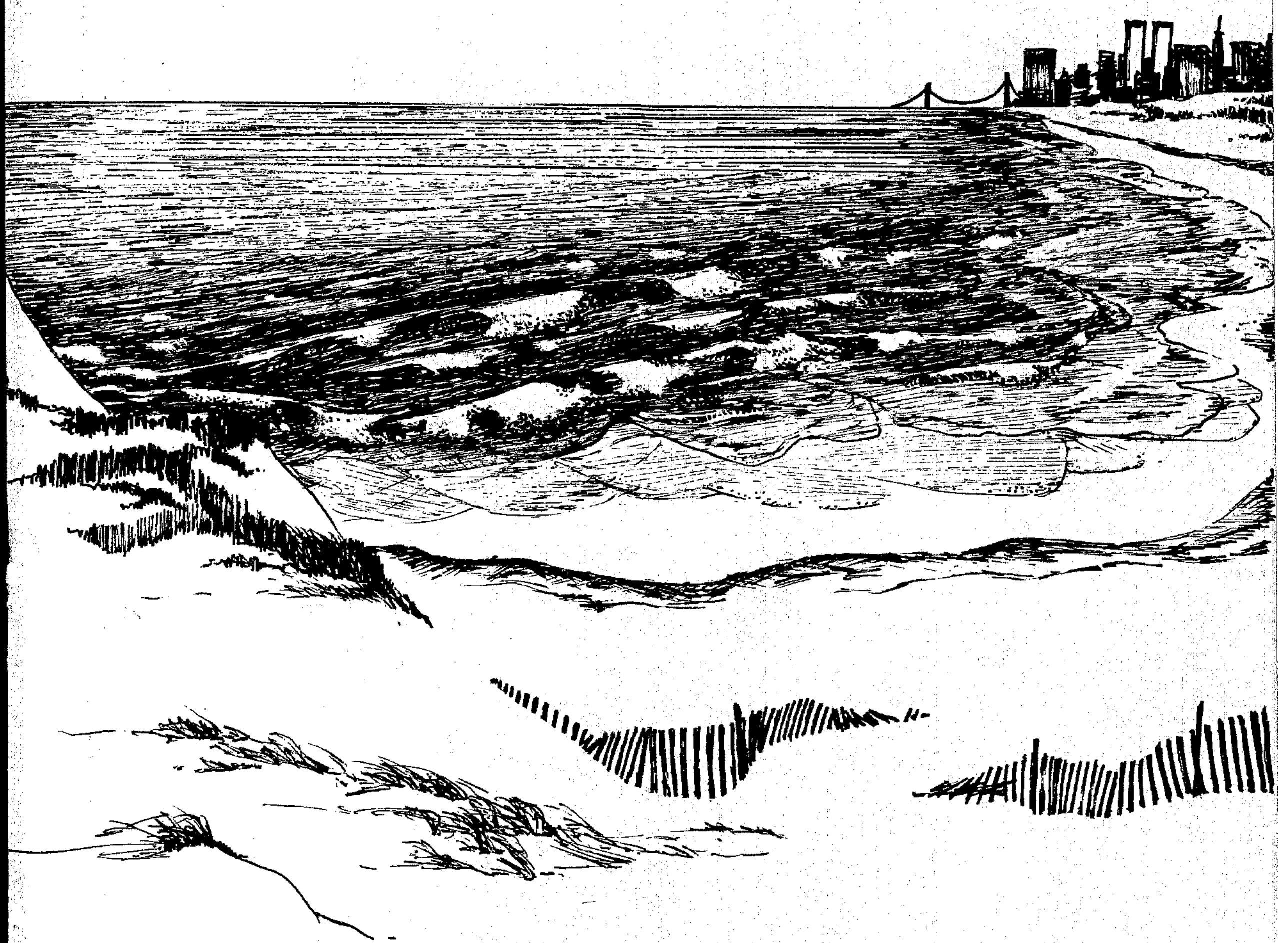
Plankton Systematics and Distribution

Thomas C. Malone



MESA NEW YORK BIGHT ATLAS MONOGRAPH 13

The offshore water in the bend of the Atlantic coastline from Long Island on one side to New Jersey on the other is known as New York Bight. This 15,000 square miles of the Atlantic coastal ocean reaches seaward to the edge of the continental shelf, 80 to 120 miles offshore. It's the front doorstep of New York City, one of the world's most intensively used coastal areas—for recreation, shipping, fishing and shellfishing, and for dumping sewage sludge, construction rubble, and industrial wastes. Its potential is being closely eyed for resources like sand and gravel—and oil and gas.

This is one of a series of technical monographs on the Bight, summarizing what is known and identifying what is unknown. Those making critical management decisions affecting the Bight region are acutely aware that they need more data than are now available on the complex interplay among processes in the Bight, and about the human impact on those processes. The monographs provide a jumping-off place for further research.

The series is a cooperative effort between the National Oceanic and Atmospheric Administration (NOAA) and the New York Sea Grant Institute. NOAA's Marine EcoSystems Analysis (MESA) program is responsible for identifying and measuring the impact of man on the marine environment and its resources. The Sea Grant Institute (of State University of New York and Cornell University, and an affiliate of NOAA's Sea Grant program) conducts a variety of research and educational activities on the sea and Great Lakes. Together, Sea Grant and MESA are preparing an atlas of New York Bight that will supply urgently needed environmental information to policy-makers, industries, educational institutions, and to interested people.

ATLAS MONOGRAPH 13 describes the distribution and abundance of phytoplankton and zooplankton species in New York Bight. Phytoplankton species composition in the Bight is strongly influenced by estuarine processes; zooplankton species composition is more strongly influenced by oceanic processes. Using published and unpublished data collected over the past 75 years, Malone summarizes the known plankton ecology in the Bight but concludes that this knowledge is of limited value. To more thoroughly understand plankton distribution and the effects of man's activities on plankton population in the Bight, it will be necessary to conduct more systematic observations using standardized methodologies.

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Plankton Systematics and Distribution

Thomas C. Malone

MESA NEW YORK BIGHT ATLAS MONOGRAPH **13**

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Contents

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Abstract

This paper uses published and unpublished data collected over the past 75 years to describe the distributions of phytoplankton and zooplankton species in New York Bight. Phytoplankton and zooplankton densities were found to decrease with distance from the Raritan-Hudson River estuary. Phytoplankton populations were dominated by diatoms (cold months) and chlorophytes (warm months) in the estuary and apex and by diatoms in the outer Bight. Zooplankton populations were dominated by copepods and meroplankton (summer only) in the estuary and by copepods in the Bight.

Among phytoplankton assemblages, the strongest similarities were between those in estuary waters and in apex waters; in the outer Bight, phytoplankton groups were different. Diatoms abundant throughout the area, both estuarine and Bight, were *Skeletonema costatum, Asterionella japonica, Leptocylindrus danicus, Thalassionema nitzschioides,* and *Chaetoceros debilis.* In the outer Bight, proportionately more of the following diatoms were present than in apex waters: *Rhizosolenia alata, Rhizosolenia faeroense, Chaetoceros socialis,* and *Nitzschia closterium.* Peaks in diatom abundance occurred from late autumn through spring in the apex and during winter in the outer Bight. Nanoplankton, dominated by the chlorophyte *Nannochloris atomus,* became abundant during summer and early autumn in estuarine waters and in the apex.

Among zooplankton assemblages—in contrast to phytoplankton--the strongest similarities were between those in the apex and in the outer Bight. The zooplankton of the apex and outer Bight were dominated by estuarine-marine *(Oithona similis),* euryhaline-marine *(Paracalanus parvus, Pseudocalanus minutus, Temora longicornis),* and stenohaline-marine copepods *(Centropages typicus).* Warm-water, oceanic species, not reported at all from the estuary, were present throughout the Bight during summer and autumn months. Estuarine species assemblages were dominated by estuarine (*Eurytemora* spp.) and estuarine-marine (*Acartia* spp.) copepods and, during summer, by polychaete, lamellibranch, gastropod, and barnacle larvae.

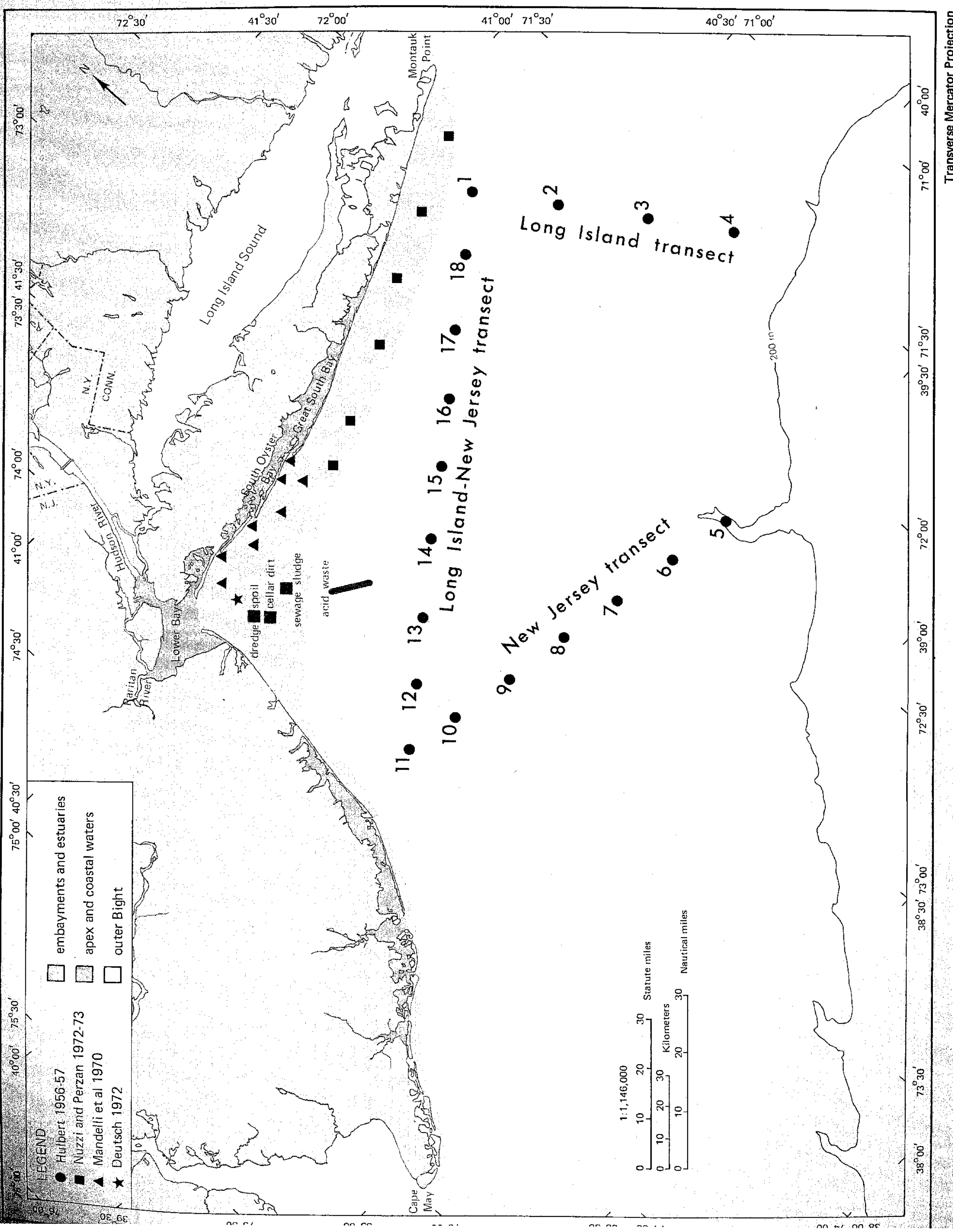
These observations suggest that phytoplankton species composition in New York Bight is strongly influenced by estuarine processes, whereas zooplankton species composition is more strongly influenced by oceanic processes. Increases in zooplankton abundance may reflect growth within the Bight or advective transport into the region. Decreases in copepod abundance during late summer and autumn appear to be due to ctenophore predation. The data are insufficient to assess the effects of man's activities on plankton populations in the Bight.

Introduction

Planktonic organisms, because of their small size, high surface area-to-volume ratios, and high metabolic rates, play an important role in the distribution, transfer, and recycling of materials in aquatic systems. In the New York-New Jersey metropolitan area, more and more trace metals, plant nutrients, organic compounds, and synthetic materials (for example, herbicides, pesticides, and plastics) are entering New York Bight through wastes discharged into the Raritan-Hudson River estuary and through ocean dumping. These activities, together with changes in the freshwater flows of the Hudson and Raritan rivers and in circulation patterns within the Bight itself, profoundly affect the species composition and production of plankton in the Bight. This in turn influences local fisheries, whose productivity depends on plankton food chains; not only fish abundance *per se* is affected but also quality (for example, concentrations of chlorinated hydrocarbons and heavy metals in the tissues of commercial fishes). Understanding the role of biological processes in the transport of materials in aquatic systems and the effects of human activities on commercial fish production and water quality depends on the extent to which spatial and temporal distributions of planktonic organisms are known or can be predicted. Unfortunately, as this monograph demonstrates, plankton research data in the Bight are too sketchy even to describe plankton distributions comprehensively, let alone determine or predict with certainty how human activities, such as waste disposal practices, have affected or will affect these distributions.

The explanation is simple. Sampling techniques are neither standardized nor intercalibrated. Data on

Map 1. General locator



species composition and abundance of organisms depend on the type of sampling device used, the depth or depth range sampled, and the time of day sampling was conducted, as well as time of year and location. The spatial distribution of stations in the Bight and the frequency of sampling with respect to hydrographic seasons and growth rates of the organisms have been so localized and sporadic that even broad, generalized descriptions of plankton distributions over the Bight as a whole cannot be generated at this time.

This report attempts to bring together existing information on the distribution and abundance of planktonic organisms in three general geographic areas: (1) embayments and estuaries adjacent to the Bight, (2) the Bight apex and coastal waters, and (3) the outer Bight (Map 1). This at least spotlights the large gaps in our knowledge and the need for broad, synoptic, geographic coverage and a coordinated time series approach to understand regulation of biological processes in marine environments.

Refer to the Glossary for definitions of terms.

Phytoplankton

This section summarizes the distributions of phytoplankton species occurring frequently enough to establish spatial or temporal patterns of distribution; a comprehensive description is not possible at this time. E.M. Hulburt's observations (1963, 1966, 1970; Hulburt and Rodman 1963) provide the only intensive information on phytoplankton species distribution presently available.

The strongest similarities among phytoplankton assemblages were between those in estuary waters and in apex waters; phytoplankton groups in the outer Bight were different.

Phytoplankton densities were found to decrease with distance from the Raritan-Hudson River estuary. Cell densities ranged from 10^6 to 10^9/liter in the estuary, compared with 10^4 to 10^7/liter in the apex and 10^3 to 10^5/liter in the outer Bight. Diatoms (cold months) and chlorophytes (warm months) were dominant in the estuary and apex; diatoms were dominant in the outer Bight.

Embayments and Estuaries

Long Island: Great South Bay and South Oyster Bay. The phytoplankton composition of Great South Bay is characterized by low species diversity and high dominance (Hulburt 1963, 1970). *Nannochloris atomus* dominated the summer phytoplankton, reaching cell densities of 1 to 3 x 10^9 cells/liter (Hulburt 1963, 1970; Lackey 1963, 1967). Hulburt (1963) also found the flagellate *Calycomonas gracilis* occasionally abundant during summer. *Thalassiosira pseudonana* reached cell densities of 3 x 10^8/liter in September 1958 (Hulburt 1970). *Chaetoceros simplex, Thalassiosira nana,* and *Chroomonas vectensis* were observed at cell densities above 10^6/liter.

Cassin (1973) reported that diatoms dominated the phytoplankton from May through October 1972. Mean cell density ranged from a May maximum of 3 x 10^6/liter to an October minimum of 0.3 x 10^6/liter. The diatoms *Navicula pelagica, Cylindrotheca closterium, Coscinodiscus radiatum, T. pseudonana,* and *Suriella striatula* dominated the May bloom. The diatoms *Skeletonema costatum, Cyclotella striata, C. closterium;* the dinoflagellate *Prorocentrum minimum;* and the euglenoid *Eutreptiella marina* were consistently abundant. *S. costatum* dominated the phytoplankton in August. The relative abundance of chlorophyte species, such as *N. atomus,* was not reported.

Lower Hudson and Raritan River Estuaries. The netplankton of Raritan Bay have been described by Patten (1962). Diatoms dominated the phytoplankton from late autumn through the spring bloom. *S. costatum, Chaetoceros decipiens,* and *Gyrosigma acumunatum* exhibited bimodal temporal distribution, with abundance peaking in spring and late summer. *S. costatum* dominated the spring bloom, reaching cell densities of 1.7 x 10^8/liter. The summer phytoplankton were dominated by *N. atomus, Prorocentrum micans, Peridinium trochoideum, Peridinium breve,* and *Peridinium divaricatum. N. atomus* dominated the late summer phytoplankton: cell densities were as high as 5.7 x 10^8/liter. Winter dominants included *Nitzschia seriata, Thalassionema nitzschioides, Leptocylindrus danicus, Rhizosolenia setigera,* *Rhizosolenia imbricata, Rhizosolenia alata, Guinardia flaccida, Melosira sulcata,* and *Actinoptychus undulatus. Coscinodiscus asteromphalus, Coscinodiscus subtilis,* and *Lithodesmium undulatum* were present throughout the year.

Quantitative observations of species abundance in Raritan Bay were made by Hulburt (personal communication) on whole water samples collected from May through November 1971. *S. costatum* exhibited peaks of 2.9 x 10^6 cells/liter in May and 5.2 x 10^6 cells/liter in September. *Asterionella japonica, Thalassiosira nordenskioldii, Chaetoceros debilis, Chaetoceros compressus,* and *L. danicus* were present in May but at cell densities less than 10^6/liter. The July species assemblage included *N. atomus, S. costatum,* and *T. nitzschioides. N. atomus* reached a maximum cell density of 1.3 x 10^8/liter in July, decreasing to 1.9 x 10^6/liter in September and 0.5 x 10^6/liter in November. *A. japonica, Schroederella delicatula,* and *Chaetoceros didymus* appeared at low cell densities (less than 10^5/liter) in November.

Observations have been made in Lower Bay by Deutsch (1972) and Hulburt (personal communication). Samples collected by Deutsch in February, March, and April 1972 show a *S. costatum* dominated bloom of diatoms peaking in late April (Figure 1). Five species accounted for over 85% of the total phytoplankton cell density; *S. costatum* contributed about 50% in February and March and over 90% in April. The cell density of *S. costatum* increased from a February low of 2.9 x 10^6 cells/liter to a late April maximum of 82.5 x 10^6 cells/liter. *A. japonica* followed the same trend, increasing from 0.05 x 10^6 to 2.8 x 10^6 cells/liter. *L. danicus* and *T. nitzschioides* remained relatively constant, fluctuating between 0.2 x 10^6 and 1.7 x 10^6 cells/liter; *T.*

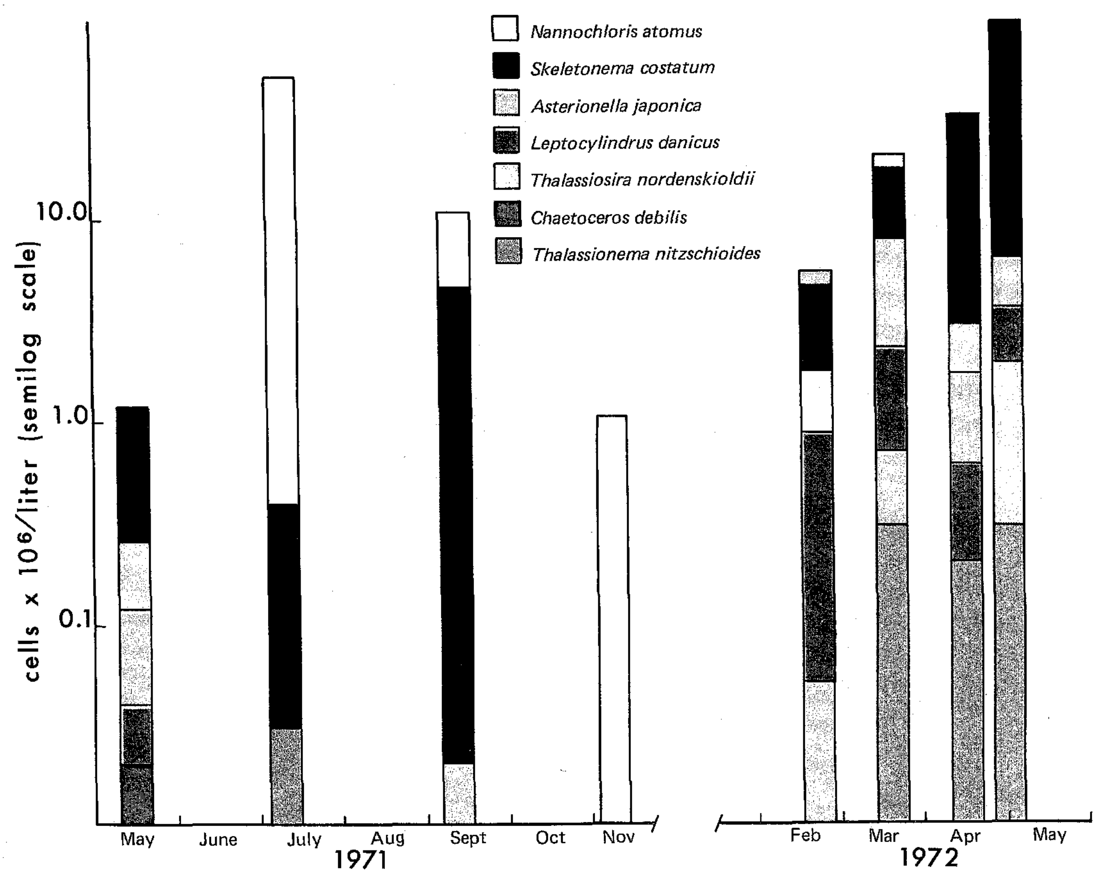


Figure 1. Phytoplankton species abundance in Lower Bay

nordenskioldii decreased from a March maximum of 5.5 x 10^6 cells/liter to a late April minimum of 1.6 x 10^6 cells/liter.

