IP04-07, 34; 4-8 mm. Rare.

Family Chironomidae

Midge larvae. Benthic, planktonic; 2.3-28.0 C; 0.0-12.0 ppt; Jan.-Dec.; T1S1-3, T2S1-3, T3S2-6, T4S1-3, T4S5, T5S4, T7S1, T7S3, T8S1, T8S3, IP05, 34. Uncommon in benthos; rare in macroinvertebrate plankton.

Family Membraniporidae

Benthic; 2.0-25.2 C; 2.0-12.0 ppt; April-Dec.; T4S2, T4S3, T5S1, T5S2, T8S1, T8S2. Uncommon.

PHYLUM CHAETOGNATHA

Sagitta elegans Verrill, 1873 - Arrow worm. Planktonic; 8.3 C; 10.0 ppt; Nov.; IP11. One specimen during 1973. Poly-to euhaline (Wass et al., 1972).

PHYLUM CHORDATA
Order Pleurogona
Family Molgulidae

Molgula manhattensis (DeKay, 1843) - Sea grape. Benthic; 2.1-21.1 C; 7.0-15.1 ppt; T5S2, T6S2, T8S2. Rare. More abundant near Ship John Shoal (Annual Progress Report, 1974) and further south in Delaware Bay (Maurer and Watling, 1973).

*Range Extension of the Mactrid Clam
Rangia Cuneata (Gray)

Rangia cuneata, the brackish water clam, is extremely abundant in the oligohaline reaches of many estuaries from Florida to northern Maryland. In the present study the first live specimen (29 mm in length) was collected August 20, 1971 off Oakwood Beach, New Jersey in 1.0 m of water from substrate consisting of sand, gravel, and organic mud. Since then it has been collected at up to seven stations and in each of six (1971-76) consecutive years. These specimens represent a northern range extension for this species. Peak diversity of the brackish water clam was recorded in August 1974 (ca. 70/m^2) in substrate consisting of sand and organic mud. That it is at the northern limit of its range is evidenced by the absence of live clams in benthos samples collected during 1977 and 1978 following the extremely cold winters of 1976-77 and 1977-78. A similar dramatic temperature related decline in density was reported in the upper Chesapeake Bay in 1968 (Gallagher and Wells, 1969). Its occurrence in the study area probably resulted from the transport of larvae through the Chesapeake and Delaware Canal from the upper Chesapeake Bay where it became initially established during or just prior to 1967.

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APPENDIX B

ANNOTATED CHECKLIST OF THE FISHES OF THE DELAWARE RIVER AND TIDAL TRIBUTARIES NEAR ARTIFICIAL ISLAND, NEW JERSEY

The fish community of the Delaware River Estuary has been studied and inventoried (Fowler, 1952; Daiber, 1954; de Sylva et al., 1962, Daiber and Smith, 1971; Wang and Kernehan, 1979), but much of this work was restricted to the Delaware Bay. This checklist enumerates the fishes taken by plankton net, seine, trawl, and gill net in the lower Delaware River and upper Bay (RK 61-97; RM 38-60) and local tidal tributaries (Appoquinimink Creek, Delaware; Alloway and Hope creeks, New Jersey). It presents data which characterize the occurrence of these fishes in this region with respect to seasonality, relative abundance, and habitat utilization. This checklist is a compilation of data previously reported in Annual Progress Reports of the Artificial Island Ecological Study (Schuler et al., 1971-1977).

This list includes 93 taxa (92 to species) of marine, estuarine, and freshwater fishes, most of which either occur as residents or utilize the region seasonally for nursery, feeding, and/or spawning activities. Several are anadromous and pass through the area to spawning grounds upriver. Others are strays which appear only during or after unusual environmental conditions.