Hulburt's observations in Lower Bay were made in May, July, September, and November 1971 (Figure 1). *S. costatum* dominated the May and September phytoplankton, reaching a maximum cell density of 10.9 x 10^6/liter in September. The July and November phytoplankton were dominated by *N. atomus*, with cell densities of 50 x 10^6/liter and 6.2 x 10^6/liter, respectively. Other species included *A. japonica, T. nordenskioldii, Thalassiosira gravida, C. debilis, C. compressus, C. didymus, L. danicus, S. delicatula*, and *T. nitzschioides.*

Nuzzi and Perzan (1974) reported cell densities of 0.06 to 1.74 x 10^6/liter, based on surface samples collected from three stations across the mouth of Lower Bay in December 1972 and in January and May 1973 (Figure 2). Cell densities increased from a December minimum of 0.06 x 10^6/liter to a May maximum of 1.74 x 10^6/liter; *S. costatum* accounted for 60% to 80% of the cells. Other abundant species included *Paralia sulcata* and *T. nitzschioides* (December); *Thalassiosira subtilis, T. nordenskioldii,* and *T. nitzschioides* (January); and *A. japonica, Ceratium lineatum, Gymnodinium* sp., and *Ankistrodesmus falcatus* (May).

Summary. A total of 35 phytoplankton species have been reported in embayments adjacent to the Bight: 22 diatoms, 9 dinoflagellates, and 4 chlorophytes (Table 1). Of these, six of the dinoflagellates and eight of the diatoms have not been reported in the Bight. Cell densities ranged between 10^6 and 10^9/liter, with a winter minimum and spring and summer maxima. Diatoms dominated the winter-spring phytoplankton; the chlorophyte *N. atomus* dominated the summer phytoplankton. Dinoflagellates were also abundant during summer months. High cell densities during spring were due primarily to blooms of *S. costatum, A. japonica*, and *T. nordenskioldii.*

Apex and Coastal Waters

Apex. Phytoplankton species composition and cell densities in the Bight apex have been described by Deutsch (1972), Hulburt (personal communication), Mandelli et al (1970), Nuzzi and Perzan (1974), and Cassin (1973).

Hulburt's results are based on surface (top 1 m) samples collected from 12 stations during May, July, September, and November 1971 (Figure 3). Total cell density was highest in July (2 to 40 x 10^6/liter) and lowest in November (0.02 to 1 x 10^6/liter). This variation reflected changes in the abundance of *N.*

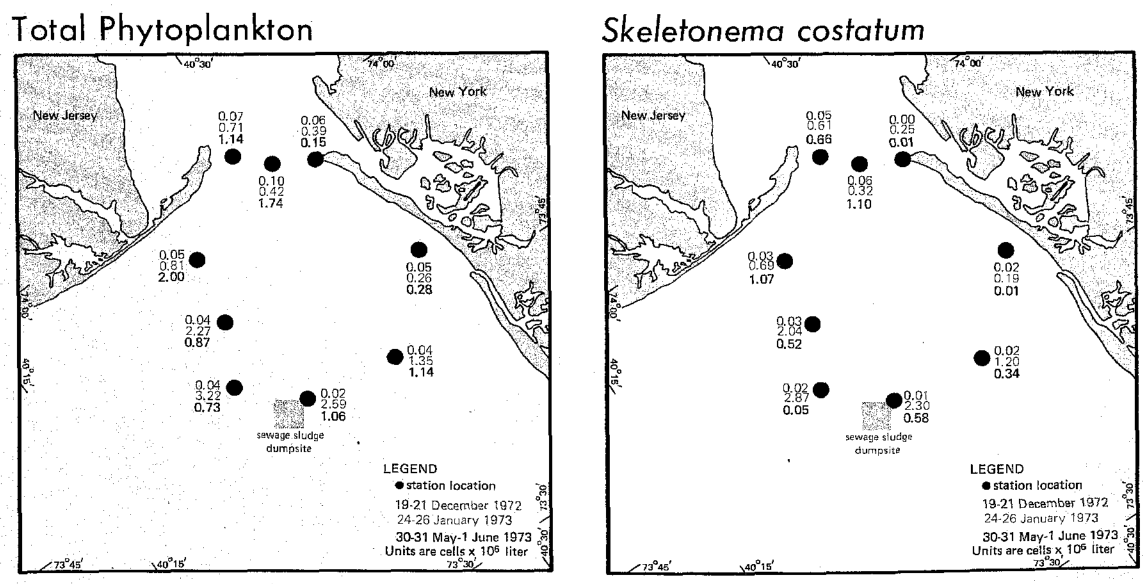


Figure 2. Phytoplankton cell densities in the apex

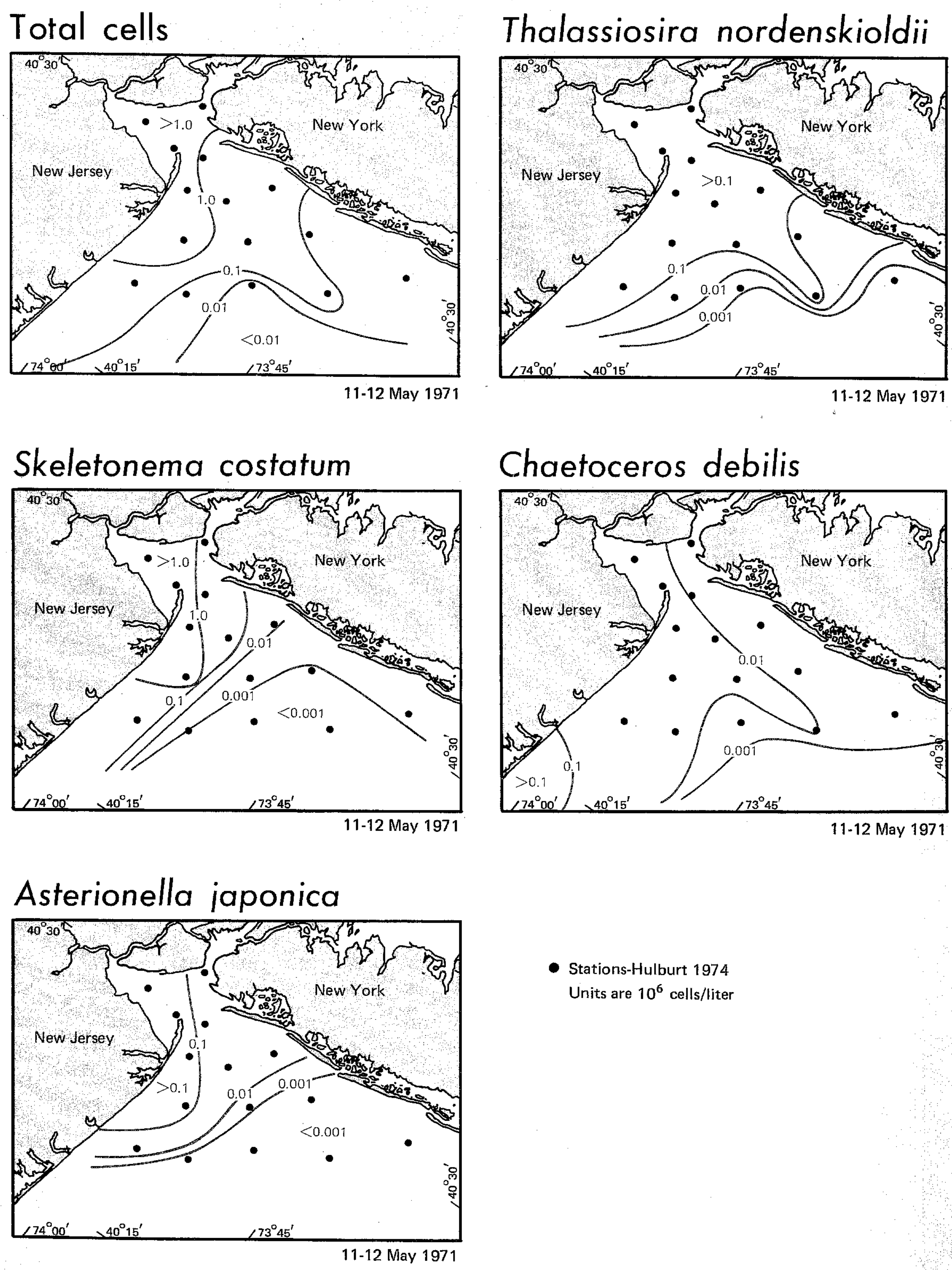
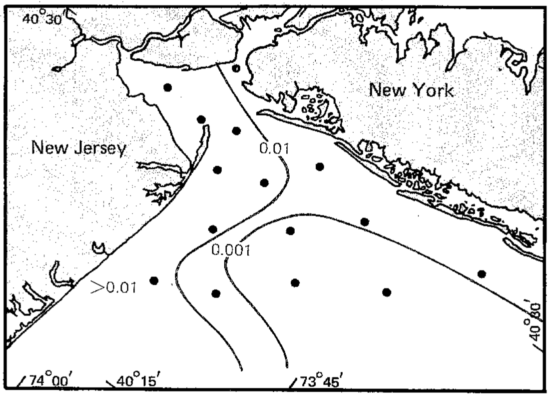


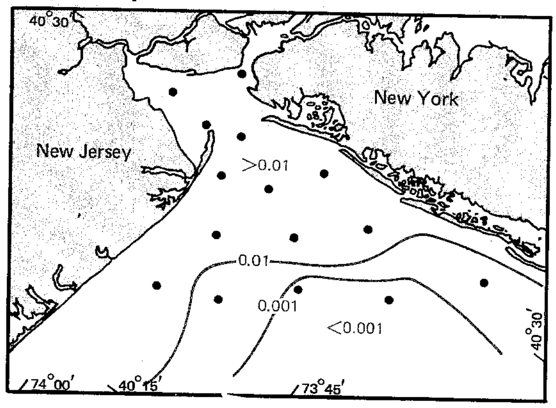
Figure 3. Phytoplankton distribution in the apex

Chaetoceros compressus



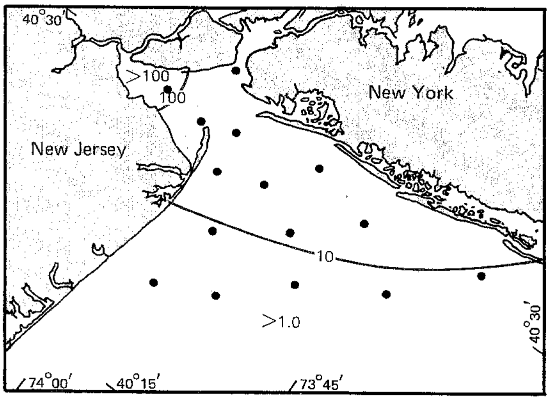
11-12 May 1971

Leptocylindricus danicus



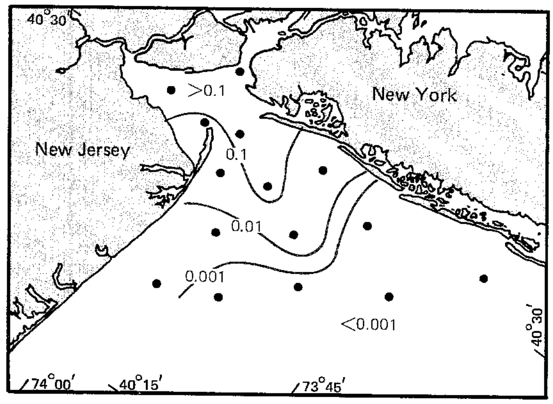
11-12 May 1971

Total cells



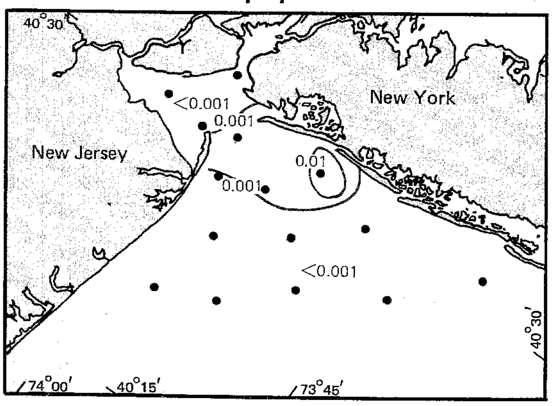
8-9 July 1971

Skeletonema costatum



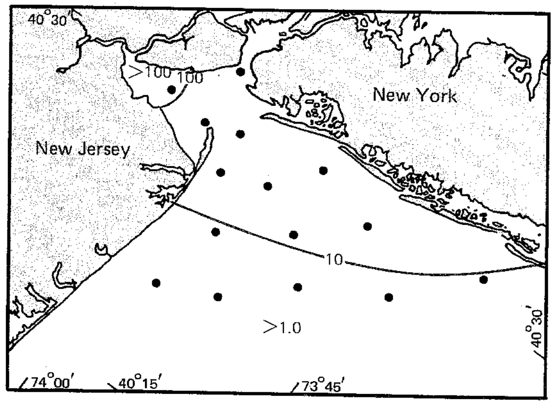
8-9 July 1971

Asterionella japonica



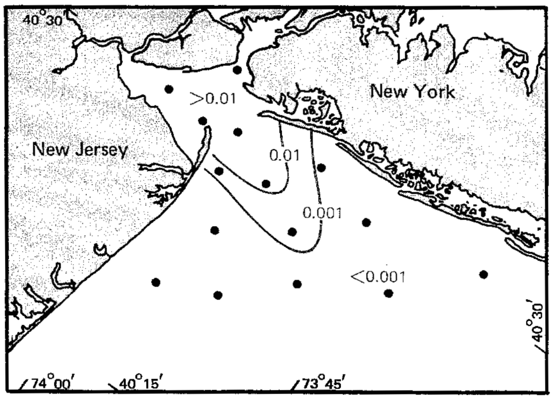
8-9 July 1971

Nannochloris atomus



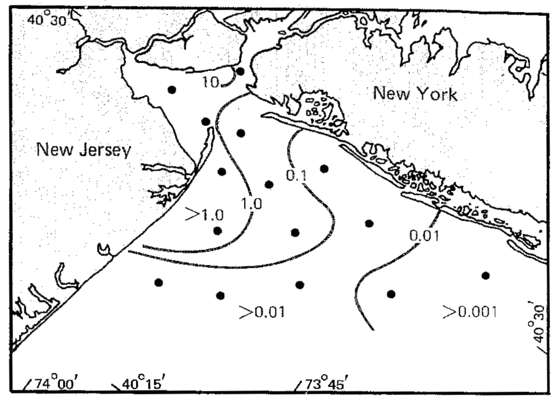
8-9 July 1971

Thalassionema nitzschioides



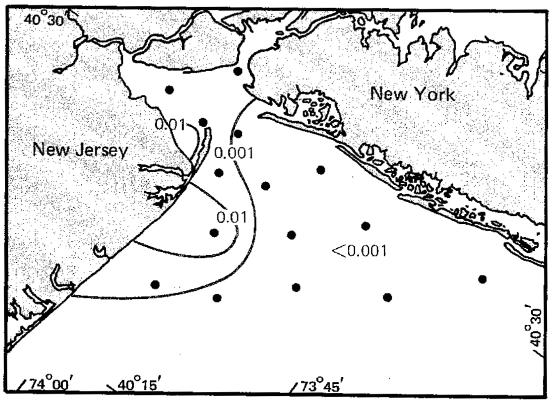
8-9 July 1971

Total cells



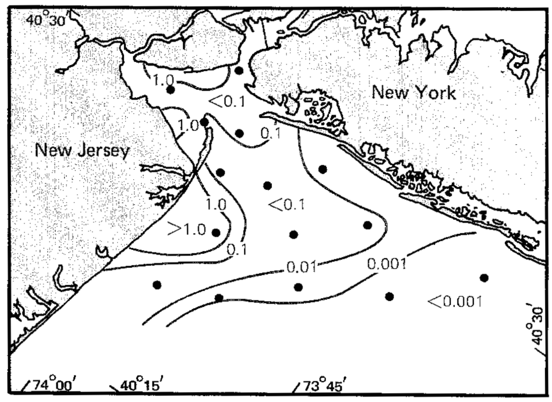
12-14 September 1971

Thalassiosira gravida



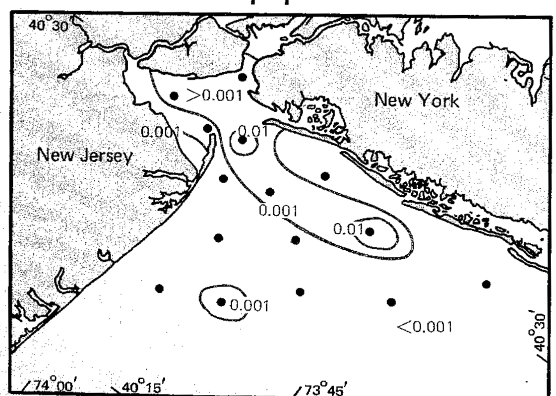
12-14 September 1971

Skeletonema costatum



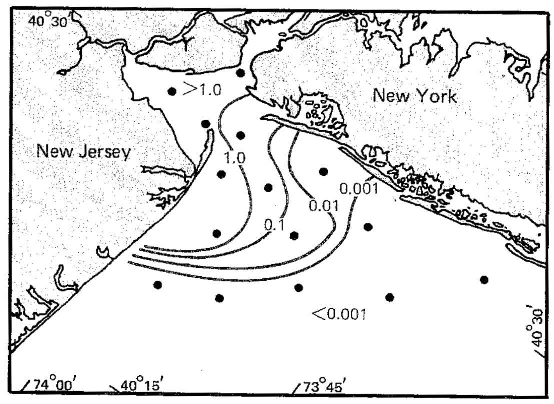
12-14 September 1971

Asterionella japonica



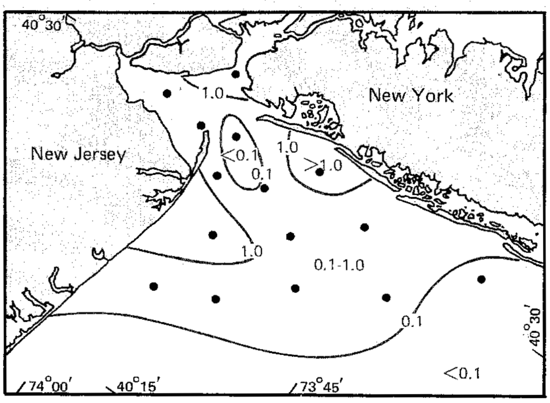
12-14 September 1971

Nannochloris atomus



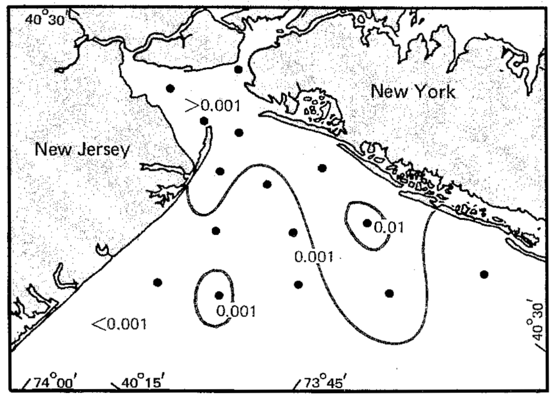
12-14 September 1971

Total cells



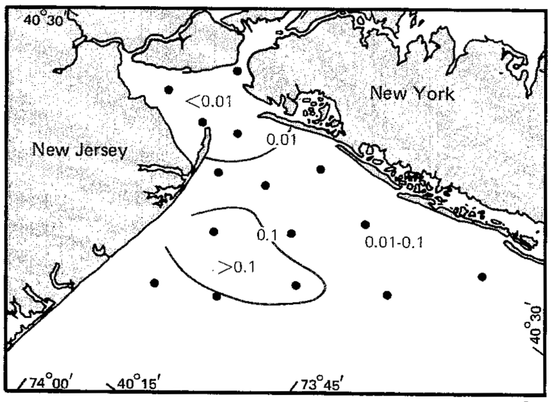
5-6 November 1971

Chaetoceros didymus



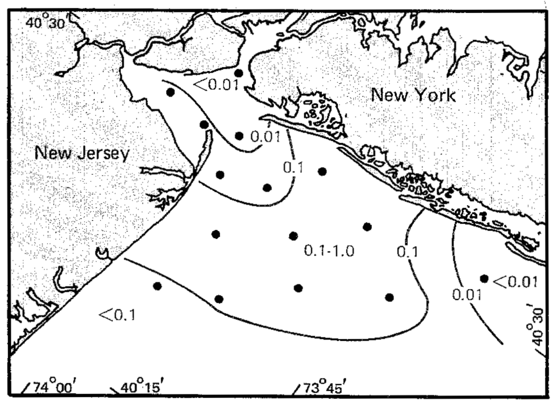
5-6 November 1971

Schroederella delicatula



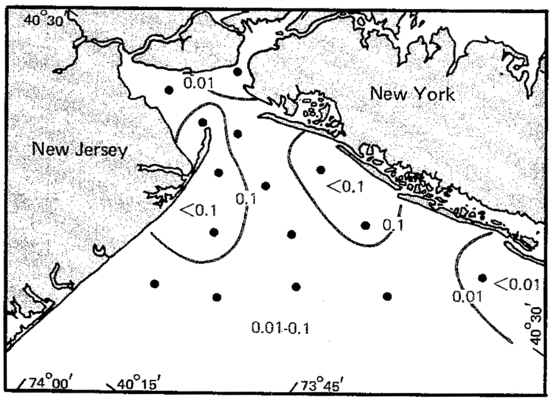
5-6 November 1971

Skeletonema costatum



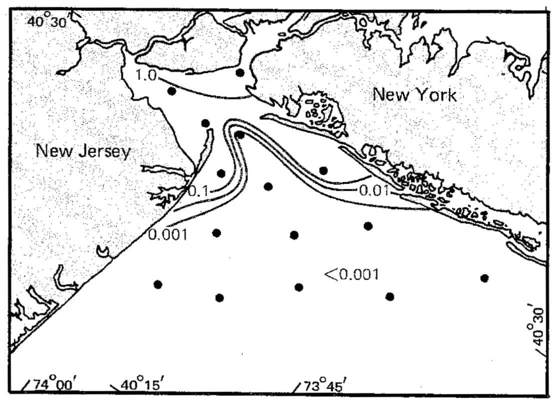
5-6 November 1971

Asterionella japonica



5-6 November 1971

Nannochloris atomus



5-6 November 1971

Source: Hulburt (personal communication) *atomus**, a chlorophyte most prolific at temperatures above 15°C (59°F) in organically enriched embayments (Ryther 1954). Diatom abundance exhibited bimodal distribution similar to that described by Patten (1962) in Raritan Bay. Cell density peaked in May (2.06×10^6/liter) and in September (1.18×10^6/liter), with a July minimum (0.30×10^6/liter).

The May, September, and November distributions described by Hulburt are characterized by tongues of high cell density extending into the apex from the New Jersey shore (Figure 3). A more uniform distribution of cells was observed in July when densities were highest near the mouth of Lower Bay. These distributions reflect the growth and dispersion of a relatively small number of estuarine and coastal species. The high cell densities observed off the New Jersey shore in May were due to *S. costatum* and *A. japonica;* both occur in the plankton throughout the year. Off Long Island, *T. nordenskioldii* and *C. debilis* dominated the May phytoplankton. The July phytoplankton consisted almost entirely of *N. atomus,* most abundant near the mouth of Lower Bay and along the southern shore of western Long Island. The July-September-November period was characterized by a decrease in the abundance and aerial distribution of *N. atomus,* a shift in the position of the center of maximum abundance from the mouth of Lower Bay to the New Jersey shore, and an increase in the abundance of diatoms dominated by *S. costatum, A. japonica,* and *S. delicatula.*

The winter phytoplankton, as described by Nuzzi and Perzan (1974), was dominated by diatoms. Total cell density increased from a mean of 0.04×10^6/liter in December to 2.05×10^6/liter in January (Figure 2). Most of this increase was due to a bloom of *S. costatum* near the sewage sludge dumping area. Other abundant species included *T. subtilis, T. decipiens, P. sulcata,* and *T. nitzschioides* in December; and *T. subtilis, T. nordenskioldii, T. nitzschioides,* and *Nitzschia closterium* in January. By the end of May, mean cell density had dropped to 1.16×10^6/liter, but *S. costatum* remained the dominant species; *A. japonica, Gymnodinium* sp., *C. lineatum,* and *A. falcatus* were also abundant.

Deutsch (1972) described a *S. costatum*-dominated spring bloom (Figure 4) at a station near Ambrose Light, west of the sewage sludge dumping area (Map 1). As total cell density increased from 10.1×10^6/liter in February 1972 to 96.5×10^6/liter by early May, the proportion of diatoms increased from 42% to 95%. *T. nitzschioides, T. nordenskioldii,* and *S. costatum* were the most abundant species in February, March, and April, respectively. By early May, *S. costatum* had increased from 0.04×10^6 cells/liter in February to 87×10^6 cells/liter and from 0.4% to 90% of total phytoplankton cells.

*Often confused with *Stichococcus* sp.

Table 1. Phytoplankton species abundance in embayments

Species	Season	Reference
CHLOROPHYTES		
Nannochloris atomus	sum	1,2,3,7
Ankistrodesmus falcatus	spr	6
Calycomonas gracilis	spr, sum	1
Chroomonas vectensis	sum	1
DINOFLAGELLATES		
**Glenodinium danicum*	sum	4
Gymnodinium splendens	sum	4
**Peridinium breve*	sum	7
**Peridinium divaricatum*	sum	7
**Peridinium trochoideum*	sum	4,7
**Gonyaulax spinifera*	sum	4,5
Prorocentrum micans	sum	1,4,7
Prorocentrum triangulatum	sum	4
**Exuviella lima*	sum	4,5
DIATOMS		
**Melosira sulcata*	win	7
Skeletonema costatum	win, spr, aut	1,2,6,7
Thalassiosira nordenskioldii	win, spr	1,2
Thalassiosira gravida	spr, aut	2,7
Thalassiosira pseudonana	aut	1
Coscinodiscus radiatum	spr	8
**Actinoptychus undulatus*	win	7
**Chaetoceros decipiens*	spr, aut	7
Chaetoceros curvisteus	spr	8
Chaetoceros didymus	spr	8
Leptocylindrus danicus	win, spr, sum	1,2,7
Guinardia flaccida	win, sum	1,7
Rhizosolenia alata	win, spr, sum	1,7
**Rhizosolenia setigera*	win	7
**Rhizosolenia imbricata*	win	7
Asterionella japonica	win, spr, aut	2,6,7
Thalassionema nitzschioides	win, spr, sum, aut	1,2,6,7
Nitzschia seriata	win, sum, aut	1,7
**Cylindrotheca closterium*	spr	8
**Gyrosigma acuminatum*	spr	7
**Navicula pelagica*	spr	8
Suriella striatula	spr	8

*Not reported in New York Bight

References: 1 Hulburt 1970
2 Hulburt, personal communication
3 Lackey 1967
4 Martin 1929
5 Mountford 1967
6 Nuzzi and Perzan 1974
7 Patten 1962
8 Cassin 1973

Mandelli and his associates (1970) described the species composition of the netplankton (No. 20 net) along the southern coast of western Long Island (see Map 1 for station locations). Phytoplankton biomass, as indicated by chlorophyll *a* concentration, peaked during autumn and late winter. Both these peaks were produced by *S. costatum* blooms. Diatoms dominated the September-March 1966 period; dinoflagellates were most abundant during the April-August 1966 period. Among the diatoms, *S. costatum, Thalassiosira* sp., *Chaetoceros* sp., and *R. alata* were successively abundant from September through December. This succession appeared to be repeated during February and March. *Peridinium depressum* and *Ceratium massilence* bloomed in April and May, respectively. *Ceratium tripos* was the dominant netplankton from June to August.

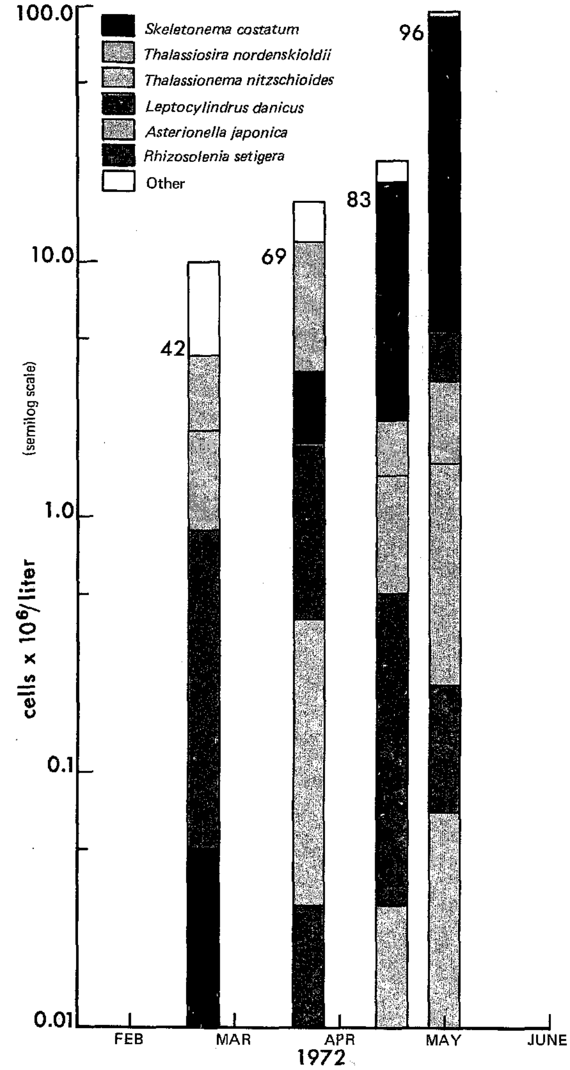


Figure 4. Variations in phytoplankton species abundance

In 1967 Mandelli and his associates (1970) observed the succession of netplankton species during a March phytoplankton bloom. *S. costatum* dominated the phytoplankton early in March. After two weeks the diatoms *T. nitzschioides, Rhizosolenia* sp., *A. japonica,* and *N. seriata* had surpassed *S. costatum* in abundance. During the last two weeks of the month an assemblage of dinoflagellate species, dominated by *C. tripos, Ceratium macroceros, Ceratium furca,* and *P. depressum,* became more abundant than the diatoms.

This alternating diatom and dinoflagellate abundance appears characteristic of shallow coastal waters off western Long Island. On the basis of monthly observations from May through October 1972, cell density ranged from 1.1 x 10^6/liter in late September to 0.2 x 10^6/liter in October. The dinoflagellates *Peridinium* spp., *Diplopsalsis lenticula, Dinophysis* spp., *Phalacroma rotundatum, Ceratium* spp., *Prorocentrum redfeldii,* and *Katodinium rotundatum* dominated during late spring and early summer, whereas the diatoms *S. costatum, Streptotheca tamesis,* and *Biddulphia biddulphiana* dominated the phytoplankton during August, September, and October, respectively.

Southern Long Island Coastal Waters. A phytoplankton survey was made along the southern coast of Long Island by Nuzzi and Perzan (1974) in December 1972, January and May 1973 (see Map 1 for station locations). Mean cell density increased from a December-January low of 0.07 x 10^6/liter (range = 0.03 to 0.21 x 10^6/liter) to a May high of 0.17 x 10^6/liter (range = 0.03 to 0.32 x 10^6/liter). The December-January phytoplankton was dominated by *T. nitzschioides, P. sulcata,* and *S. costatum; T. decipiens* and *N. closterium* were locally abundant. By late May, the phytoplankton species assemblage was dominated by *L. danicus, Chaetoceros* sp., and *Gymnodinium* sp. *N. closterium* and *S. costatum* were locally abundant.

Summary. Thirty-six phytoplankton species have been reported to occur abundantly (greater than 10^3 cells/liter) in the Bight apex and in coastal waters of southern Long Island: 16 diatoms, 17 dinoflagellates, and 3 chlorophytes. Cell densities ranged from 10^4 to 10^7/liter, two orders of magnitude less than the range of densities observed in adjacent embayments.

Maximum cell densities were recorded during summer and minimum during winter. This pattern reflected variations in the growth and dispersion of the chlorophyte *N. atomus*, which reached densities of 40 x 10^6 cells/liter near the mouth of Lower Bay. Diatom cell densities were highest (usually about 2 x 10^6/liter but as high as 90 x 10^6/liter) during autumn, winter, and spring, due primarily to periodic blooms of *S. costatum*. Maximum cell densities occurred off the New Jersey coast when diatoms dominated the phytoplankton and along the coast of western Long Island near the mouth of Lower Bay when chlorophytes (notably *N. atomus*) dominated. Cell densities were generally lower along the south shore of Long Island than in the apex. These patterns must be interpreted with care: because of the low frequency of observations, it is probable that peaks in abundance were not recorded.

Outer Bight

The taxonomic composition and species abundance of phytoplankton in offshore shelf waters have been described by Hulburt (1963, 1966, 1970) and Hulburt and Rodman (1963). Their papers are based on water samples collected during seven bimonthly cruises to the continental shelf during 1956 and 1957. Because of differences in species composition and cell density, the stations shown in Map 1 are divided into three transects and discussed separately: Long Island transect, stations 1-4; New Jersey transect, stations 5-11; and Long Island-New Jersey transect, stations 12-18. Table 2 summarizes the occurrence of species observed to exceed 10^4 cells/liter along the three transects.

Long Island Transect. Phytoplankton cell densities ranged from 10^3/liter to 2 x 10^5/liter and typically decreased with distance from shore (Figure 5). Cell densities exceeded 10^5/liter at station 1 in December due to a bloom of *T. nitzschioides* and in February when *S. costatum*, *Rhizosolenia faeroense*, and *T. nitzschioides* were the most abundant species. However, the highest cell density observed along this transect occurred at station 4 in March when *C. debilis* was the most abundant species.

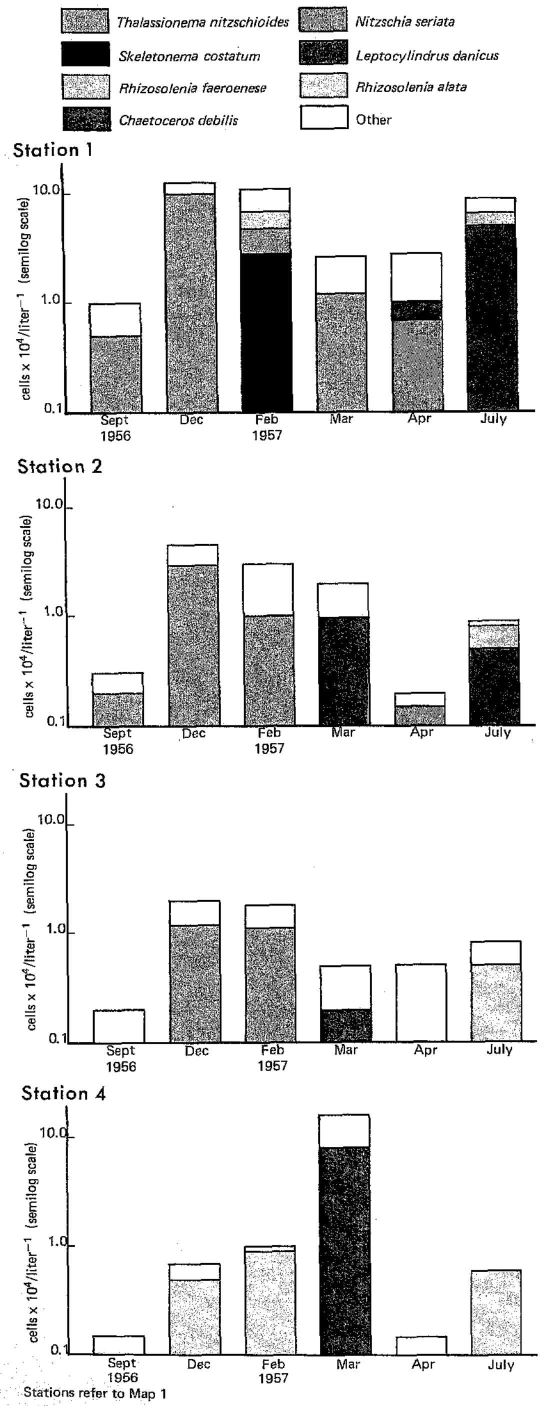


Figure 5. Phytoplankton species abundance, Long Island transect

New Jersey Transect. The outer Bight off the New Jersey coast was characterized by cell densities ranging from 2 x 10^3/liter to 7 x 10^5/liter. Cell density tended to decrease with distance from shore, but densities over 10^5/liter were often observed as far out as station 8 (Figure 6). Phytoplankton cell density was highest in December due to an inshore bloom of *S. costatum* and an offshore bloom of *T. nitzschioides.* Inshore, cell densities also exceeded 10^5/liter in February due to blooms of *A. japonica* and *T. nitzschioides,* in March when *Chaetoceros socialis* was the most abundant species, and in April when the flagellate *C. gracilis* bloomed.

Long Island-New Jersey Transect. Cell densities along this transect ranged between 3 x 10^3/liter and 7 x 10^5/liter and exhibited little seasonal and spatial variability, compared with the Long Island and New Jersey coastline transects (Figure 7). Maximum cell densities were observed in December when *S. costatum* and *T. nitzschioides* were most abundant and total cells exceeded 10^5/liter at all stations. In February, cell densities were greater than 10^5/liter at stations 14 through 18, due to the abundance of *A. japonica, S. costatum,* and *T. nitzschioides.* By March most of these species had declined in number, cell densities were low except at stations 13 and 14 where *C. socialis* reached cell densities of 3 to 9 x 10^5/liter.

Summary. Hulburt described 33 abundant phytoplankton species: 27 diatoms, 4 dinoflagellates, and 2 nanoflagellates. In contrast with inshore and estuarine waters, phytoplankton comminities in the outer Bight were dominated by diatoms during most of the year, except for a localized *C. gracilis* bloom at station 11 (Map 1) in April. Cell densities ranged between 10^3/liter and 10^6/liter, compared with 10^4 to 10^7/liter in the apex and 10^6 to 10^9/liter in embayments.

Cell densities decreased with distance from land along the New Jersey and Long Island transects. Maximum cell densities were observed in December (7 x 10^3 to 7 x 10^7/liter) and minimum densities in July (4 x 10^3 to 9 x 10^4/liter), paralleling variations in diatom abundance observed inshore. With the exception of the *C. gracilis* bloom in April at station 11, major pulses in phytoplankton abundance were due to four neritic diatom species: *S. costatum, A. japonica, C. socialis,* and *L. danicus.* Uniform distributions were exhibited by *R. alata* in July and September and by *T. nitzschioides* in December and February. The flagellates *Chilomonas marina, C. gracilis, C. lineatum, K. rotundatum, Oxytoxum variabile,* and *P. micans* were locally abundant but rarely dominant during April and July.