Fishes are listed phylogenetically. The order and the scientific and common names are those found in "A list of common and scientific names of fishes from the United States and Canada" American Fisheries Society Special Publication No. 6, 1970. Each species account includes (when available) the following information: Scientific name - Common name. Basic habitat. Primary activity in area. Length range. By life stage - relative abundance; period of occurrence; temperature range at capture; salinity range at capture; general distribution (offshore (river), shore zone (river), tributaries). In certain cases, early life stages were not identified to species because of the absence of descriptive taxonomic information in the literature; these are listed by genus. Species discussed in the Fisheries Section within the main body of the report are indicated by "(see text)".

Order Petromyzontiformes
Family Petromyzontidae

Petromyzon marinus Linnaeus - Sea lamprey. Anadromous. Migratory. 130-914 mm. Young and adult - rare; March, April, June, December; 4.8-26.0 C; 0.0-3.0 ppt; offshore, tributaries.

Order Rajiformes
Family Myliobatidae

Rhinoptera bonasus (Mitchill) - Cownose ray. Marine, brackish. Stray. 600, 766 mm. Adult - rare; 26.0 C; 9.5 ppt; offshore.

Order Acipenseriformes
Family Acipenseridae

Acipenser oxyrhynchus Mitchill - Atlantic sturgeon. Anadromous. Migratory, nursery. 340-765 mm. Young - rare; March, May, June, September; 8.1-23.0 C; 0.0-6.0 ppt; offshore.

Order Anguilliformes
Family Anguillidae

Anguilla rostrata (Lesueur) - American eel. Catadromous. Migratory, summer feeder, nursery. 40-760 mm. Young and adult - common; January-December; 0.5-31.0 C; 0.0-15.0 ppt; offshore, shore zone, tributaries. (See text).

Family Congridae

Conger oceanicus (Mitchill) - Conger eel. Marine. Stray. 85 mm. Young - rare; June; 19.5 C; 4.0 ppt; shore zone.

Order Clupeiformes
Family Clupeidae

Alosa spp. Eggs - rare; April; 11.5-12.5 C; 0.0 ppt. Larvae - uncommon; April-July; 9.0-29.0 C; 0.0-12.0 ppt; 4-34 mm.

Alosa aestivalis (Mitchill) - Blueback herring. Anadromous. Migratory, spawning, nursery. 12-300 mm. Young and adult - common to abundant; January-December; 1.0-32.8 C; 0.0-12.0 ppt; offshore, shore zone, tributaries. (See Text).

Alosa mediocris (Mitchill) - Hickory shad. Anadromous. Migratory. 12-498 mm. Young and adult - rare to uncommon; March-August, October, November; 6.0-29.9 C; 0.0-9.5 ppt; offshore, shore zone, tributaries. (See Text).

Alosa pseudoharengus (Wilson) - Alewife. Anadromous. Migratory, spawning, nursery. 16-310 mm. Young and adult - common to abundant; January-December; 0.2-30.0 C; 0.0-14.0 ppt; offshore, shore zone, tributaries. (See Text).

Alosa sapidissima (Wilson) - American shad. Anadromous. Migratory. 39-580 mm. Young and adult - uncommon; March-June, October-December; 2.9-23.0 C; 0.0-12.0 ppt; offshore, shore zone, tributaries. (See Text).

Brevoortia tyrannus (Latrobe) - Atlantic menhaden. Marine, brackish, freshwater. Nursery, summer feeder. 19-365 mm. Larvae - common; March-June; 1.5-26.5 C; 0.0-8.0 ppt. Young and adult - abundant to very abundant; January, March-December; 4.9-32.0 C; 0.0-15.0 ppt; offshore, shore zone, tributaries. (See Text).

Clupea harengus harengus Linnaeus - Atlantic herring. Marine, brackish. Stray. 22-325 mm. Young and adult - rare; March-August; 3.0-26.4 C; 0.0-12.0 ppt; offshore.

Dorosoma cepedianum (Lesueur) - Gizzard shad. Freshwater, brackish. Resident. 5-337 mm. Larvae - rare; June; 22.2 C; 0.5 ppt. Young and adult - uncommon to common; January-December; 0.2-29.9 C; 0.0-10.5 ppt; offshore, shore zone, tributaries.