Table 2. Phytoplankton species with cell densities over 10^4 liter

Species	Station[a]	Month	Maximum Observed Density
LONG ISLAND TRANSECT			
Thalassionema nitzschioides	1	Dec	1 x 10^5
Skeletonema costatum	1	Feb	3 x 10^4
Rhizosolenia faeroense	1	Feb	2 x 10^4
Chaetoceros debilis	4	Mar	8 x 10^4
Leptocylindrus danicus	1	Jul	5 x 10^4
Rhizosolenia alata	1	Jul	2 x 10^4
NEW JERSEY TRANSECT			
Skeletonema costatum	10	Dec	6 x 10^5
Thalassionema nitzschioides	9	Dec	7 x 10^4
Rhizosolenia alata	11	Dec	2 x 10^4
Asterionella japonica	11	Feb	1 x 10^5
Rhizosolenia delicatula	8	Feb	2 x 10^4
Chaetoceros socialis	8, 10	Mar	1 x 10^5
Calycomonas gracilis	11	Apr	9 x 10^4
LONG ISLAND-NEW JERSEY TRANSECT			
Nitzschia closterim	17	Sept	2 x 10^4
Rhizosolenia alata	12-15, 17	Sept	1 x 10^4
Skeletonema costatum	12	Dec	5 x 10^5
Thalassionema nitzschioides	17, 18	Dec	1 x 10^5
Rhizosolenia faeroense	17	Feb	4 x 10^4
Chaetoceros socialis	13	Mar	9 x 10^5
Chaetoceros debilis	18	Apr	2 x 10^4

[a]Stations refer to Map 1

Sources: Hulburt 1963, 1966, 1970; Hulburt and Rodman 1963

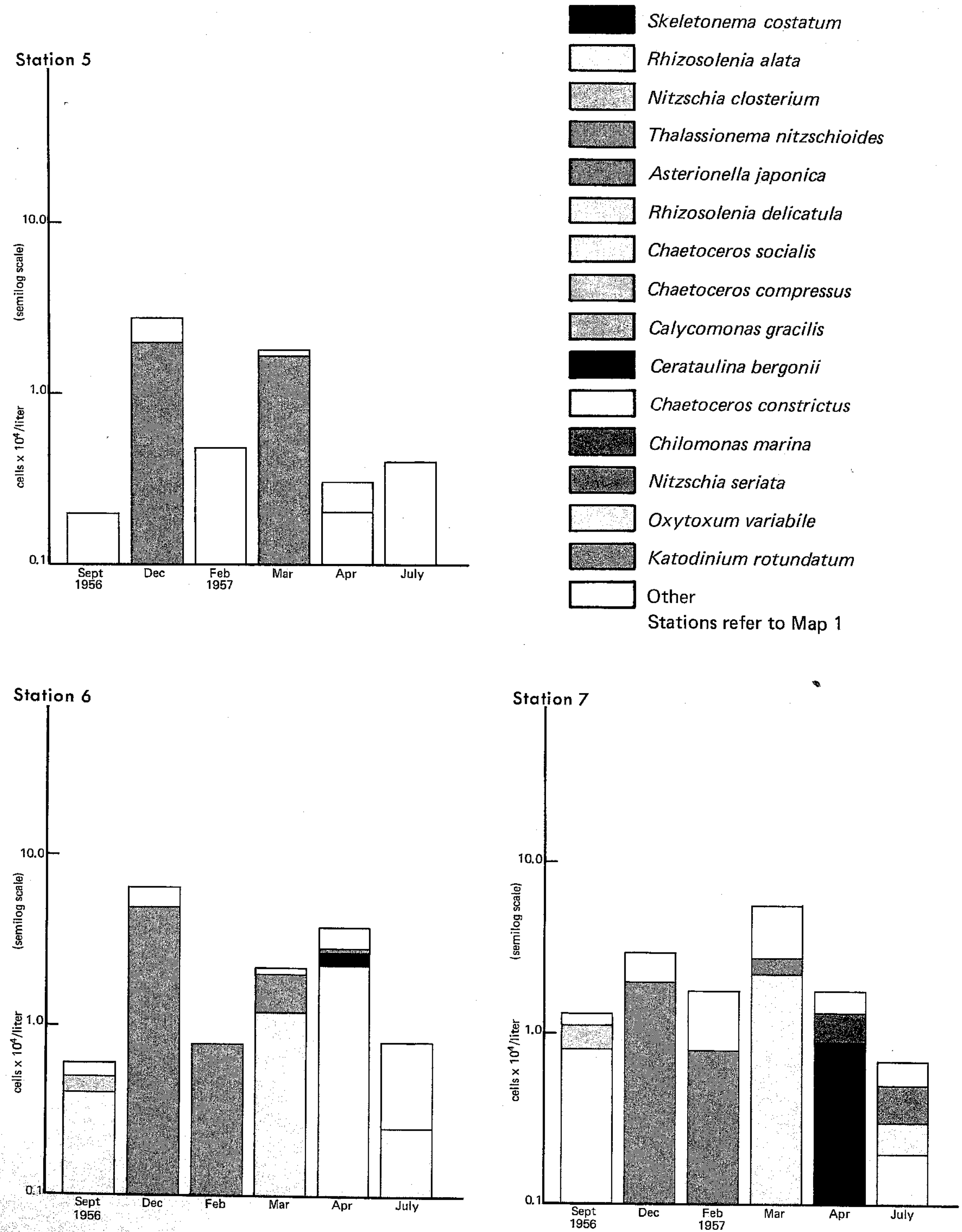
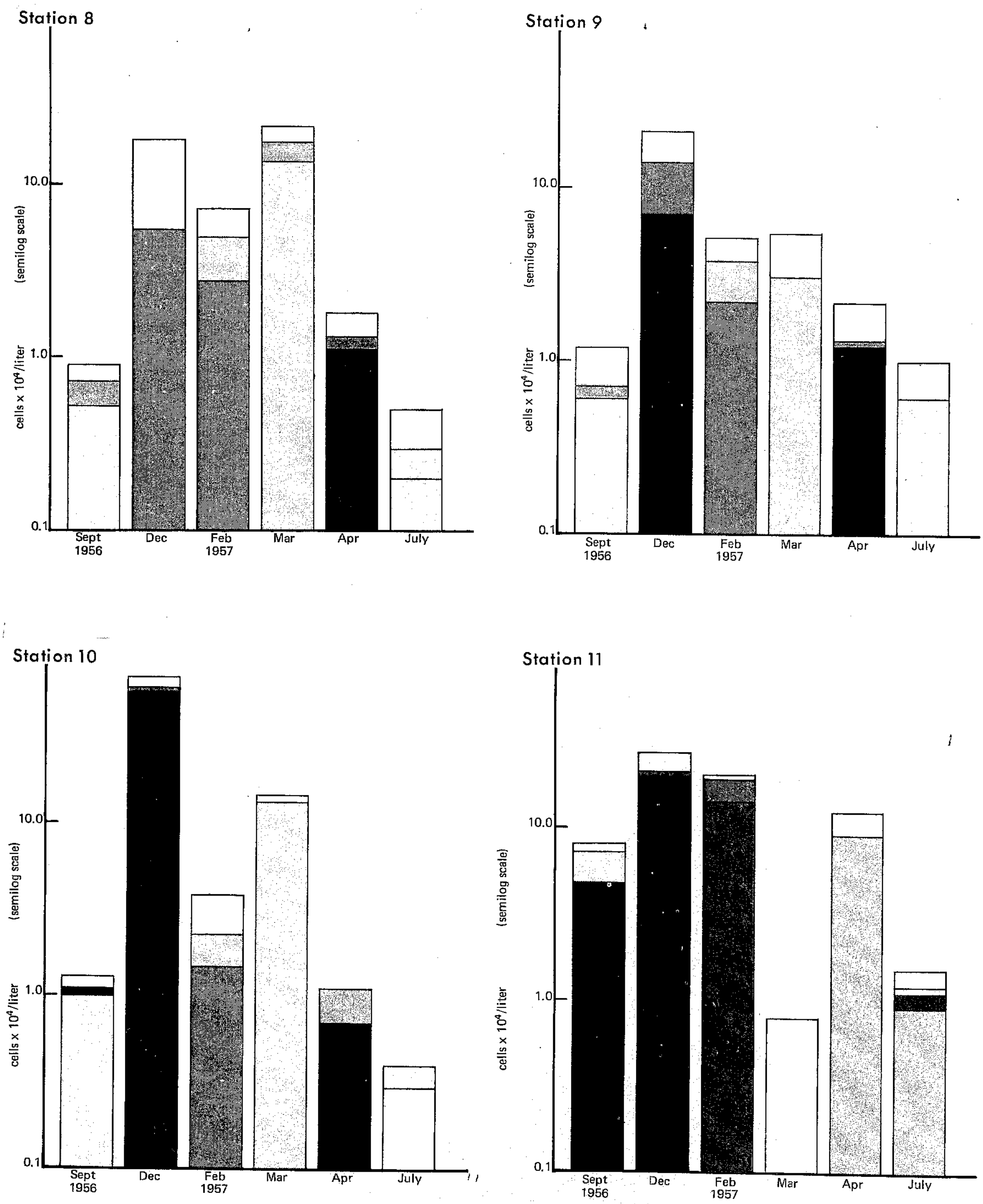


Figure 6. Phytoplankton species abundance, New Jersey transect


Station 8
Station 9
Station 10
Station 11
cells x 10⁴/liter
(semilog scale)
10.0
1.0
0.1
Sept 1956
Dec
Feb 1957
Mar
Apr
July

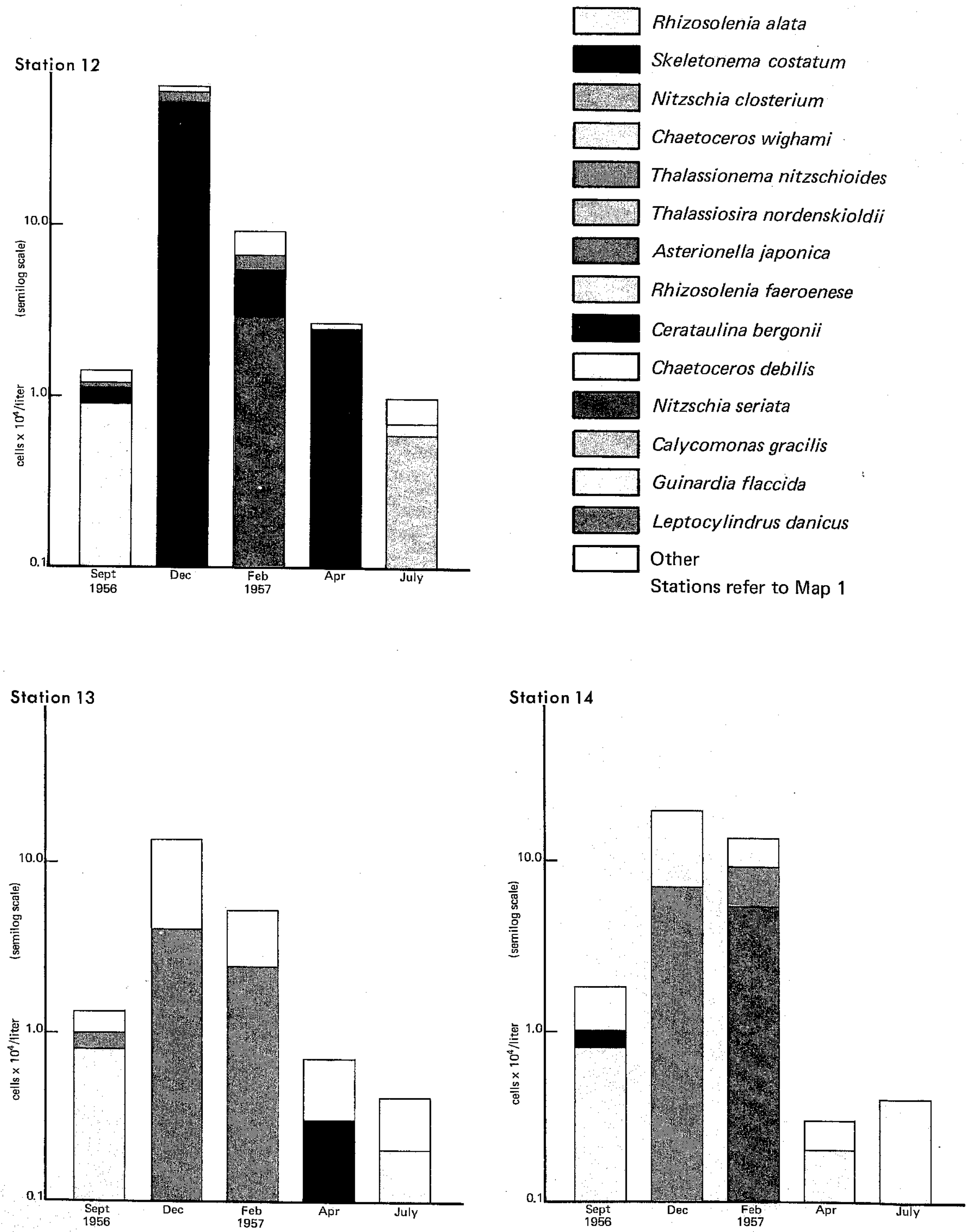
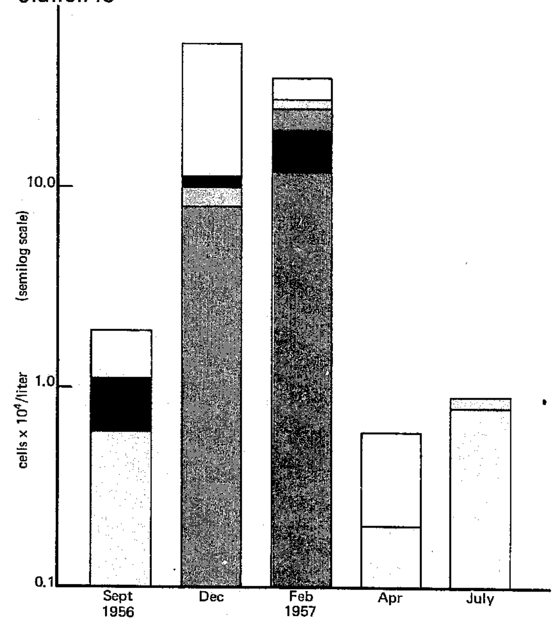
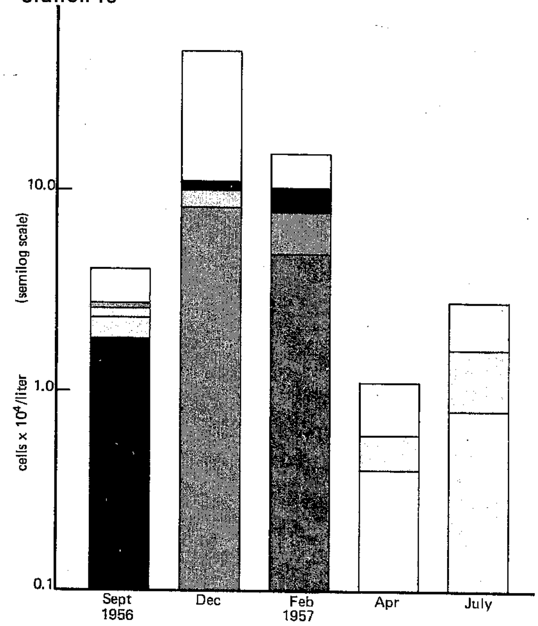


Figure 7. Phytoplankton species abundance, Long Island-New Jersey transect

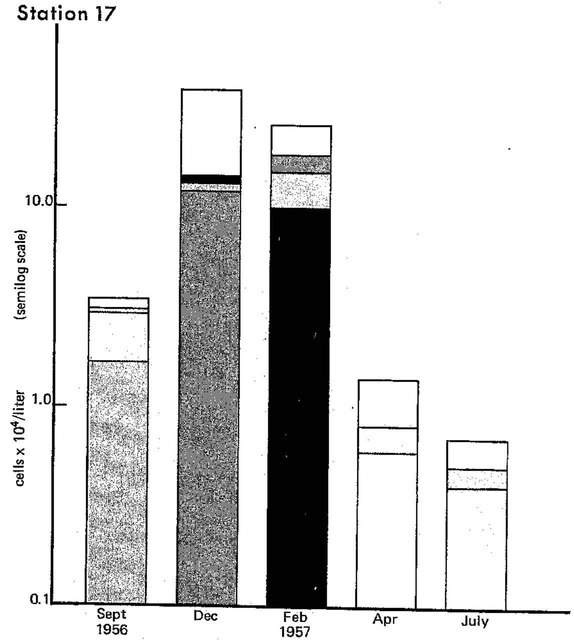
Station 15



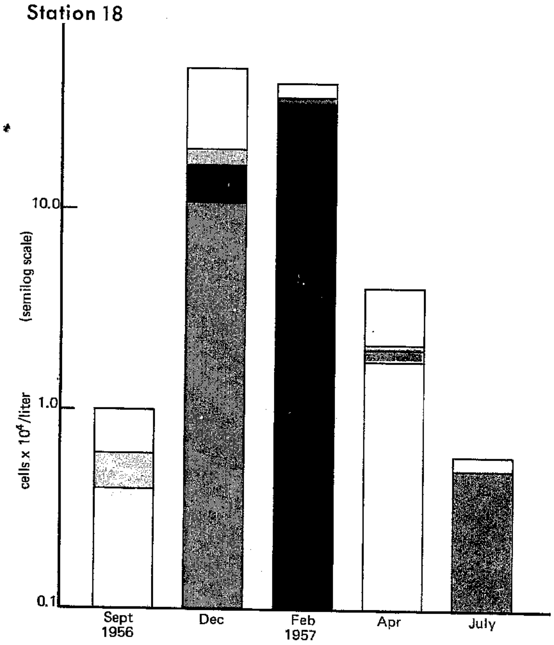
Station 16



Station 17



Station 18



Zooplankton

The zooplankton of the Bight have been subject to very few comprehensive studies. The work of Deevy (1952), Jeffries (1962*a,b,c*, 1964, 1967), Grice and Hart (1962), and Gibson (1973) are important contributions to our knowledge of zooplankton ecology and systematics. Nevertheless, these and other studies have been restricted to small geographic areas, to short periods of time, or to select taxonomic groups. Little data on species distributions exist for most of the Bight, and whole taxa of organisms have been ignored. The information available is difficult to compare because of the wide variety of mesh sizes (No. 2 to No. 10 mesh nets) and towing procedures (vertical, horizontal, and oblique). Consequently, the term "dominant" in this monograph refers to the species or taxon most abundant in the sample captured by the particular net and towing procedure. On the basis of mesh size alone, the microzooplankton represent a virtually unsampled group of organisms in the Bight.

The geographic regions here coincide with those for phytoplankton species. Because of the close relationship often observed between salinity and zooplankton species distributions, many species are categorized according to the salinity classification (Table 3) used by Jeffries (1967).

Among zooplankton assemblages—in contrast to phytoplankton—the strongest similarities were between those in the apex and in the outer Bight. Zooplankton densities were found to decrease with distance from the Raritan-Hudson River estuary. Densities ranged from 10^3 to 10^6 individuals/m^3 in the estuary, compared with 10^3 to 10^5/m^3 in the

Table 3. Salinity characteristics for zooplankton

Category	Definition Characteristics
true estuarine	propagate only in brackish water; tolerance for reproduction under natural conditions of interplay between members of the community is approximately 5 to 30°/oo; found in open ocean as strays from less saline waters
estuarine-marine	propagate throughout major portion of estuary's length, usually spanning gradient zone; reproduction not limited to marine zone; population development usually limited by salinities less than 10°/oo; estuarine population maintained by indigenous recruitment, not dependent on influxes from offshore for critical population densities; ocean populations generally most abundant near coast
euryhaline-marine	all stages usually found throughout marine zone but are adventitious migrants from ocean, carried landward by tidal action; eggs, nauplii, and copepodites have incomplete development, probably including molts; maintenance of population dependent on continuous supply from ocean
stenohaline-marine	adults and other late copepodites occur infrequently near estuary mouth, occasionally straying through marine zone; nauplii and copepodite stages 1-3 absent or very scarce; characterize open neritic waters

Source: After Jeffries 1967

apex and 10^2 to $10^4/m^3$ in the outer Bight. Zooplankton populations were dominated by copepods and meroplankton (summer only) in the estuary and by copepods in the Bight.