Family Engraulidae

Anchoa hepsetus (Linnaeus) - Striped anchovy. Marine, brackish. Stray. 55-105 mm. Young and adult - rare; August-October; 5.0-28.2 C; 5.0-10.0 ppt; offshore, shore zone.

Anchoa mitchilli (Valenciennes) - Bay anchovy. Estuarine. Summer feeder, spawning, nursery. 2-107 mm. Eggs - very abundant; May-October; 17.0-30.0 C; 0.0-13.0 ppt. Larvae - very abundant; May-December; 6.0-30.2 C; 0.0-15.0 ppt. Young and adult - very abundant; January-December; 0.6-32.0 C; 0.0-20.0 ppt; offshore, shore zone, tributaries. (See Text).

Order Salmoniformes
Family Umbridae

Umbra pygmaea (DeKay) - Eastern mudminnow. Freshwater. Stray. 64-89 mm. Adult - rare; February-April; 4.0-6.0 C; 0.0-4.0 ppt; shore zone.

Family Esocidae

Esox americanus americanus Gmelin - Redfin pickerel. Freshwater. Resident. 50-151 mm. Young and adult - rare; January, May-July, September; 4.3-27.1 C; 0.0-3.0 ppt; shore zone, tributaries.

Esox niger Lesueur - Chain pickerel. Freshwater. Resident. 40-457 mm. Young and adult - rare; May-September; 16.5-28.3 C; 0.0 ppt; tributaries.

Order Myctophiformes
Family Synodontidae

Synodus foetens (Linnaeus) - Inshore lizardfish. Marine, brackish. Stray. 32-195 mm. Young and adult - rare; June, August, September; 19.0-27.0 C; 6.0-12.0 ppt; offshore, shore zone.

Order Cypriniformes
Family Cyprinidae

Cyprinid spp. Larvae - uncommon; May-July; 19.1-29.0 C; 0.0-5.0 ppt; 3-9 mm.

Carassius auratus (Linnaeus) - Goldfish. Freshwater, brackish. Resident (introduced). 106-315 mm. Young and adult - rare; January-July, September, December; 4.6-29.4 C; 0.0-4.5 ppt; offshore, shore zone, tributaries.

Cyprinus carpio Linnaeus - Carp. Freshwater, brackish. Resident (introduced). 80-900 mm. Young and adult - common; January-December; 1.5-30.8 C; 0.0-10.5 ppt; offshore, shore zone, tributaries.

Hybognathus nuchalis Agassiz - Silvery minnow. Freshwater, brackish. Resident. 8-158 mm. Young and adult - common; January-December; 0.2-31.5 C; 0.0-9.5 ppt; offshore, shore zone, tributaries.

Notemigonus crysoleucas (Mitchill) - Golden shiner. Freshwater, brackish. Resident. 9-203 mm. Young and adult - rare to abundant; March-December; 0.9-31.5 C; 0.0-2.0 ppt; offshore, shore zone, tributaries.

Notropis analostanus (Girard) - Satinfin shiner. Freshwater. Resident. 19-81 mm. Young and adult - uncommon; February-December; 3.0-31.0 C; 0.0-2.0 ppt; tributaries.

Notropis hudsonius (Clinton) - Spottail shiner. Freshwater, brackish. Resident. 9-125 mm. Young and adult - rare to uncommon; March-November; 4.5-31.5 C; 0.0-10.0 ppt; shore zone, tributaries.

Semotilus atromaculatus (Mitchill) - Creek chub. Freshwater. Stray. 51 mm. Adult - rare (one specimen); February; 18.0 C; 0.0 ppt; tributaries.

Family Catostomidae

Catostomus commersoni (Lacépède) - White sucker. Freshwater. Resident. 157, 158 mm. Adult - rare; June, July; 21.0-25.7 C; 0.0-2.0 ppt; tributaries.

Erimyzon oblongus (Mitchill) - Creek chubsucker. Freshwater. Resident. 21 mm. Young - rare to uncommon; June, July; 21.0-26.0 C; 0.0 ppt; tributaries.

Order Siluriformes
Family Ictaluridae

Ictalurus catus (Linnaeus) - White catfish. Freshwater, brackish. Resident. 19-480 mm. Young and adult - uncommon to common; February-December; 2.1-31.5 C; 0.0-10.0 ppt; offshore, shore zone, tributaries.

Ictalurus nebulosus (Lesueur) - Brown bullhead. Freshwater, brackish. Resident. 32-375 mm. Larvae - rare; June; 18.6 C; 0.0 ppt. Young and adult - common; January-December; 0.5-30.0 C; 0.0-12.0 ppt; offshore, shore zone, tributaries.

Ictalurus punctatus (Rafinesque) - Channel catfish. Freshwater, brackish. Resident. 19-515 mm. Young and adult - uncommon to common; January-December; 2.5-30.0 C; 0.0-11.0 ppt; offshore, shore zone, tributaries.

Order Batrachoidiformes
Family Batrachoididae

Opsanus tau (Linnaeus) - Oyster toadfish. Estuarine. Summer feeder. 12-261 mm. Larvae - rare; October; 13.0-14.0 C; 5.5-8.5 ppt. Young and adult - uncommon; May-October; 17.0-29.5 C; 5.0-15.5 ppt; offshore.

Order Gadiformes
Family Gadidae

Merluccius bilinearis (Mitchill) - Silver hake. Marine, brackish. Stray. 45-99 mm. Young - rare; April, November; 4.8-12.5 C; 2.0-8.0 ppt; offshore.

Urophycis chuss (Walbaum) - Red hake. Marine, brackish. Nursery, spring feeder. 37-160 mm. Young - rare to uncommon; March-June; 3.0-19.8 C; 0.0-12.0 ppt; offshore.

Urophycis regius (Walbaum) - potted hake. Marine, brackish. Nursery, spring feeder. 38-196 mm. Young - rare to common; January, March-July, November; 1.3-26.0 C; 0.0-12.0 ppt; offshore, shore zone.

Family Ophidiidae

Rissola marginata (DeKay) - Striped cusk-eel. Marine, brackish. Summer feeder. 24-227 mm. Young and adult - rare to common; April-November; 3.0-30.0 C; 1.0-15.5 ppt; offshore, shore zone, tributaries.

Order Atheriniformes
Family Exocoetidae

Hyporhamphus unifasciatus (Ranzani) - Halfbeak. Marine, brackish. Stray. 38-44 mm. Young - rare; June; 24.7-25.0 C; 4.0-7.0 ppt; shore zone.

Family Belonidae

Strongylura marina (Walbaum) - Atlantic needlefish. Marine, brackish, freshwater. Summer feeder. 48-390 mm. Young and adult - rare to uncommon; June-September; 20.0-31.5 C; 0.0-11.0 ppt; offshore, shore zone, tributaries.

Family Cyprinodontidae

Cyprinodon variegatus Lacépède - Sheepshead minnow. Estuarine. Summer feeder. 28-49 mm. Young and adult - rare; April, June, October-December; 4.1-20.0 C; 0.0-9.5 ppt; shore zone, tributaries.

Fundulus spp. Eggs - rare; May; 16.9 C; 1.0 ppt. Larvae - rare to common; May-August; 16.1-29.0 C; 0.0-8.0 ppt; 7.0 mm.

Fundulus diaphanus (Lesueur) - Banded killifish. Brackish, freshwater. Resident. 9-108 mm. Young and adult - common to abundant; January-December; 1.0-31.0 C; 0.0-10.0 ppt; shore zone, tributaries.