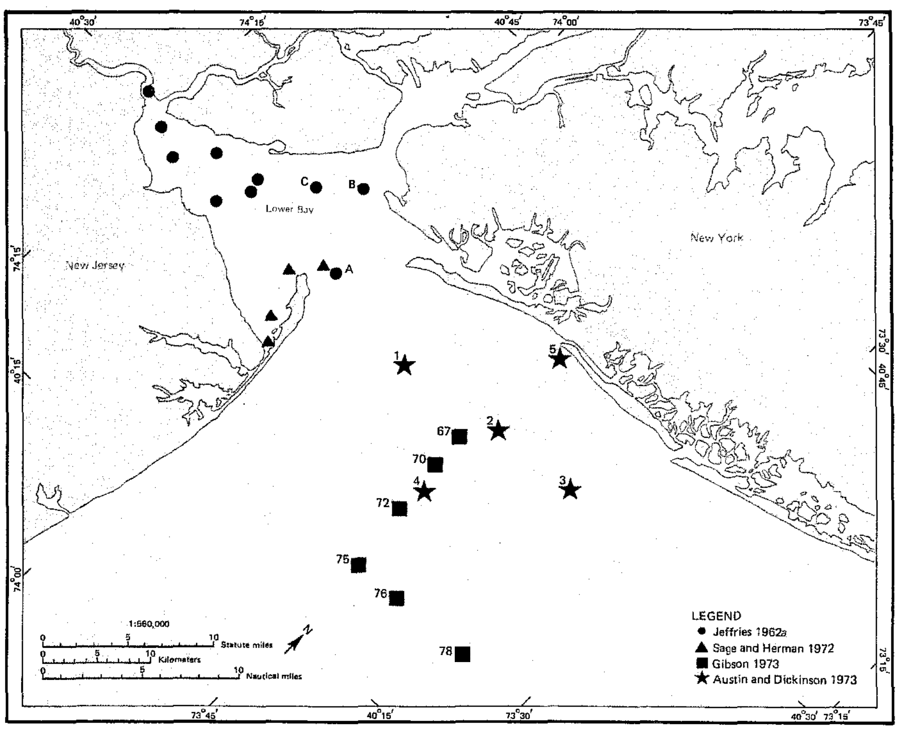
Embayments and Estuaries

Lower Hudson and Raritan River Estuaries. Jeffries (1962*a,b,c,* 1964, 1967) described the distribution of zooplankton in Raritan Bay based on samples collected with a No. 8 net (202μ mesh) with specific reference to the copepods *Acartia clausi, Acartia tonsa, Eurytemora americana,* and *Eurytemora affinis.* The zooplankton of Sandy Hook Bay have been described by Sage and Herman (1972), who used a No. 12 net (116μ mesh) for collecting samples. Data on species abundance in Lower Bay are limited to semiquantitative observations (Jeffries 1962*c*). The stations occupied by Jeffries and Sage/Herman are shown in Map 2; species lists are given in Tables 4 and 5.

Calanoid copepods dominated (greater than 60% by number) the zooplankton in Raritan Bay during most of the period of observation—June 1957-September 1958. Copepod abundance exhibited two peaks: 80 to 90 x 10^3 individuals/m^3 during late spring and early summer and 70 to 80 x $10^3/m^3$ during autumn. Densities of less than 20 x $10^3/m^3$ were observed during March, April, and July. Species indigenous to the estuary were more abundant than species introduced from adjacent waters, usually by an order of magnitude.

Of the copepods indigenous to Raritan Bay, *A. clausi, A. tonsa, E. americana,* and *E. affinis* were most numerous (Table 4). The distributions of all four species were bimodal and sensitive to fluctuations in temperature and salinity. *Eurytemora* spp. were most abundant during winter and spring, whereas *A. clausi* and *A. tonsa* were most abundant during spring and summer, summer and fall, respectively. *E. americana* exceeded *E. affinis* in abundance during

Map 2. Raritan-Hudson River estuary and apex stations



Transverse Mercator Projection

January when temperature was low. At the high temperatures and low salinities characteristic of late spring, *E. affinis* was more abundant than *E. americana*. A similar temporal replacement was observed for *Acartia* spp. *A. clausi* was more abundant than *A. tonsa* at low temperatures and salinities, so *A. clausi* preceded *A. tonsa* as the dominant species in the estuary during the warm months.

Several species found in the Raritan estuary were recruited from adjacent coastal waters. These included *Oithona similis, Pseudocalanus minutus, Paracalanus crassirostris, Temora longicornis, Temora stylifera, Centropages typicus, Centropages hamatus,* and *Labidocera aestiva.* The maximum abundance of these species rarely exceeded 2 x 10^3 individuals/m^3. As a group, adventitious species were most numerous during winter and spring when *O. similis* and *P. minutus* were most abundant. Jeffries (1962*c*) found that these species were good indicators of the intrusion of high salinity water into the estuary.

The species composition of zooplankton in Lower Bay reflected its proximity to the Bight. Jeffries (1962c) gives data on the relative abundance of five

Table 4. Peak abundances of zooplankton species common to Raritan estuary

Species	Season	Abundance ($10^3/m^3$)
HOLOPLANKTON		
Copepoda		
Acartia clausi	spr/sum	50.0/62.5
Acartia tonsa	sum/aut	50.0/60.0
Eurytemora americana	win/spr	2.0-5.0/4.0
Eurytemora affinis	win/spr	2.0/10.0
Pseudocalanus minutus	win	2.4
Oithona similis	spr	2.6
Centropages hamatus	sum	0.2
Cladocera		
Podon polyphemoides	sum	1.0
MEROPLANKTON		
Mollusca		
Mercenaria mercenaria	sum	5.5
Mya arenia		
Polychaeta		
Polydora sp.	spr/sum	36.4/10.5
Crustacea		
Balanus sp.	sum/spr	1.4/1.0

Sources: Jeffries 1962*a,b,c,* 1964, 1967; Sage and Herman 1972

Table 5. Unenumerated zooplankton species in Raritan estuary

Species	Season
HOLOPLANKTON	
Copepoda	
Oithona brevicornis	sum, aut
Oithona sprinirostris	win
Paracalanus crassirostris	sum, aut
Temora longicornis	win, spr
Temora stylifera	
Centropages typicus	win, sum, aut
Labidocera aestiva	win, sum, aut
Eurytemora hermandii	spr, sum
Tachidius lattoralis	win, spr
Tisbe furcata	sum, aut
Pseudodiaptomus coranatus	sum, aut
Calanus finmarchicus	spr
Alteutha depressa	
Tortanus discaudatus	
Cladocera	
Podon intermedius	
Podon leukarti	sum
Evadne nordmanni	spr
Evadne spinifera	
Penilia avirostris	sum
Cnidaria	spr
Nemopsis bachei	
Obelia sp.	
Chrysaora quinquecirrha	
Ctenophora	spr, sum
Mnemiopsis leidyi	
Pleurobrachia brunnea	
Beroe ovata	
Amphipoda	
Grammarus fasciatus	
Mysidacea	
Neomysis americana	
Chaetognatha	
Sagitta elegans	
MEROPLANKTON	
Gastropoda spp.	sum, aut
Pelecypoda	spr, sum, aut
Decapoda	
Crangon septemspinosa	win
Cancer irroratus	spr
Carcinides maenas	spr, sum
Neopanope texana	sum
Pagurus longicarpus	sum, aut
Uca sp.	spr, sum
Callinectes sapidus	

Sources: Jeffries 1962*a,b,c,* 1964, 1967; Sage and Herman 1972 zooplankton species (Table 6). *C. typicus*, a stenohaline-neritic species, was dominant near the mouth of Lower Bay. Eleven kilometers (7 mi) landward, near the mouth of Raritan Bay, *A. tonsa* dominated.

Meroplankton abundance in Raritan Bay increased from less than 5 x 10^3 larvae/m^3 in May to a July maximum of 76 x $10^3/m^3$ (30% of total zooplankton). Polychaete larvae, consisting primarily of *Polydora* spp. and *Merinides* sp., accounted for 78% of the meroplankton. Lamellibranch, gastropod, and *Balanus* spp. larvae were also abundant, accounting for 10%, 6%, and 6% of the meroplankton, respectively. The larval species present are listed in Tables 4 and 5.

Sage and Herman (1972) described a bimodal distribution of zooplankton abundance in Sandy Hook Bay similar to that found by Jeffries in Raritan Bay. Zooplankton numbers peaked in May (52 x $10^3/m^3$) and in September (29 x $10^3/m^3$) and were low (less than $10^3/m^3$) from December through March. Calanoid copepods dominated the zooplankton throughout the year, but harpacticoid copepods, cladocera, and meroplankton were seasonally abundant.

In Sandy Hook Bay *A. tonsa* was the most abundant zooplankton species, accounting for 30% of the zooplankton (annual mean). Population densities peaked in late August and early September when *A. tonsa* made up 52% to 92% of the zooplankton. The congeneric species *A. clausi* reached peak abundance in February and March, but it never comprised more than 1.5% of the zooplankton.

E. affinis was the second most abundant species in Sandy Hook Bay. Maximum population density was observed in April and May when it made up 50% of the zooplankton. The congeneric species *E. americana* was present in low numbers with *E. affinis* from February to May. In April when population density was maximum, *E. americana* accounted for 5% of the zooplankton. Both species were most abundant in low salinity water.

Harpacticoid copepods were abundant during the winter and spring and dominated the late winter zooplankton, occasionally exceeding 50% of the zooplankton in Sandy Hook Bay. *Tachidius littoralis* reached high enough densities during this time to rank third in overall abundance (5.3%) during the year.

Several species of cladocera were also abundant in Sandy Hook Bay, especially during spring and early summer. The two most abundant species, *Evadne nordmanni* and *Podon polyphemoides*, reached maximum densities during early May (11% of the zooplankton) as well as during June to early July.

Table 6. Relative abundance of copepods in Lower Bay

Species	Station[a] A	B	C
Centropages typicus	++++	+++	++
Paracalanus spp.	+	++	+
Oithona spp.	+	++	o
Temora longicornis	o	+	o
Acartia tonsa	+++	++++	+++

[a]See Map 2

Source: Jeffries 1962c

The meroplankton were dominated by polychaete, pelecypod, and gastropod larvae. Pelecypod and gastropod larvae reached maximum densities during August (0.51 x $10^3/m^3$) and October (6.74 x $10^3/m^3$), respectively. Polychaete larvae did not begin to increase in abundance until August and reached peak density during December when they comprised 8% of the zooplankton.

Hydrozoans (*Nemopsis bachei* and *Obelia* sp.) and ctenophores *(Mnemiopsis leidyi)* were abundant during late June and July. Nelson (1925) described the ctenophores of New Jersey embayments. *Pleurobrachia brunnea, Beröe ovata,* and *M. leidyi* were found during summer but were never abundant. Both Nelson and Sage/Herman concluded that these carnivores are transient visitors from oceanic waters.

Block Island Sound. Deevy (1952) described the zooplankton of Block Island Sound in 1949 based on samples collected with No. 2 (363μ mesh) and No. 10 (153μ mesh) nets. For this monograph, data from the net that captured the largest number of individuals for a given species are presented. The stations occupied by Deevy are shown in Map 3; species lists are given in Tables 7 and 8.

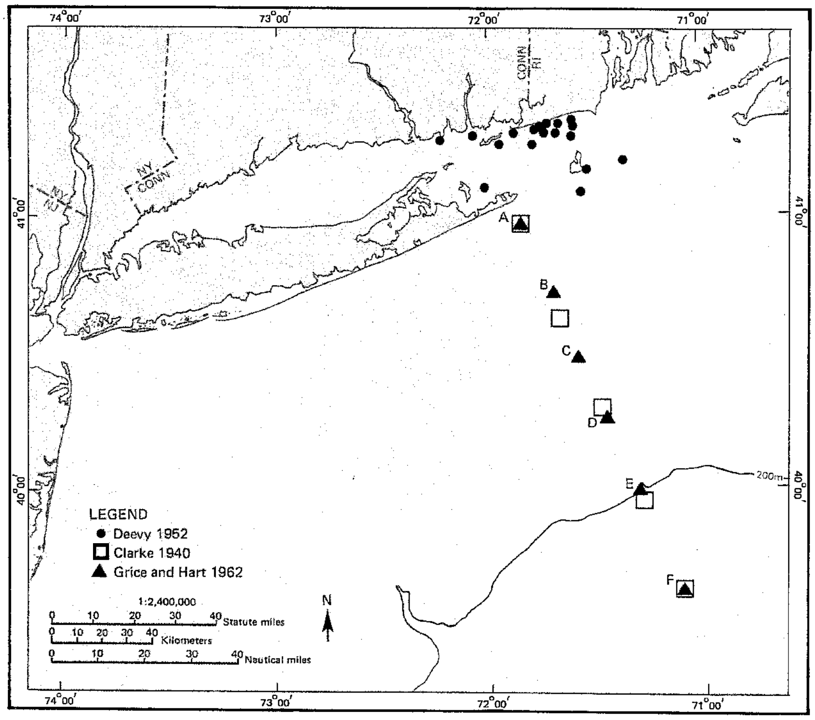
The zooplankton exhibited three seasonal peaks in abundance: a winter peak of 20 to 30 x 10^3 individuals/m^3, a late spring peak of 32 x $10^3/m^3$, and a late summer-early autumn peak of 20 to 35 x $10^3/m^3$. Minimum zooplankton densities (less than 10 x $10^3/m^3$) were observed during spring, from March to May.

Copepods dominated the zooplankton, and copepod nauplii were abundant at all stations throughout the year. Meroplankton, pelagic tunicates, cladocera, and coelenterates were also abundant. Peaks in copepod abundance coincided with peaks in total zooplankton. Copepod nauplii were most abundant in early June, but peaks were also observed during winter and autumn months. The remaining abundant groups exhibited bimodal distribution with peaks in late summer or early autumn.

P. minutus and *O. similis* were present throughout the year but alternated with each other in abundance. *P. minutus* dominated the winter and spring zooplankton with peak densities of 8, 13, and 3 x 10^3 individuals/m^3 during January, February, and April, respectively. *O. similis* was least abundant during spring, whereas *P. minutus* declined in abundance through the summer and was least abundant during autumn.

Seasonal variations in species composition were pronounced (Tables 7 and 8). Based on relative abundance, the winter zooplankton were dominated by *P. minutus* (10% to 65%), *O. similis* (7% to 49%), *P. crassirostris* (0 to 34%), and *C. typicus* (1% to 12%). During the spring period of minimum zooplankton abundance *P. minutus* (6% to 25%), *O. similis* (10% to 16%), and *T. longicornis* (0 to 18%) were the dominant zooplankters. The number of dominant zooplankton increased during summer and autumn. The summer plankton were characterized by *O. similis* (11% to 57%), *Oikopleura dioica* (4% to 21%), *Doliolum nationalis* (0 to 31%), *C. typicus* (0 to 16%), *A. tonsa* (0 to 15%), and *C. hamatus* (0 to 10%). *O. similis* remained dominant during autumn (16% to 21%), but *A. tonsa* (0 to 8%), *P. crassirostris* (0 to 6%), *Microsetella norvegica* (0 to 6%), and *C. typicus* (0 to 3%) were also abundant.

Map 3. Block Island Sound stations



Transverse Mercator Projection

During the first seven months of the year the zooplankton were composed almost exclusively of littoral and neritic species characteristic of the region (for instance, *C. typicus, C. hamatus, A. tonsa, T. longicornis, P. minutus,* and *O. similis*). The presence of the cold-water pelagic tunicates *Fritillaria borealis* and *Oikopleura labradoriensis* from February to June was indicative of the intrusion of northern Atlantic waters into Block Island Sound. The increase in the total number of species (not including larvae) from 28 during the first half of the year to 52 from August to December reflects the influx of warm-water species as the Gulf Stream attains its northernmost penetration. These include the copepods *Candacia armata, Calanus minor, Mecynocera clausi, Oncaea venusta, Eucalanus monachus, Eucalanus crassus, Sapphirina auronitens, Corycaceus venustus, Corycaceus ovalus, Corycaceus speciosus, Corycaceus elongatus, T. stylifera, Temora turbinata, Euchaeta marina,* and

Table 7. Peak abundances of zooplankton species common to Block Island Sound

Species	Season	Abundance ($10^3/m^3$)
HOLOPLANKTON		
Copepoda		
Oithona similis	year-round	0.1-5.5
Pseudocalanus minutus	win/spr	0.6-3.0/1.0-3.7
Centropages typicus	year-round	0.1-1.5
Centropages hamatus	spr/sum	1.4/6.1
Temora longicornis	spr/sum	0.8-2.5/1.3-2.0
Acartia tonsa	sum/aut	1.2-3.0/1.0-1.4
Acartia clausi	win, spr/sum	0.9/1.9
(Copepod nauplii)	year-round	9.0-10.0
Paracalanus parvus	year-round	0.2-0.7
Tortanus discaudatus	spr/sum	0.1/0.4
Cladocera		
Evadne nordmanni	spr	2.0
Podon leukarti	sum	2.0
Podon intermedius	sum/aut	0.9/0.2
Penilia avirostris	sum/aut	0.8/1.0
Tunicata		
Fritillaria borealis	spr	0.2
Oikopleura dioica	sum/aut	4.0/2.0
Doliolum nationalis	sum, aut	7.0
Dolioletta gegenbauri	sum/aut	0.4/0.3
MEROPLANKTON		
Gastropoda spp.	spr/sum, aut	0.1/0.3
Polychaeta spp.	spr	0.3
Bryozoa	year-round	0.2
Cyphonautes sp.		
Lamellibranchata	spr, sum/aut	4.0/7.0

Sources: From Deevy 1952; Frolander 1955

Table 8. Zooplankton species in Block Island Sound, with mean annual abundance less than $0.1 \times 10^3/m^3$

Species	Season
HOLOPLANKTON	
Copepoda	
Tortanus discaudatus	spr, sum, aut
Labidocera aestiva	win, sum, aut
Altheutha depressa	aut
Oithona brevicornis	year-round
Eurytemora spp.	spr
Acartia longiremis	win, spr, sum
Thalestris gibba	sum
Calanus finmarchicus	spr, sum
Calanus minor	win, spr, sum
Macrostella gracilis	win, aut
Microstella norvegica	win, aut
Clytemnestra rostrata	aut
Candacia armata	win, spr, sum
Metridia lucens	spr, sum, aut
Corycaeus speciosus	win, aut
Corycaeus ovalis	aut
Corycaeus venustus	win, aut
Corycaeus elongatus	aut
Eucalanus monachus	win, aut
Eucalanus crassus	aut
Centropages bradyi	win, aut
Rhincalanus nasutus	win, aut
Sapphirina auronitens	win, aut
Oncaea venusta	win, aut
Temora stylifera	sum, aut
Temora turbinata	win, aut
Cladocera	
Evadne spinifera	aut
Tunicata	
Oikopleura labradoriensis	spr, sum
Coelenterata	
Hybocodon prolifer	spr, sum
Rathkea octopunctata	spr, sum
Obelia sp.	spr, sum, aut
Podocoryne carnea	sum
Liriope sp.	sum
Aglantha digitale	sum
Bougainvillea autumnalis	sum
Chaetognatha	
Sagitta elegans	win, spr, sum
Sagitta serratodentata	win, spr, sum
Sagitta enflata	win, spr, sum

Sources: From Deevy 1952; Frolander 1955

Centropages bradyi; the penaeid *Lucifer taxoni;* the ostracod *Euconchaecia chierchiae;* and chaetognaths *Sagitta serratodentata* and *Sagitta enflata;* the cladoceran *Penilia avirostris;* and the tunicates *D. nationalis, Dolioletta gegenbauri, Thalia democratica, O. doioca,* and *Oikopleura longicanda.*

Copepod nauplii were by far the most abundant group of larvae found throughout the year. Peak numbers were observed in January (41%), March (74%), June (37%), and October (22%). Also present, but at much lower densities, were lamellibranch larvae, gastropod larvae, *Balanus* nauplii, polychaete larvae, echinoderm larvae, cyphonautes larvae, and fish larvae. Only lamellibranch larvae made up a significant proportion of the zooplankton, with peaks in June (12%) and October (22%).

The relative abundance of species varies from year to year as indicated by the observations of Frolander (1955) from July 1950 to December 1951 (Tables 7 and 8) and Jeffries (unpublished) from January 1965 to December 1966. Frolander, using a No. 6 net (243μ mesh), found that *C. hamatus,* a rare species in Deevy's study, dominated the zooplankton during June and July (26% to 55%) and that *A. tonsa* dominated from August to December (43% to 65%). Jeffries, using a No. 2 net (363μ mesh), found that the copepods *Tortanus discaudatus* and *Calanus finmarchicus* dominated the zooplankton in April and May (52% to 58%) and in June and July (39% to 83%), respectively. In addition, the cladocerans *P. avirostris, Podon* sp., and *Evadne* spp. successively dominated the zooplankton in October (56%), November (45%), and December (36%). At no time were meroplankters abundant. Although some of these differences are undoubtedly due to the different mesh sizes employed, Deevy used both No. 2 and No. 10 nets, suggesting that major changes in the proportion of zooplankton species do occur from year to year.