Fundulus heteroclitus (Linnaeus) - Mummichog. Estuarine. Resident. 9-108 mm. Young and adult - common to abundant; January-December; 0.2-32.0 C; 0.0-15.0 ppt; offshore, shore zone, tributaries. (See Text).

Fundulus majalis (Walbaum) - Striped killifish. Estuarine. Summer feeder. 17-182 mm. Young and adult - rare to uncommon; March-December; 4.0-32.8 C; 0.0-10.5 ppt; offshore, shore zone, tributaries.

Lucania parva (Baird) - Rainwater killifish. Estuarine. Summer feeder. 26-29 mm. Young and adult - rare; July, October; 13.3-26.7 C; 0.0-8.5 ppt; shore zone.

Family Poeciliidae

Gambusia affinis (Baird and Girard) - Mosquitofish. Brackish, freshwater. Resident. 20-22 mm. Adult - rare; July, October; 15.0-31.0 C; 0.0 ppt; tributaries.

Family Atherinidae

Membras sp./Menidia spp. Eggs - uncommon; May-August; 18.0-27.8 C; 0.0-8.0 ppt. Larvae - common; May-September; 17.2-30.0 C; 0.0-13.0 ppt; 3-18 mm.

Membras martinica (Valenciennes) - Rough silverside. Estuarine. Summer feeder. 14-105 mm. Young and adult - uncommon to common; May-October; 12.8-32.8 C; 0.0-9.5 ppt; offshore, shore zone, tributaries. (See Text).

Menidia beryllina (Cope) - Tidewater silverside. Estuarine. Resident. 10-100 mm. Young and adult - common to abundant; January, March-December; 0.2-31.0 C; 0.0-20.0 ppt; offshore, shore zone, tributaries. (See Text).

Menidia menidia (Linnaeus) - Atlantic silverside. Estuarine. Resident. 10-125 mm. Young and adult - very abundant; January-December; 0.2-32.8 C; 0.0-15.0 ppt; offshore, shore zone, tributaries. (See Text).

Order Gasterosteiformes
Family Gasterosteidae

Apeltes quadracus (Mitchill) - Fourspine stickleback. Estuarine. Winter feeder. 34-48 mm. Adult - rare; February-May; 6.0-22.5 C; 0.0-2.0 ppt; shore zone, tributaries.

Gasterosteus aculeatus Linnaeus - Threespine stickleback. Anadromous. Winter feeder. 21-70 mm. Larvae - rare; May; 16.1 C; 2.0 ppt. Young and adult - rare to uncommon; January-May; 2.0-19.1 C; 0.0-6.0 ppt; offshore, shore zone, tributaries.

Family Syngnathidae

Hippocampus erectus Perry - Lined seahorse. Marine, brackish. Stray. Adult - rare (one specimen); April; 5.5 C; 8.0 ppt; offshore.

Syngnathus fuscus Storer - Northern pipefish. Estuarine. Nursery, summer feeder. 11-220 mm. Larvae - uncommon; June - August; 21.0-27.3 C; 4.0-12.0 ppt. Young and adult - uncommon to common; April-December; 5.9-29.5 C; 0.0-17.0 ppt; offshore, shore zone, tributaries.

Order Perciformes
Family Percichthyidae

Morone americana (Gmelin) - White perch. Anadromous - estuarine. Resident. 3-325 mm. Eggs - uncommon; April-May; 11.0-20.0 C; 0.0-5.0 ppt. Larvae - uncommon; April-July; 11.0-28.7 C; 0.0-6.0 ppt. Young and adult - abundant to very abundant; January-December; 0.2-31.3 C; 0.0-20.0 ppt; offshore, shore zone, tributaries. (See Text).

Morone saxatilis (Walbaum) - Striped bass. Anadromous - marine. Migratory, nursery, summer feeder. 4-950 mm. Eggs - uncommon; April-June; 11.0-22.7 C; 0.0-5.0 ppt. Larvae - uncommon; April-June; 11.0-22.3 C; 0.0-2.5 ppt. Young and adult - common to abundant; January-December; 1.0-29.8 C; 0.0-14.5 ppt; offshore, shore zone, tributaries. (See Text).

Family Serranidae

Centropristis striata (Linnaeus) - Black sea bass. Marine, brackish. Stray. 52-141 mm. Young - rare; April, May, August, October; 12.5-24.2 C; 0.0-12.0 ppt; offshore.

Family Centrarchidae

Enneacanthus gloriosus (Holbrook) - Bluespotted sunfish. Freshwater, brackish. Stray. 20-76 mm. Young and adult - rare; July-September; 24.0-27.8 C; 0.0 ppt; tributaries.

Lepomis spp. Larvae - rare; June; 26.0-29.0 C; 1.0 ppt; 12 mm.

Lepomis gibbosus (Linnaeus) - Pumpkinseed. Freshwater, brackish. Resident. 10-164 mm. Young and adult - uncommon to common; January-December; 1.8-31.0 C; 0.0-8.0 ppt; offshore, shore zone, tributaries.

Lepomis macrochirus Rafinesque - Bluegill. Freshwater, brackish. Resident. 8-189 mm. Young and adult - uncommon to abundant; January-December; 3.0-31.0 C; 0.0-8.5 ppt; offshore, shore zone, tributaries.

Micropterus dolomieui Lacépède - Smallmouth bass. Freshwater, brackish. Stray. 93-111 mm. Young - rare; August; 29.9 C; 1.0 ppt; tributaries.

Micropterus salmoides (Lacépède) - Largemouth bass. Freshwater, brackish. Resident. 18-330 mm. Young and adult - rare to uncommon; March-December; 4.9-29.1 C; 0.0-2.5 ppt; offshore, shore zone, tributaries.

Pomoxis annularis Rafinesque - White crappie. Freshwater, brackish. Resident. 20-209 mm. Young and adult - rare to uncommon; April-October, December; 4.8-28.8 C; 0.0-5.0 ppt; offshore, shore zone, tributaries.

Pomoxis nigromaculatus (Lesueur) - Black crappie. Freshwater, brackish. Resident. 10-255 mm. Young and adult - uncommon to common; January, March-December; 3.0-31.5 C; 0.0-6.5 ppt; offshore, shore zone, tributaries.

Family Percidae

Etheostoma olmstedi Storer - Tessellated darter. Freshwater, brackish. Resident. 0-97 mm. Young and adult - uncommon to common; January-December; 4.3-29.9 C; 0.0-8.0 ppt; shore zone, tributaries.

Perca flavescens (Mitchill) - Yellow perch. Freshwater, brackish. Resident. 7-310 mm. Larvae - rare; April; 7.0-12.0 C; 0.0-2.0 ppt. Young and adult - uncommon to common; January-December; 0.2-30.0 C; 0.0-10.0 ppt; offshore, shore zone, tributaries.

Family Pomatomidae

Pomatomus saltatrix (Linnaeus) - Bluefish. Marine, brackish. Nursery, summer feeder. 24-725 mm. Young and adult - common; May-November; 11.5-32.8 C; 0.0-15.0 ppt; offshore, shore zone, tributaries.

Family Carangidae

Caranx hippos (Linnaeus) - Crevalle jack. Marine, brackish. Nursery, summer feeder. 34-165 mm. Young - uncommon to common; June-November; 11.9-30.0 C; 0.0-1.5 ppt; offshore, shore zone.

Selene vomer (Linnaeus) - Lookdown. Marine, brackish. Stray. 22-78 mm. Young - rare; July-September; 20.0-28.1 C; 5.0-15.0 ppt; offshore, shore zone.

Family Sparidae

Lagodon rhomboides (Linnaeus) - Pinfish. Marine, brackish. Stray. 93 mm. Young - rare; August; 25.5 C; 5.0 ppt; shore zone.