Summary. Zooplankton densities ranged from 10^3 individuals/m^3 to 400 x 10^3/m^3 in the Raritan estuary and from 5 x 10^3/m^3 to 35 x 10^3/m^3 in Block Island Sound. A bimodal seasonal distribution was observed in both regions, with major peaks in abundance in late spring and early autumn. Summer densities were higher in the estuary due to the abundance of meroplankton.

Copepods, the dominant group of zooplankton, ranged in abundance from 10^3 individuals/m^3 to 150 x 10^3/m^3 in the estuary and from 2 x 10^3/m^3 to 24 x 10^3/m^3 in Block Island Sound. *A. tonsa, A. clausi, E. affinis,* and *E. americana* dominated the estuarine zooplankton. *Eurytemora* spp. were most abundant during winter and spring; *Acartia* spp. were most abundant during spring, winter, and autumn. *E. americana* preceded *E. affinis,* and *A. clausi* preceded *A. tonsa* as the dominant species. Of the species recruited from outside the estuary, *O. similis* and *P. minutus* were most abundant. These and several other adventitious species were found to be good indicators of the intrusion of high salinity water into the estuary.

The zooplankton of Block Island Sound were dominated by *P. minutus, O. similis, C. hamatus, T. discaudatus, C. finmarchicus,* and several species of cladocera, depending on time of year, year, and mesh size of nets used to collect samples. It is apparent that the species composition of zooplankton in Block Island Sound is markedly different from that observed in the Raritan estuary. This reflects the Sound's high, less variable salinities and the Bight's exposure to continental shelf and slope waters.

Apex and Coastal Waters

Seasonal variations in zooplankton abundance and species composition have been described by Gibson (1973). Using a No. 8 net (202μ mesh), Gibson sampled three depths (surface, mid-depth, near-bottom) at 15 stations from January 1969 through April 1970, but species abundance was determined for only six stations (Map 2). Austin and Dickinson (1973) sampled two depths (surface, bottom) at five stations (Map 2) in September and November 1971, using a No. 2 net (363μ mesh). Wiebe, Grice, and Hoagland (1973) made oblique tows at 16 stations in June 1970, using a No. 6 net (239μ mesh). The 16 stations sampled were arranged into two grids of eight stations each, with one grid over the acid waste disposal area (see Map 1) and a control grid 9 km (6 mi) to the northeast. The study by Wiebe and his associates was designed to detect small-scale variations in species abundance that could be related to acid waste disposal in the Bight. They found no effect. A survey of zooplankton abundance in shallow coastal waters off western Long Island was conducted from May through October 1972 (Alesi 1973). Vertical and oblique tows with a No. 10 net (130μ mesh) were made monthly at 25 stations.

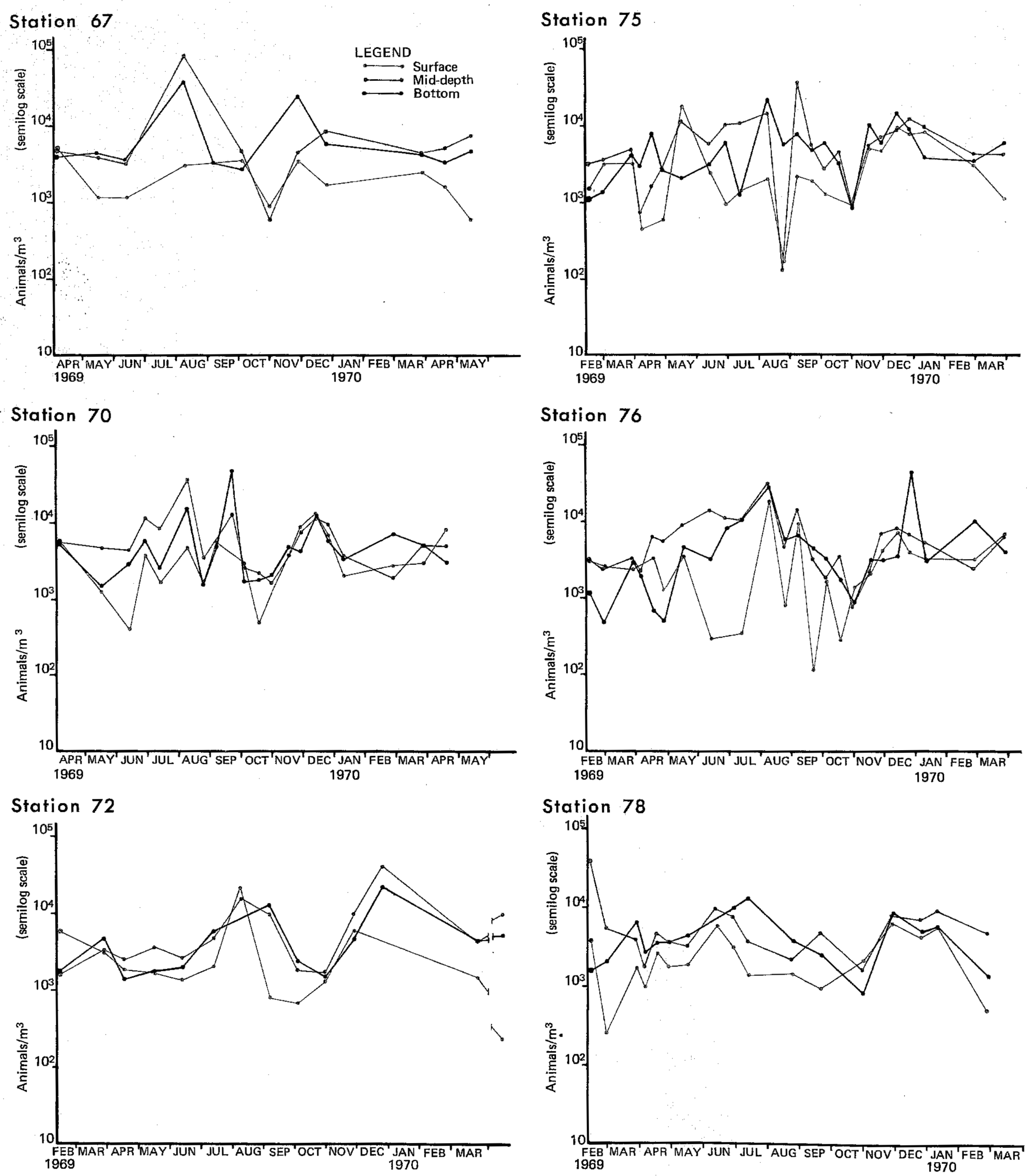


Figure 8. Copepods: seasonal distribution in the apex

Seasonal Variations (Gibson 1973). Mean copepod densities for all stations and times ranged from 0.7 x $10^3/m^3$ to 41 x $10^3/m^3$. Seasonal distributions of abundance were typically bimodal with peaks most frequently in July and November (Figure 8). Maximum surface densities ranged from 4 x $10^3/m^3$ to 20 x $10^3/m^3$. Mid-depth densities ranged from 10 x $10^3/m^3$ to 90 x $10^3/m^3$; near-bottom densities ranged from 10 x $10^3/m^3$ to 30 x $10^3/m^3$. Density and the amplitude of seasonal variations were typically less at the surface than at subsurface depths. Although the seasonal pattern of abundance varied between stations for any given species, no significant difference was observed.

Four copepod genera dominated the zooplankton. *Oithona* was the dominant genus in abundance and frequency of occurrence. *Paracalanus* ranked second in abundance and third in frequency; *P. minutus* ranked third in abundance and second in frequency. The fourth most abundant and frequent genus was *Centropages*. *Oithona* and *Pseudocalanus* were abundant throughout the year, whereas *Paracalanus* and *Centropages* were seasonally abundant.

Three species of *Oithona* were identified: *O. similis*, *O. brevicornis*, and *O. plumifera*. *O. similis* was by far the most abundant of the three, with a mean annual abundance of 3.1 x 10^3 individuals/m^3. Population density generally peaked in July (maximum = 49 x $10^3/m^3$ at station 67) and November (maximum = 15 x $10^3/m^3$ at station 72) as shown in Figure 9. Population density tended to be higher near the mouth of the estuary than farther offshore.

Two species of *Paracalanus* were found during the study: *P. parvus* and *P. crassirostis*. *P. parvus* was the dominant form, comprising a mean of 80% of the congeneric individuals. *Paracalanus* spp. had a mean

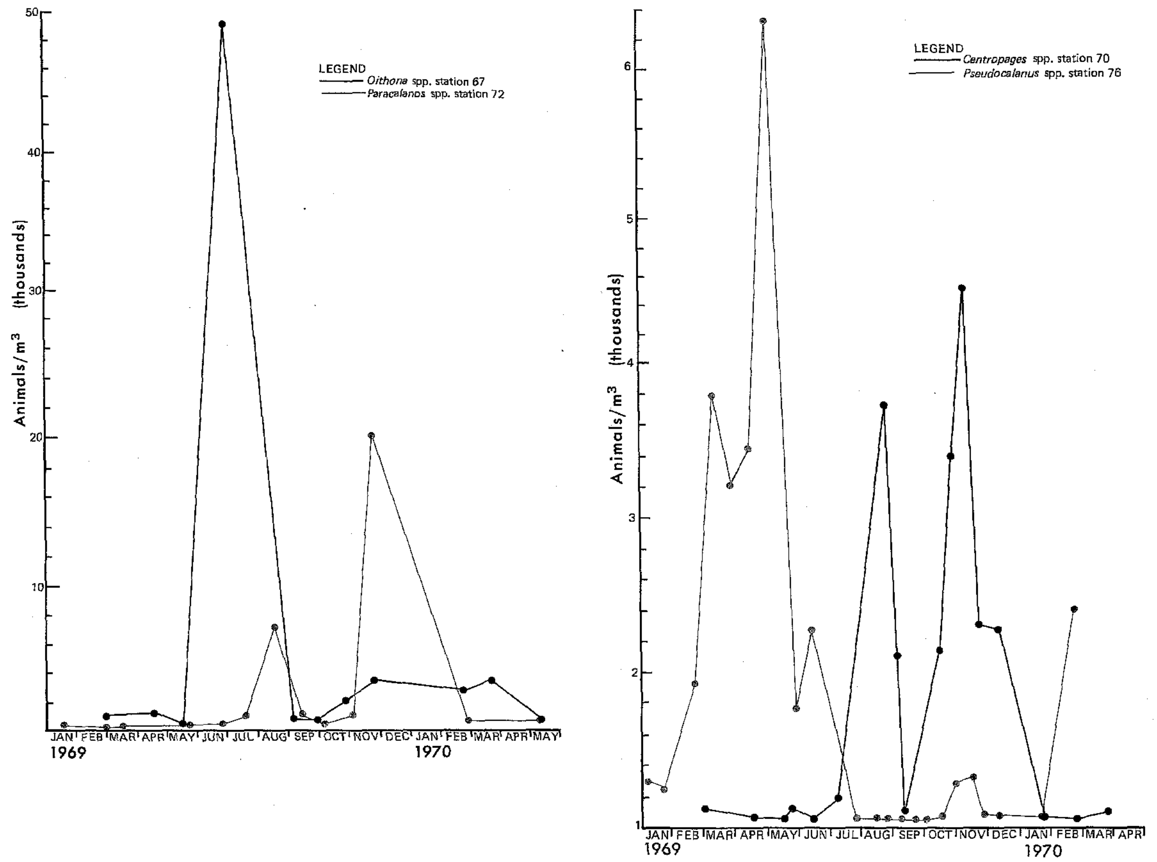


Figure 9. Copepod species distribution: mid-depth samples from the apex

annual abundance of 10^3 individuals/m^3 and exhibited at least two major peaks (Figure 9). During the August peak, maximum population densities of 7 to 10 x 10^3/m^3 were observed at stations 72 and 76. The November peak was characterized by maximum densities of 13 to 21 x 10^3/m^3 at stations 72 and 76.

P. minutus had a mean annual population density of 0.7 x 10^3/m^3 and was most abundant during spring (Figure 9). Two peaks were ususally observed from February through May, with a third peak occasionally in July. Maximum densities usually occurred in May or July and ranged from 2.5 to 5.4 x 10^3/m^3. Minimum densities of less than 0.5 x 10^3/m^3 were observed throughout most of autumn and winter.

Two species of *Centropages* were observed: *C. hamatus* and *C. typicus.* The latter made up over 90% of the congeneric individuals. The mean annual population density of *Centropages* spp. was 0.6 x 10^3/m^3. Two peaks were usually observed, one during July-August and a second, more pronounced peak in November. Summer peak densities ranged between 1 and 5 x 10^3/m^3 with most values between 1 and 3 x 10^3/m^3: autumn peak densities ranged as high as 14 x 10^3/m^3, with most values between 3 and 5 x 10^3/m^3.

Two other copepod species exhibited peak abundances in excess of 10^3 individuals/m^3. *T. longicornis* reached peak densities most frequently in July and was abundant from April to July. *Tortanus discaudatus* typically peaked in June. Both species were virtually absent during autumn and winter.

Other copepod species were found sporadically and in small numbers (Table 9). These included *A. clausi, A. tonsa, Acartia longiremis, Eurytemora* sp., *L. aestiva, C. finmarchicus, Corycaeus* spp., *Oncea* spp., *C. armata, Metridia lucens,* and *Clytemnestra* sp. *Acartia* spp. never exceeded 0.3 x 10^3 individuals/m^3 and were most abundant in surface samples near the mouth of the estuary. Peaks in the abundance of *L. aestiva* and *Corycaeus* spp. occurred during autumn and coincided with the seasonal influx of Gulf Stream water.

Several other groups of zooplankton were seasonally abundant or present at low densities throughout the year. These included cladocerans, pelagic gastropods, chaetognaths, pelagic tunicates, siphonophores, and meroplankton.

Three genera of cladocera were identified. *Podon* sp. was present at low densities near the surface during summer, except at station 70 in July when its density exceeded 20 x 10^3/m^3. *Evadne* sp. and

Table 9. Seasonal occurrence of zooplankton in apex

Species	Season			
	Win	Spr	Sum	Aut
HOLOPLANKTON				
Copepoda				
Oithona similis	A	A	A	A
Paracalanus parvus	A	A	A	A
Paracalanus crassirostris	A	A	A	A
Pseudocalanus minutus	A	A	A	A
Centropages hamatus	A	A	A	A
Centropages typicus	A	A	A	A
Temora longicornis	A	A	A	A
Tortanus discaudatus	B	A	A	B
Acartia clausi	B	A	A	A
Acartia tonsa	B	A	A	A
Labidocera aestiva	B	A	—	A
Corycaeus	B	B	—	A
Calanus finmarchicus	B	A	A	A
Eurytemora	B	B	B	—
Canadia	—	—	—	—
Eucalanus	—	—	—	B
Metridia	—	B	—	B
Rhincalanus	—	—	—	B
Clytemnestra	B	B	B	B
Cladocera				
Podon	—	—	A	B
Evadne	A	A	A	A
Penilia	—	—	A	A
Siphonophora	B	A	A	A
Ctenophora	—	—	—	B
Mysidacea	B	—	B	B
Amphipoda				
Gamaridae	—	—	B	B
Hyperidae	—	—	—	B
Tunicata				
Thalacen	—	—	B	A
Oikopleura	B	B	B	A
Polychaetea				
Tomopteridae	B	—	—	—
Nematoda	—	B	—	B
Ectoprocta	B	A	B	A
Chartoynatha	A	A	A	A
MEROPLANKTON				
Polychaeta	A	A	A	A
Gastropoda	A	A	A	A
Bivalve	A	A	A	A
Barnacle	B	B	B	B
Decapoda	B	B	A	A
Phoronida	—	B	B	B
Echinodermata	—	B	B	A
Fish larvae	—	B	B	B
Fish eggs	B	A	A	B

— = no occurrence
A = present at 50% or more of stations (Gibson stations on Map 2) sampled
B = present at less than 50% of stations (Gibson stations on Map 2) sampled

Source: After Gibson 1973

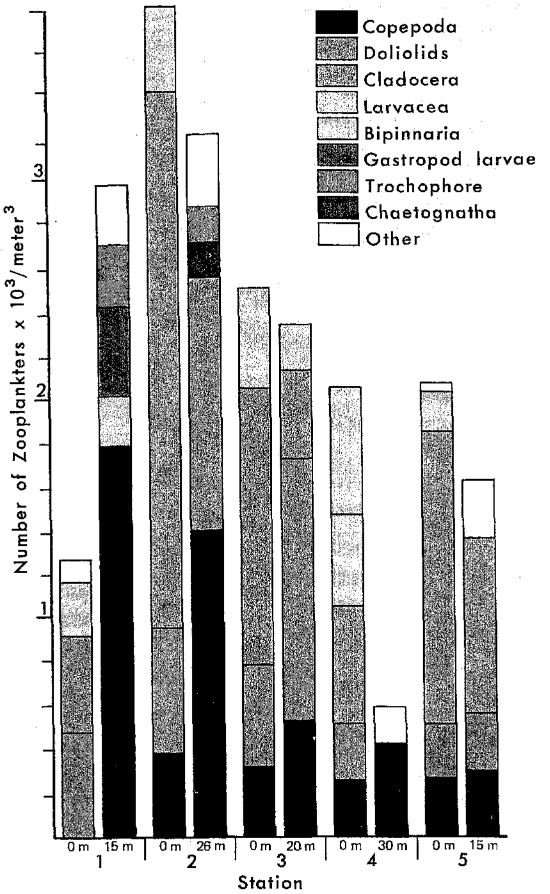


Figure 10. Taxonomic composition of zooplankton in the apex, September 1971

Penilia sp. were present during late summer and autumn, also at low densities. The one exception was noted at station 76 in August when *Penilia* sp. and *Evadne* sp. were present in the surface layer at densities of 62 x $10^3/m^3$ and 31 x $10^3/m^3$, respectively.

Limnacia sp., a pelagic gastropod, was present at low densities throughout most of the year. A maximum density of 1.8 x $10^3/m^3$ was recorded in October. Secondary peaks occurred in August and February.

Chaetognaths, present in the study area throughout the year, were most abundant in near-bottom water. Abundance peaked during May and July, with a maximum of 0.7 x 10^3 individuals/m^3 at station 78.

Pulses of bivalve larvae into the plankton took place from January through March and again from August through November. Larval densities during the winter peaks ranged from 0.1 x $10^3/m^3$ to 15 x $10^3/m^3$. During the autumn peak, densities ranged from 0.3 x $10^3/m^3$ to 8 x $10^3/m^3$. Polychaete larvae were also present but at very low densities. Peak densities were usually during spring and never exceeded 0.6 x $10^3/m^3$.

Other Studies of Seasonal Variations. Austin and Dickinson (1973) collected zooplankton from the surface and below the thermocline (15 to 25m down) in September and November 1971. The abundance and distribution of major taxa are summarized in Figures 10 and 11.

During September, zooplankton densities ranged from 0.6 x $10^3/m^3$ to 3.8 x $10^3/m^3$, compared with 0.1 x $10^3/m^3$ to 1.3 x $10^3/m^3$ in November. Surface and subthermocline samples showed no consistent trends in relative zooplankton abundance. Cladocera, copepods, doliolids, and larvacea were abundant (greater than 0.1 x 10^3 individuals/m^3) at all stations. Surface samples were dominated by cladocerans (0.3 to 2.5 x 10^3 individuals/m^3); copepods (0.3 to 1.8 x 10^3 individuals/m^3) dominated the subthermocline samples. Copepods dominated all stations and depths in November, ranging in abundance from less than 0.1 x $10^3/m^3$ to 1.2 x $10^3/m^3$.

Copepod species composition did not vary much between September and November (Figure 12). The surface copepod populations in September were dominated by *Centropages* spp. (predominantly *C. typicus*), which comprised 52% of the copepods. *A. tonsa* (32%) and *Pseudocalanus* spp. (15%) were also abundant. *Pseudocalanus* spp. (76%) dominated the subthermocline copepod populations, followed by *Centropages* spp. (9%), *Oithona* spp. (9%), and *A. tonsa* (5%). Copepod species present in November included *Centropages* spp. (69%), *Pseudocalanus* spp. (22%), *Calanus* sp. (18%), *Acartia* spp. (less than 1%), and *Oithona* spp. (less than 1%).

The distributions of *C. typicus, A. tonsa,* and *Oithona* spp. were closely related to salinity. *C. typicus* represented more than 50% of the copepods at salinities above 30°/oo. Below 30°/oo its abundance decreased dramatically. *A. tonsa* and *Oithona* spp. were more abundant at low salinities (less than 30°/oo) than at high salinities.

Three genera of cladocera were identified. In September when cladocera dominated the surface zooplankton, *P. avirostris* comprised 65% to 67% of the cladocera at the inshore stations. Offshore, *Evadne* spp. made up 66% and *P. polyphemoides* 19% to 34% of the cladocera.

Predators, such as polychaetes, chaetognaths, and ctenophores, were typically found only in subthermocline samples, as were the meroplanktonic bivalve and gastropod larvae.

The September abundance of *A. tonsa* in surface waters and the presence of the subtropical pteropods *Cresis conica* and *Limacina inflata* below the thermocline suggest different origins for their two water masses. During September the surface waters were primarily estuarine; subthermocline water probably originated offshore to the south.

Wiebe and his associates (1973) used tows to collect zooplankton samples in June. Copepods were the most abundant taxon, comprising more than 96% of the zooplankton. Two species, *Pseudocalanus* sp. (mean = 5.9 x 10^3 individuals/m^3) and *T. longicornis* (mean = 4.6 x 10^3 individuals/m^3), accounted for 88% of the zooplankton collected. Other abundant species were *C. typicus* (0.5 x 10^3 individuals/m^3), *O. similis* (0.4 x 10^3/m^3), *Sagitta elegans* eggs (0.1 x 10^3/m^3), and *T. discaudatus* (0.1 x 10^3/m^3). A complete species list is given by Wiebe et al (1973).

Zooplankton densities along the coast of western Long Island ranged from 2.8 to 10.5 x 10^3/m^3, with peaks during June and July (Alesi 1973). The copepods *T. longicornis, P. minutus, C. typicus,* and *O. similis* dominated from May through July; *A. tonsa* dominated the October zooplankton. The cladoceran *P. avirostris* was the most abundant zooplankton species during September (69%); *E. nordmanni* and *O. diocica* were also abundant. The decline in zooplankton abundance following the June-July maximum was accompanied by an increase in the abundance of the ctenophores *Pleurobrachia pileus* and *M. leidyii.* This suggests that the decline in copepod abundance during late summer and autumn was due to ctenophore predation.

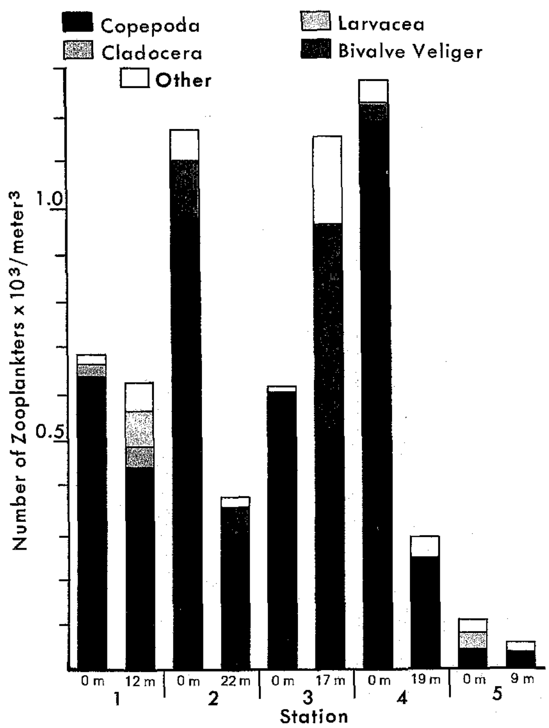


Figure 11. Taxonomic composition of zooplankton in the apex, November 1971

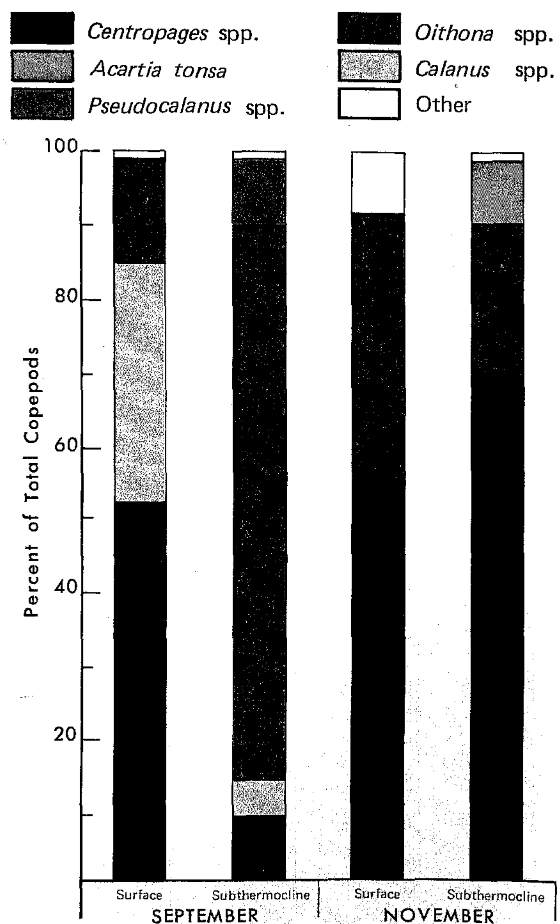


Figure 12. Species composition of copepods in the apex, September and November 1971

Summary. Copepods dominate the zooplankton throughout most of the year, with periodic pulses in the abundance of cladocera, pelagic tunicates, and meroplankton. Gibson (1973) reported mean copepod densities of 0.7 x $10^3/m^3$ to 41 x $10^3/m^3$, with values as high as 90 x $10^3/m^3$. Copepod abundance in the Bight may be due to predation, as evidenced by the concurrent increase in carnivorous ctenophores. This supposition is supported by the observation that copepods were usually very abundant in the lower Hudson and Raritan estuaries during late summer and autumn when predators are most abundant in the Bight and virtually absent from the estuaries. Meroplankton, predominantly bivalve larvae, are most abundant from January to March (0.1 to 15 x 10^3 individuals/m^3) and again from August to November (0.3 to 8 x $10^3/m^3$). Local blooms of *Podon* sp. (greater than 20 x 10^3 individuals/m^3), *Evadne* sp. (31 x 10^3 individuals/m^3) and *Penilia* sp. (62 x 10^3 individuals/m^3) are observed in July and August.

Four copepod species dominated the zooplankton in Gibson's study (1973). *O. similis* (mean annual density = 3.1 x $10^3/m^3$) reached peak abundance in July and November. *P. parvus* (mean = 0.8 x $10^3/m^3$) also exhibited a distinct bimodal distribution, peaking in August and November. *P. minutus* (mean = 0.7 x $10^3/m^3$) and *C. typicus* (mean = 0.5 x $10^3/m^3$) were less periodic and often exhibited more than two peaks. *P. minutus* peaks were observed from February through May and again in July, whereas *C. typicus* most frequently bloomed during July, August, and November.

The results of Wiebe et al (1973) and of Austin and Dickinson (1973) provide insight on the variability of seasonal patterns of abundance and species composition. The observations of Wiebe and his associates were based on a grid of stations near Gibson's station 76. Total copepod abundance averaged 11.6 x 10^3 individuals/m^3 in June 1970, within the range of values reported by Gibson for June 1969. The species composition reported by Wiebe and his associates is similar. However, Austin and Dickinson's observations in September and November 1971 contrast with Gibson's 1969 observations. Two of Austin and Dickinson's stations correspond to stations 67 and 72 in Gibson's study. Gibson reports copepod densities of 0.6 x 10^3 to 6 x $10^3/m^3$ in September and 2 x 10^3 to 40 x $10^3/m^3$ in November. Copepod densities in the Austin and Dickinson study ranged from 0.6 x 10^3 to 4 x $10^3/m^3$ in September and 0.1 x 10^3 to 1.3 x $10^3/m^3$ in November. The Austin and Dickinson report (1973) shows *Pseudocalanus* spp. (76%) and *A. tonsa* (32%) abundant during September. Gibson found *Pseudocalanus* spp. abundant during spring and summer and rare during autumn. *A. tonsa* was never abundant. These differences probably reflect the dynamic nature of the Bight apex, as well as the different sampling techniques used.

The zooplankton of the Bight apex differ in several respects from the zooplankton of adjacent estuarine waters. Peak zooplankton densities were lower in the apex than in the Raritan River estuary, primarily due to reduced levels of meroplankton but also due to low peak densities of copepods. Bimodal distributions were observed in both environments, but peak abundances in the apex generally occurred one to two months after the peaks observed in the estuary. The major flux of benthic larvae into the plankton took place during the summer months in the estuary; two major pulses occurred in the apex, one from January through March and a second from August to November.

Outer Bight

Grice and Hart (1962) described the spatial and seasonal distribution of zooplankton in continental shelf and slope waters based on bottom-to-surface vertical tows with a No. 6 net (230μ mesh). Samples were collected along a transect from Montauk Point across the shelf and slope in September and December 1959 and March and July 1960 (Map 3).

Annual mean zooplankton density in shelf waters (stations A, B, C, and D) was 1.5 x $10^3/m^3$ compared with 0.3 x $10^3/m^3$ in slope waters (stations E and F). Zooplankton densities at inshore stations A and B were low (0.4 x 10^3 to 1.3 x $10^3/m^3$) in September and March and high (1.2 x 10^3 to 8.0 x $10^3/m^3$) in December and July. In contrast, offshore shelf stations C and D were characterized by a steady decline from peak densities in September (1.6 x 10^3 to 3.3 x $10^3/m^3$) to minimum densities in July (0.2 x $10^3/m^3$). The low July value may reflect clogging of the nets by pelagic tunicates abundant at that time. Maximum density (3.3 x $10^3/m^3$) at station D in September coincided with the occurrence of the largest number of species in shelf waters (35 copepods, 3 cladocera, 3 chaetognaths, 2 euphausiids, 7 amphipods, 2 siphonophores, and 1 decapod crustacean), and is indicative of the influx of Gulf Stream water.

The proportion of major taxa in the zooplankton of shelf waters is shown in Figure 13. Except for July when pelagic tunicates were abundant (predominantly *Salpa fusiformis*), copepods dominated, forming 90% to 99% of the zooplankton. A total of 42 copepod species were identified. The three dominant species were *P. minutus, C. typicus,* and *O. similis* (Figure 14). Other frequently sampled species in order of abundance included *T. longicornis, P. parvus, C. finmarchicus, M. lucens,* and *C. armata.* A more complete species list is given in Table 10. Other numerically abundant taxa include medusae, chaetognaths, ctenophores, cladocera, euphausiids, and amphipods. Polychaetes, ostrapods, siphonophores, pteropods, heteropods, and decapod crustaceans were rare or not present.

The September zooplankton assemblage was dominated by *C. typicus,* comprising a mean of 50% of the copepods present. Two species showed peaks in abundance at isolated stations. *A. tonsa,* an estuarine-marine species, accounted for 80% of the copepods at station A; the oceanic species *Clausocalanus furcatus* accounted for 11% at station B. The remaining 32 species present in shelf waters at this time were rare, never exceeding 0.20 x 10^3 individuals/m^3. Of these 32 species, 14, in addition to *C. furcatus,* are oceanic species, indicating the intrusion of warm, oceanic waters over the shelf. Consistent with this conclusion was the presence of five euphausiid species: *Meganyctiphares norvegica, Thysanoessa longicandata, Euphausia tenera, Dematoscelis megalops.* and *Thysanoessa gregaria. E. tenera, D. megalops,* and *T. gregaria* are strictly oceanic species.

By December the number of copepod species had decreased to 16, of which 15 were present in September. *C. typicus* remained the dominant species with a mean abundance of 0.40 x 10^3 individuals/m^3 (30% of all copepods). *P. minutus* and *O. similis* were equally abundant (0.25 x 10^3/m^3), each accounting for 20% of the copepods. *Oithona atlantica* was locally abundant at stations B and C where it made up 18% of the copepods. The decrease in copepod abundance compared to September may have been due to predation by the chaetognaths *S. elegans, S. serratodentata,* and *S. enflata,* which reached their seasonal peak density at this time (mean = 0.04 x 10^3/m^3).

Only 10 copepod species were present in March when the zooplankton biomass reached its annual minimum. *P. minutus* was the most abundant zooplankter, especially at stations A and B where it formed 93% and 53% of the copepods, respectively. Of the 16 copepod species present in December, six remained. The four new species, *A. longiremis, C. hamatus, T. longicornis,* and *T. discaudatus,* were not abundant. The ctenophore *P. pileus* was abundant at station B where it formed 50% of the zooplankton by volume.

By July the number of copepod species had increased to 15. *P. minutus* continued to dominate the zooplankton, especially at the inshore stations; it reached densities of 5.4 x 10^3/m^3 at station A (68% of total zooplankton) and 0.4 x 10^3/m^3 at station B (33% of total zooplankton). *C. typicus* (0.38 x 10^3 individuals/m^3), *T. longicornis* (0.27 x 10^3 individuals/m^3), and *O. similis* (0.39 x 10^3 individuals/m^3) were also abundant. The low copepod densities observed at offshore stations C and D may have been due to the presence of predatory ctenophores (*Pleurobrachia* spp.) or to the high densities of pelagic tunicates (99% of the zooplankton by volume) that clogged the nets.

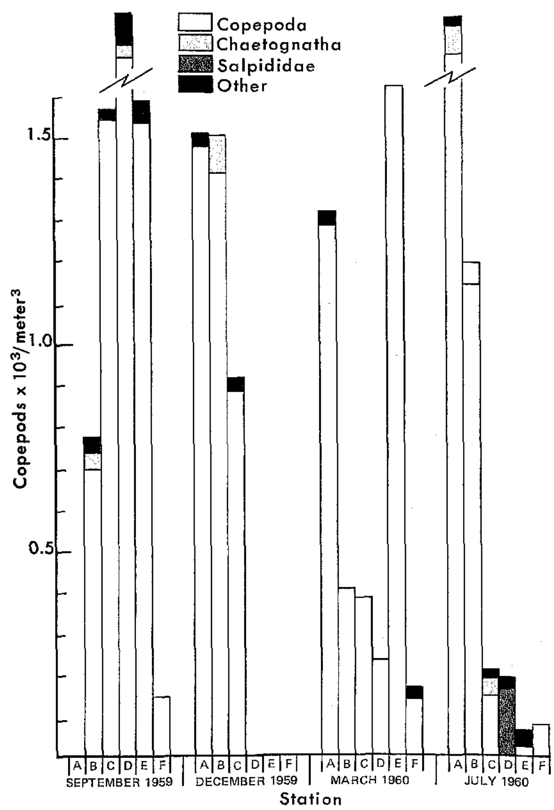


Figure 13. Relative abundance of major taxa in outer Bight, September 1959 through July 1960

Table 10. Copepod species found in outer Bight

Species	Shelf				Slope
	Sept	Dec	Mar	July	
Centropages typicus	1300/m^3	400/m^3	10/m^3	379/m^3	X
Calanus finmarchicus	$<$200/m^3	$<$100/m^3	–	–	X
Candacia armata	$<$200/m^3	$<$100/m^3	0	X	–
Metridia lucens	$<$200/m^3	$<$100/m^3	–	–	X
Oithona similis	$<$200/m^3	250/m^3	–	388/m^3	X
Paracalanus parvus	$<$200/m^3	$<$100/m^3	0	X	X
Temora longicornis	$<$200/m^3	0	X	274	–
Acartia tonsa	X	X	0	–	0
Oithona atlantica	–	X	–	–	X
Pseudocalanus minutus	0	250	X	X	X
**Clausocalanus furcatus*	X	0	0	0	X
**Clausocalanus arcuicornis*	X	X	0	0	X
**Labidocera aestiva*	–	X	0	–	0
Centropages hamatus	–	0	X	–	–
Temora discaudatus	–	0	X	–	0
Acartia clausi	0	0	0	X	–
**Acartia danae*	X	0	0	0	X
Acartia longiremis	0	0	X	–	–
**Calanus tenuicornis*	X	–	–	0	X
**Calocalanus pavo*	X	X	0	0	–
**Eucalanus attenuatus*	X	0	0	0	X
**Eucalanus pileatus*	X	0	0	0	X
**Euchaeta marina*	X	0	0	0	X
**Labidocera actuifrons*	X	X	0	0	X
**Mecynocera clausi*	X	X	0	0	X
**Nannocalanus minor*	X	0	0	0	X
**Temora stylifera*	X	0	0	0	X
**Undinula vulgaris*	X	0	0	0	X
**Oithona plumifera*	X	0	0	0	X
**Macrostella gracilis*	X	X	0	0	X
Clytemnestra rostrata	–	X	0	–	–
Anomalocera patersoni	0	0	0	X	–
Euchirella rostrata	0	0	0	X	–
Microstella norvegica	0	0	0	X	–
Rhincalanus nasutus	X	0	0	X	–
Aetideus armatus	0	0	0	0	X
Calanus hyberboreus	0	0	0	0	X
Clausocalanus pergens	0	0	0	0	X
Gaidius tenuispinus	0	0	0	0	X
Heterohabdus norvegica	0	0	0	0	X
Paraeuchaeta norvegica	0	0	0	0	X
Pleuromamma robusta	0	0	0	0	X
Scolecithricella mimor	0	0	0	0	X
Candacia pachydactyla	–	–	–	–	X
Clytemnestra scutellata	–	–	–	–	X
Ctenocalanus vanus	–	–	–	–	X
Pontellina plumata	–	–	–	–	X
Rhincalanus cornutus	–	–	–	–	X
Haloptilus longicornis	–	–	–	–	X
Scolecithrix danae	–	–	–	–	X

– = no data
X = present
0 = absent
*indicator species characteristic of warm ocean water

Source: After Grice and Hart 1962

Clarke (1940) studied zooplankton abundance from October 1937 to June 1939 along the same transect selected by Grice and Hart (1962) (Map 3). Both No. 2 and No. 10 nets were used, and abundance was expressed as number/30-minute tow. Two species were analyzed numerically, *C. typicus* and *C. finmarchicus.* Both species were confined to shelf waters. *C. finmarchicus* was most abundant during spring and early summer; *C. typicus* was most abundant during late summer and autumn.

In summary, the most striking feature of the outer Bight zooplankton is the near-complete dominance of copepods. The annual mean zooplankton density was $1.5 \times 10^3/m^3$. Inshore (stations A and B, Map 3), zooplankton densities ranged from $0.4 \times 10^3/m^3$ in March to $8.0 \times 10^3/m^3$ in July. Offshore (stations C and D), densities ranged from $0.2 \times 10^3/m^3$ in July to $3.3 \times 10^3/m^3$ in September. *C. typicus* was the most abundant zooplankter in September and December, *P. minutus* dominated in March and July, *O. similis* was abundant in December and July. Locally abundant species included the estuarine-marine species *A. tonsa* (station A, September), the oceanic species *C. furcatus* (station B, September), the ctenophore *P. pileus* (station B, March), and the pelagic tunicate *S. fusiformis* (stations C and D, July).

Peak zooplankton densities were an order of magnitude less than those observed in the Bight apex. Predators, such as ctenophores and chaetognaths, were relatively more abundant in the outer Bight than in the apex, and meroplankters were relatively scarce.

The species composition of zooplankton in the outer Bight, although characterized by the presence of many oceanic species (rarely abundant), was similar to that observed in Block Island Sound and the Bight apex, especially during autumn. Differences in species composition and rank order of abundance were due primarily to the increased abundance of estuarine and estuarine-marine forms of holoplankton (Table 11) and of meroplankters in the Bight apex and in Block Island Sound.