Family Sciaenidae

Bairdiella chrysura (Lacépède) - Silver perch. Marine, brackish, freshwater. Nursery, summer feeder. 2-210 mm. Larvae - rare; June-August; 17.5-27.5 C; 2.0-8.0 ppt. Young and adult - rare to common; June-November; 10.3-29.5 C; 0.0-15.0 ppt; offshore, shore zone, tributaries.

Cynoscion regalis (Bloch and Schneider) - Weakfish. Marine, brackish, freshwater. Nursery, summer feeder. 2-690 mm. Eggs - uncommon to common; June, July; 24.2-27.0 C; 2.0-13.0 ppt. Larvae - common; May-September; 19.0-28.1 C; 0.0-13.0 ppt. Young and adult - abundant to very abundant, April-November; 6.0-32.0 C; 0.0-20.0 ppt; offshore, shore zone, tributaries. (See Text).

Leiostomus xanthurus Lacépède - Spot. Marine, brackish, freshwater. Nursery, summer feeder. 13-250 mm. Larvae - uncommon; April-June; 10.3-27.8 C; 0.0-11.0 ppt. Young and adult - rare to very abundant; March-December; 4.8-30.0 C; 0.0-17.0 ppt; offshore, shore zone, tributaries. (See Text).

Menticirrhus saxatilis (Bloch and Schneider) - Northern kingfish. Marine, brackish. Stray. Young - rare (one specimen); November.

Micropogon undulatus (Linnaeus) - Atlantic croaker. Marine, brackish, freshwater. Nursery, fall feeder. 6-301 mm. Larvae - uncommon; September-December; 2.3-28.5 C; 0.0-10.0 ppt. Young and adult - rare to very abundant; January, March-December; 0.2-30.0 C; 0.0-17.0 ppt; offshore, shore zone, tributaries. (See text).

Pogonias cromis (Linnaeus) - Black drum. Marine, brackish, freshwater. Nursery. 7-201 mm. Larvae - rare; June; 28.5 C; 1.0 ppt. Young - rare to common; June-December; 7.0-32.8 C; 0.0-13.0 ppt; offshore, shore zone, tributaries.

Family Chaetodontidae

Chaetodon ocellatus Bloch - Spotfin butterflyfish. Marine. Stray. 20 mm. Young - rare (one specimen); August; 27.0 C; 5.0 ppt; offshore.

Family Mugilidae

Mugil cephalus Linnaeus - Striped mullet. Marine, brackish. Summer feeder. 25-318 mm. Young and adult - rare; March, April, June, August-October; December; 5.0-27.1 C; 0.0-7.5 ppt; shore zone.

Mugil curema Valenciennes - White mullet. Marine, brackish. Stray. 29 mm. Young - rare; April, June, July, November; 12.5-29.6 C; 0.0-8.0 ppt; shore zone.

Family Uranoscopidae

Astroscopus guttatus Abbott - Northern stargazer. Marine, brackish. Stray. 14-106 mm. Young - rare to uncommon; 10.0-28.0 C; 5.0-15.0 ppt; offshore, shore zone.

Family Ammodytidae

Ammodytes sp. - Sand lance. Larvae - rare; March, April; 5.5-8.5 C; 1.0-7.0 ppt; 9-17 mm.

Family Gobiidae

Gobiosoma bosci (Lacépède) - Naked goby. Estuarine. Resident. 2-49 mm. Larvae - abundant; June-October; 13.0-30.2 C; 0.0-13.0 ppt. Young and adult - rare to common; January-March, June-December; 0.6-30.0 C; 0.0-12.0 ppt; offshore, shore zone, tributaries. (See Text).

Gobiosoma ginsburgi Hildebrand and Schroeder - Seaboard goby. Marine, brackish. Stray. 48 mm. Adult - rare; April; 6.0 C; 4.0 ppt; offshore.