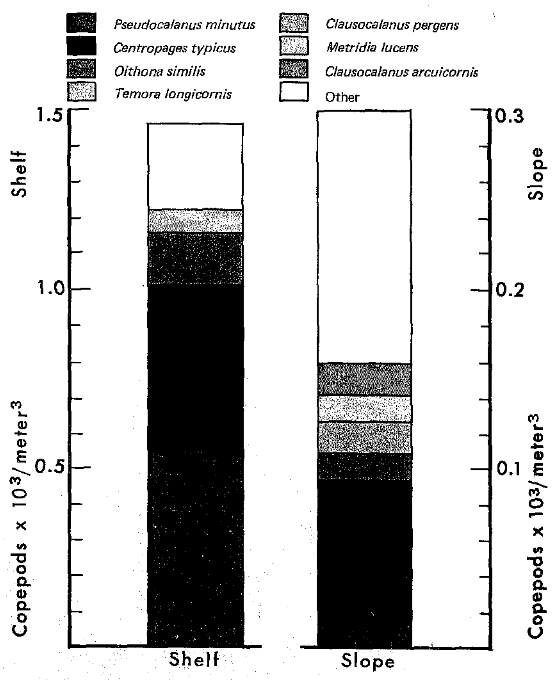


Figure 14. Mean annual abundance of copepod species, outer Bight and continental slope

Table 11. Salinity classification and location of common copepod species

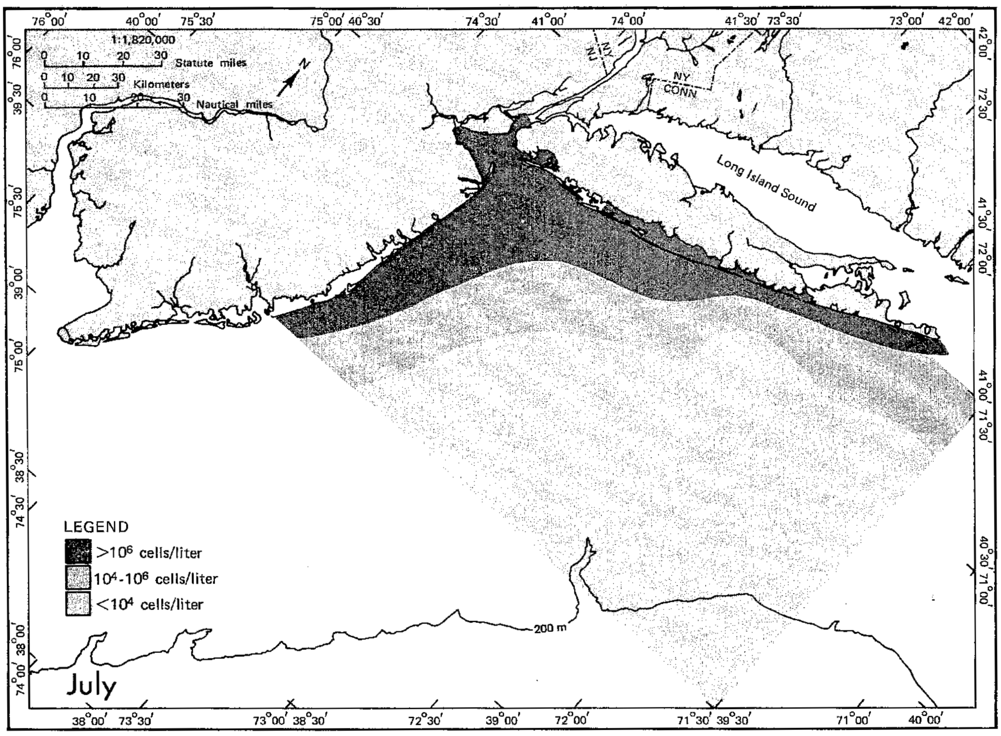
Species	Salinity Classification	Areas Found
Eurytemora affinis	e	E,IB
Eurytemora americana	e	E, BIS, IB
Eurytemora herdmani	e	E, BIS
Acartia clausi	e-m	E, BIS, IB, OB
Acartia tonsa	e-m	E, BIS, IB, OB
Pseudodiaptomus coronatus	e-m	E
Oithona brevicornis	e-m	E, BIS, IB
Oithona similis	e-m	E, BIS, IB, OB
Tortanus discaudatus	e-m	E, BIS, IB, OB
Paracalanus crassirostris	e-m	E, BIS, IB, OB
Paracalanus parvus	eu-m	BIS, IB, OB
Pseudocalanus minutus	eu-m	E, BIS, IB, OB
Labidocera aestiva	eu-m	E, BIS, IB, OB
Temora longicornis	eu-m	E, BIS, IB, OB
Temora stylifera	eu-m	BIS, OB
Centropages hamatus	eu-m	E, BIS, IB, OB
Centropages typicus	s-m	E, BIS, IB, OB
Calanus finmarchicus	s-m	E, BIS, IB, OB
Aetideus armatus	s-m	OB
Clausocalanus pergens	s-m	OB
Gaidius tenuispinus	s-m	OB

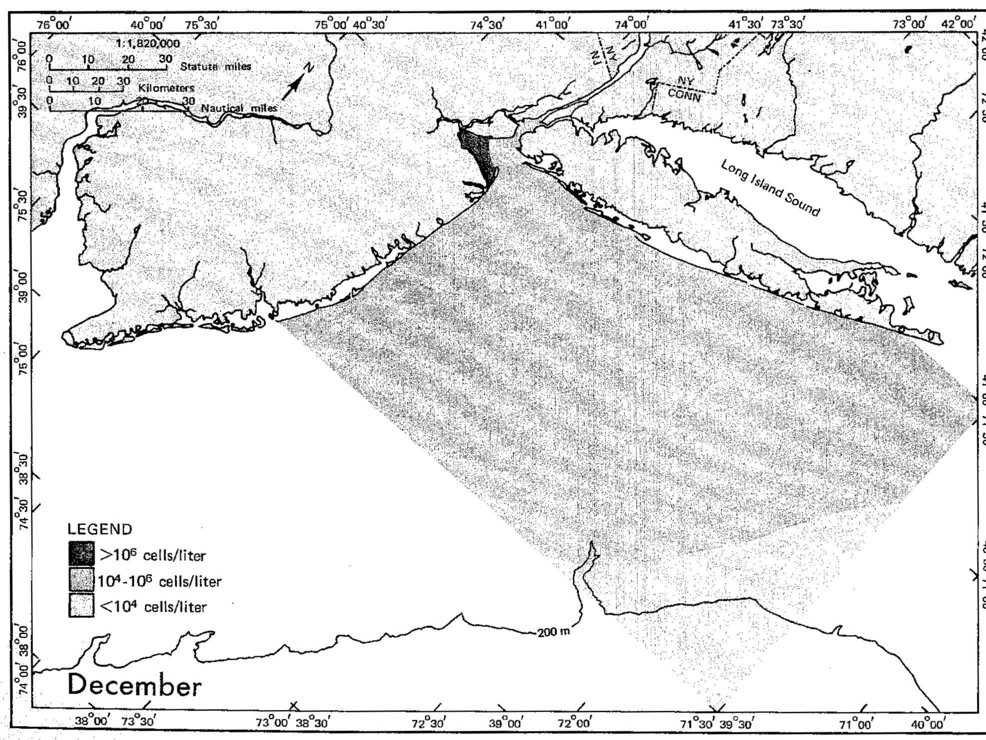
e = estuarine
e-m = estuarine-marine
eu-m = euryhaline-marine
s-m = stenohaline-marine

E = estuary
BIS = Block Island Sound
IB = inner Bight
OB = outer Bight

Sources: Grice and Hart 1962; Jeffries 1967; Sage and Herman 1972

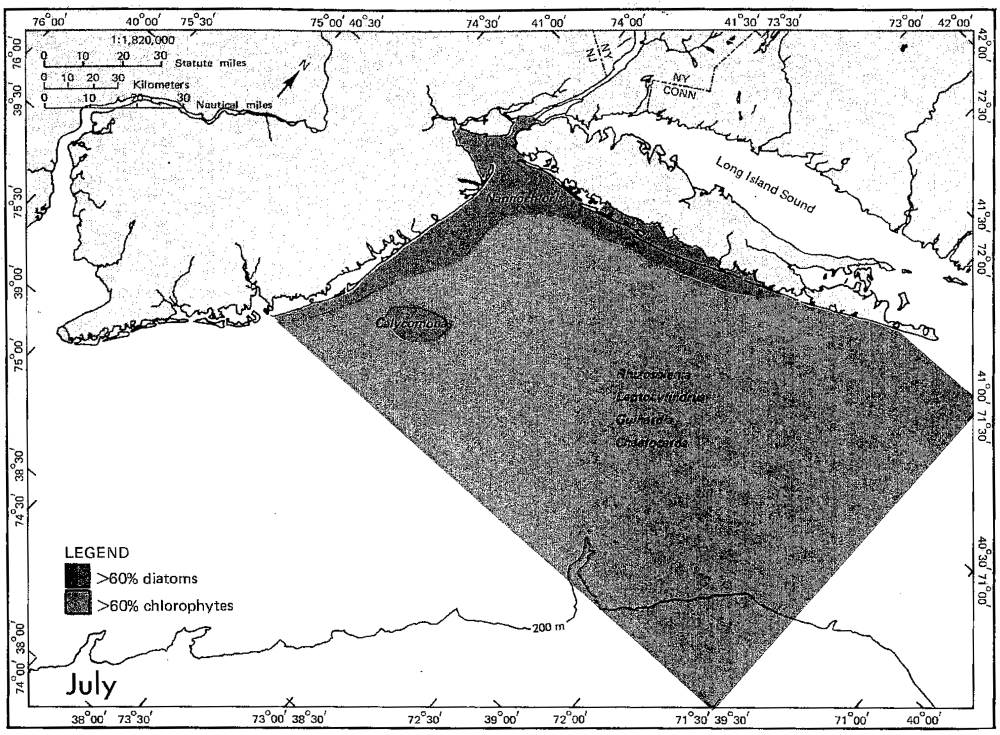
Map 4. Surface phytoplankton cell densities

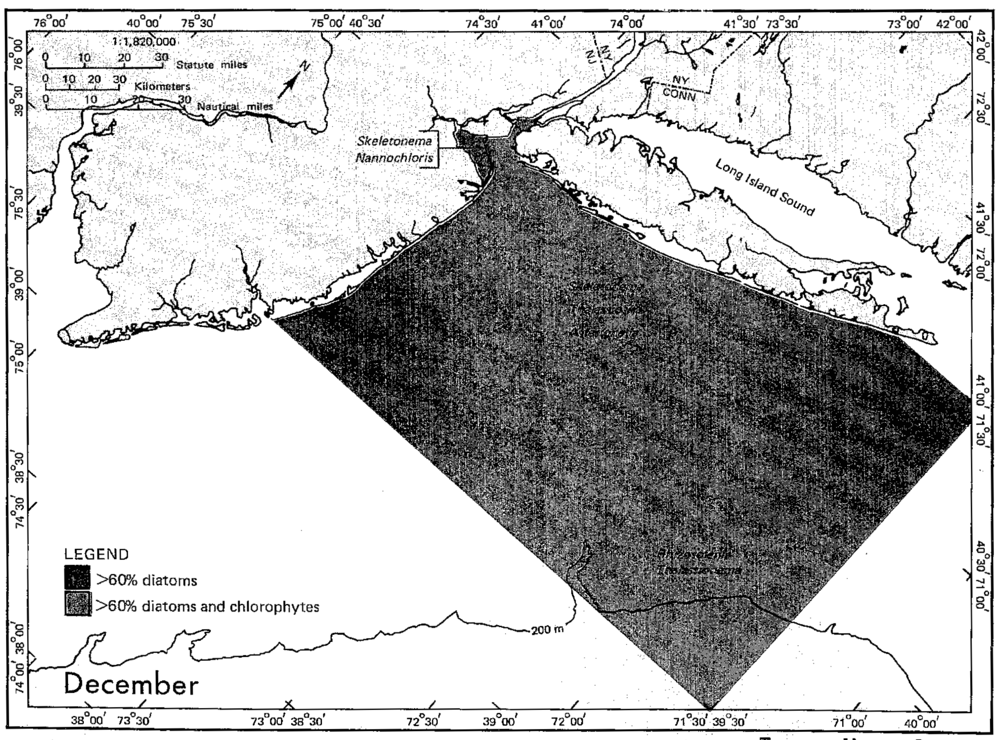




Transverse Mercator Projection

Map 5. Relative surface abundance of diatoms and chlorophytes





Transverse Mercator Projection

Summary

The spatial and temporal distributions of plankton species in New York Bight have been the subject of several investigations during the past 75 years. Combined seasonal and spatial observations have been made in three regions: the Raritan-Hudson River estuary, the Bight apex, and along one (zooplankton) to three (phytoplankton) transects in the outer Bight. Based on these and other observations, general patterns of species distributions can be described.

Phytoplankton cell densities decrease systematically with distance from the Raritan and lower Hudson River estuaries (Map 4). Estuarine cell densities range from 10^6 to 10^9/liter compared with 10^4 to 10^7/liter in the apex and 10^3 to 10^5/liter in the outer Bight. The species composition of diatoms is similar in all three regions. Bloom organisms include *S. costatum, T. nitzschioides, A. japonica, T. nordenskioldii, C. socialis, C. debilis,* and *L. danicus.* On an annual basis, *S. costatum* is most abundant, especially in estuarine waters. Nanoplankton populations are dominated by the chlorophyte *N. atomus* in the estuary and Bight apex (Map 5). The dinoflagellates *P. micans, Peridinium* spp., and *Ceratium* spp. are locally abundant. Offshore, chlorophytes are not abundant except for a local bloom of *C. gracilis* in April.

The cell density of phytoplankton in the estuary and in the Bight apex is maximum during summer and minimum during winter. This pattern reflects variations in the abundance of *N. atomus,* present at high densities during warm summer months and nearly absent during winter. The estuarine diatom distribution is bimodal, reaching peak densities during spring and late summer, due primarily to blooms of *S. costatum.* Diatom blooms in the apex occur sporadically during autumn, winter, and spring.

Offshore, where chlorophytes are rarely abundant, the diatom-dominated phytoplankton exhibit a winter maximum and a summer minimum. Again the bloom organisms include *S. costatum, T. nitzschioides, A. japonica,* and, along the Long Island coast, *R. faeroense.*

Zooplankton density decreases with distance from the estuary but not dramatically as with phytoplankton. Copepods and, during summer, meroplanktonic organisms dominate the estuarine zooplankton, ranging in abundance from 1 to 400 x 10^3 individuals/m^3. Copepod abundance varies from between 1 and 90 individuals/m^3 in the estuary and apex to between 0.2 and 8 x 10^3/m^3 in the outer Bight. Zooplankton densities are generally high in mid-depth and near-bottom samples, especially during periods of water column stratification.

The zooplankton of Raritan Bay are dominated by estuarine (*Eurytemora* spp.) and estuarine-marine (*Acartia* spp.) copepods and by polychaete (*Polydora* spp. and *Merinides* sp.), euryhaline-marine (*P. parvus, P. minutus,* and *T. longicornis*), and stenohaline-marine copepods (*C. typicus*). Local blooms of cladocera (*Podon* sp., *Evadne* sp., and *Penilia* sp.), pelagic tunicates (*S. fusiformis*), and ctenophores (*Pleurobrachia* spp.) are also observed during summer and autumn.

Seasonal variations in the abundance of estuarine zooplankton are primarily due to copepod blooms and influxes of benthic larvae. Maximum abundance is observed in the estuary during summer because of the large meroplankton influx. Estuarine copepods exhibit a late spring maximum and a secondary peak during early autumn.

In contrast, the seasonal cycle of zooplankton at apex and outer Bight stations is due primarily to variations in copepod abundance, which reaches peak densities during summer and autumn. Peaks in meroplankton abundance occur during late winter-early spring and again during late summer-early autumn.

The summer-autumn intrusion of warm oceanic waters into the Bight is reflected in the species composition of plankton assemblages. While phytoplankton densities are lowest at this time in the outer Bight, zooplankton abundance and number of species are at their seasonal high. It is not possible to determine the extent to which peaks in the abundance of holoplanktonic particle grazers (for example, copepods, cladocera, and tunicates) are growth responses to phytoplankton blooms or are a consequence of circulation patterns related to the influx of warm, high-salinity Gulf Stream water. It is likely, however, that the late summer-early autumn decline in copepod abundance is due to predation by ctenophores. The predominance of these relatively inefficient predators may be indicative of the decline of more efficient plankton predators (mackerel and

herring, for instance), possibly due to overfishing (McHugh 1972) or to the large quantities of waste materials discharged into the Bight (Gross 1976).

Finally, the phytoplankton and zooplankton distributions described are of limited value because they are based on infrequent observations using a variety of techniques. Data on phytoplankton distributions are limited to surface observations. The zooplankton data are difficult to compare because of the wide variety of sampling techniques and mesh sizes. Because of inadequate temporal and spatial coverage and the lack of standardized methodology, the plankton systematics required to understand the ecology of plankton populations in New York Bight are presently incomplete.

Glossary

Bacillariophyceae: diatoms; a class of unicellular or colonial algae with a cell wall consisting of two halves impregnated with silica; an important group of food organisms for herbivorous zooplankton and filter-feeding bivalves such as oysters and clams.

Chaetognatha: arrowworms; a phylum of small, elongate, transparent, wormlike animals; most species are planktonic, all are predators.

Chlorophyceae: green algae; planktonic forms usually unicellular with or without flagella; most abundant in warm waters and shallow embayments.

Cladocera: water fleas; a suborder of the class Crustacea; zooplankton filter-feeders that feed primarily on phytoplankton.

Coelenterata: a phylum of animals with both sessile and planktonic stages in their life cycle; planktonic stages are disc- or bell-shaped and called medusae or jellyfish; carnivores preying on other zooplankton and small fish.

Copepoda: a subclass of the class Crustacea; small (0.1 to 1 mm long), shrimplike animals, the most abundant group of zooplankton in the sea; most of the pelagic species are filter-feeders, utilizing phytoplankton as their principal food source.

Ctenophora: comb jellies; a phylum of spherical or pear-shaped animals of jellylike consistency, ranging from the size of a pea to that of a golf ball; transparent body divided into equal sections by eight bands of cilia (comb rows); predators feeding on other zooplankton.

Diatoms: *see* **Bacillariophyceae**.

Dinophyceae: dinoflagellates; a class of unicellular, flagellated algae; most abundant in warm waters; dense blooms of some species produce "red tides" that cause mass mortality of marine life through the production of toxins.

Doliolum: a genus of the subphylum Urochordata (tunicates); barrel-shaped and planktonic; filter-feeders feeding primarily on phytoplankton.

Dominance: measure of the degree to which the biomass of a given trophic level is concentrated within a small number of species populations (*see* Species diversity).

Echinodermata: sea urchins, sea cucumbers, sea stars, sea lilies, sand dollars; large phylum of invertebrates characterized by a benthic adult stage in which individuals are radially symmetrical and a planktonic larval stage in which individuals are bilaterally symmetrical.

Euglena: a genus of unicellular flagellates containing both pigmented (photosynthetic) and colorless (nonphotosynthetic) species; generally rare in marine environments.

Euryhaline: having a wide tolerance to salinity.

Gastropoda: largest class of molluscs, including limpets, abalones, sea butterflies, cone shells, conches, oyster drills; most species are benthic but heteropods and pteropods (sea butterflies) have adapted a planktonic existence and are carnivores.

Hydrozoa: class of coelenterates; many species are sessile as adults with a planktonic larval stage resembling a small jellyfish; these carnivores are important fouling organisms.

Lamellibranchia: a subclass of bivalves (clams, oysters, mussels); benthic as adults, most have a planktonic larval stage; filter-feeders feeding on phytoplankton and organic detritus.

Larvacea: class of tunicates no more than a few millimeters long; filter-feeders feeding primarily on phytoplankton.

Meroplankton: planktonic organisms that spend only part of their life cycle as plankton; larvae of benthic invertebrates and fishes.

Nanoplankton: phytoplankters too small to be retained by nets with mesh sizes from 20 to 80 nanometers (nm); usually phytoplankters smaller than 20 nm.

Netplankton: phytoplankters retained by nets with mesh sizes from 20 to 80 nm; usually phytoplankters larger than 20 nm.

Pelecypoda: class of molluscs that includes bivalves.

Phytoplankton: unicellular or colonial algae that grow in the water column and are capable of little or no sustained, directional motility in the horizontal plane; the most important primary producers in the sea, these microscopic plants are the most important food source for pelagic herbivores.

Polychaeta: marine worms; an order of annelids, including most marine, segmented worms; planktonic polychaetes are carnivorous.

Siphonophora: an order of the class Hydrozoa; individuals exist as large planktonic colonies (for example, Portuguese man-of-war); carnivorous.

Species diversity: trophic levels or communities generally characterized by a small number of species that are abundant and a large number that are rare; species diversity increases as the number of species increases and as the degree of dominance decreases.

Stenohaline: having a narrow tolerance to salinity.

Zooplankton: a diverse assemblage of planktonic animals, including all major phyla; main consumers of phytoplankton and principal food of many fishes, squid, and baleen whales; not capable of sustained, directional movement in the horizonal plane.

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