Family Scombridae

Scomber scombrus Linnaeus - Atlantic mackerel. Marine. Stray. 324 mm. Adult - rare (one specimen); May; 12.0 C; 4.0 ppt; offshore.

Scomberomorus maculatus (Mitchill) - Spanish mackerel. Marine. Stray. 370 mm. Adult - rare (one specimen); July; 25.5 C; 10.0 ppt; offshore.

Family Stromateidae

Peprilus triacanthus (Peck) - Butterfish. Marine, brackish. Summer feeder. 34-184 mm. Young and adult - rare to uncommon; April, August-November; 12.2-27.0 C; 4.0-13.0 ppt; offshore.

Family Triglidae

Prionotus carolinus (Linnaeus) - Northern searobin. Marine, brackish. Stray. 53-168 mm. Young and adult - rare; April, July, September; 6.2-26.0 C; 2.0-12.0 ppt; offshore.

Prionotus evolans (Linnaeus) - Striped searobin. Marine, brackish. Summer feeder. 23 mm. Young - rare to uncommon; April-October; 10.0-28.1 C; 2.0-13.0 ppt; offshore, shore zone.

Order Pleuronectiformes
Family Bothidae

Etropus microstomus (Gill) - Smallmouth flounder. Marine, brackish. Stray. 16-68 mm. Young and adult - rare; March, April, June, August; 4.0-26.0 C; 3.5-12.0 ppt; offshore, shore zone.

Paralichthys dentatus (Linnaeus) - Summer flounder. Marine, brackish. Summer feeder. 15-483 mm. Larvae - rare; March, April, December; 4.6-9.0 C; 0.0-6.0 ppt. Young and adult - rare to common; April-November; 4.6-28.1 C; 0.0-15.0 ppt; offshore, shore zone.

Paralichthys oblongus (Mitchill) - Fourspot flounder. Marine, brackish. Stray. 31 mm. Young - rare (one specimen); April; 26.9 C; 4.0 ppt; offshore.

Scophthalmus aquosus (Mitchill) - Windowpane. Marine, brackish. Stray. 6-208 mm. Larvae - rare; May, July; 20.5-26.2 C; 2.0-6.0 ppt. Young and adult - rare to uncommon; March-July, September-November; 6.8-28.0 C; 0.0-14.5 ppt; offshore, shore zone.

Family Pleuronectidae

Pseudopleuronectes americanus (Walbaum) - Winter flounder. Marine, brackish. Nursery, summer feeder. 33-175 mm. Larvae - rare; April, July; 7.2-27.1 C; 0.0-5.0 ppt. Young - rare to uncommon; June-December; 8.8-30.5 C; 0.0-12.0 ppt; offshore, shore zone, tributaries.

Family Soleidae

Trinectes maculatus (Bloch and Schneider) - Hogchoker. Estuarine. Nursery, summer feeder. 2-253 mm. Eggs - rare; July; 22.0-25.0 C; 4.0-12.0 ppt. Larvae - uncommon; July, August; 24.8-29.0 C; 1.5-13.0 ppt. Young and adult - abundant to very abundant; January-December; 0.6-31.0 C; 0.0-16.0 ppt; offshore, shore zone, tributaries. (See Text).

Family Cynoglossidae

Symphurus plagiusa (Linnaeus) - Blackcheek tonguefish. Marine, brackish. Stray. 30-153 mm. Young and adult - rare to uncommon; April-October; 10.9-26.0 C; 1.0-15.0 ppt; offshore.

Order Tetraodontiformes
Family Ostraciidae

Lactophrys triqueter (Linnaeus) - Smooth trunkfish. Marine. Stray. 12 mm. Young - rare (one specimen); September; 19.5 C; 3.0 ppt; offshore.

Family Tetraodontidae

Sphoeroides maculatus (Bloch and Schneider) - Northern puffer. Marine, brackish. Stray. 12-28 mm. Young - rare; July, August; 25.0-27.0 C; 4.0-15.0 ppt; offshore.

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