NOAA Technical Memorandum NOS OMA 16

THE BIOLOGY OF THE HUDSON-RARITAN ESTUARY, WITH EMPHASIS ON FISHES

Rockville, Maryland
April 1985

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

National Ocean Service

NOAA TECHNICAL MEMORANDA

National Ocean Service Series

Office of Oceanography and Marine Assessment

The National Ocean Service, through its Office of Oceanography and Marine Assessment, surveys and monitors the oceans, US coastal waters, estuarine waters, and the Great Lakes to produce data and information products that describe the physical and chemical properties of these waters for a wide range of applications. The National Ocean Service also conducts studies to assess the environmental effects of human activities in US coastal waters and provides the leadership and expertise at the Federal level required to identify compatible and potentially conflicting multiple uses of marine resources.

NOAA Technical Memoranda NOS OMA (Office of Oceanography and Marine Assessment, previously known as the Office of Oceanography and Marine Services) subseries facilitate rapid distribution of material that may be preliminary in nature and may be published formally elsewhere at a later date.

NOS

OMS 1 R. G. Riley, E. A. Crecelius, R. E. Fitzner, B. L. Thomas, J. M. Gurtisen, and S. N. Bloom. 1983. Organic and inorganic toxicants in sediment and marine birds from Puget Sound. 125 pp. (PB-84-160-233).*

OMS 2 P. M. Chapman, R. N. Dexter, J. Morgan, R. Fink, D. Mitchell, R. M. Kocan, and M. L. Landolt. 1984. Survey of biological effects of toxicants upon Puget Sound biota--III. Tests in Everett Harbor, Samish and Bellingham Bays. 48 pp. (PB-84-218122).

OMS 3 J. M. Cox, C. C. Ebbesmeyer, C. A. Coomes, J. M. Helseth, L. R. Hinchey, G. A. Cannon, C. A. Barnes. 1984. Synthesis of current measure ments in Puget Sound, Washington--Volume 1. Index to current measurements made in Puget Sound from 1908-1980, with daily and record averages for selected measurements. 38 pp. (PB-84-214105).

OMS 4 C. A. Coomes, C. C. Ebbesmeyer, J. M. Cox, J. M. Helseth, L. R. Hinchey, G. A. Cannon, C. A. Barnes. 1984. Synthesis of current measurements in Puget Sound, Washington--Volume 2: Indices of mass and energy inputs into Puget Sound: Runoff, air temperature, wind, and sea level. 45pp.(PB85-1764367AS).

OMS 5 C. C. Ebbesmeyer, C. A. Coomes, J. M. Cox, J. M. Helseth, L. R. Hinchey, G. A. Cannon, C. A. Barnes. 1984. Synthesis of current measurements in Puget Sound, Washington--Volume 3: Circulation in Puget Sound: An interpretation based on records of currents. 73 pp. (PB-85-105872).

OMS 6 J. Calambokidis, J. Peard, G. H. Steiger, J. C. Cubbage, and R. L. DeLong. 1984. Chemical contaminants in marine mammals from Washington State. 167 pp. (PB-84-072317).

OMA 7 R. J. Breteler (ed.). 1985. Chemical pollution of the Hudson-Raritan Estuary. 72 pp.

OMA 8 R. A. Young and B. F. Hillard. 1985. Suspended matter distributions and fluxes related to the Hudson-Raritan estuarine plume. 32 pp.

OMA 9 P. M. Chapman, R. N. Dexter et al. 1985. Survey of biological effects of toxicants upon Puget Sound biota. IV. Interrelationships of infauna, sediment bioassays and sediment chemistry data.

OMA 10 E. A. Quinlan, P. M. Chapman, R. N. Dexter, D. E. Konasewich, C. C. Ebbesmeyer, G. A. Erickson, B. R. Kowalski, and T. A. Silver. 1985. Toxic chemical and biological effects in Puget Sound: Status and scenarios for the future.

OMA 11 D. A. Segar and P. G. Davis. 1985. Contamination of populated estuaries and adjacent coastal ocean--A global review. 120 pp.

OMA 12 G. M. Torgrimson. 1985. The on-scene spill model. 70 pp.

OMA 13 C. N. Flagg, D. E. Frye, and P. R. Daifuku. 1985. Analysis of circulation characteristics in the vicinity of Deepwater Dumpsite 106. 60 pp.

OMA 14 E. A. Crecelius, R. G. Riley, S. N. Bloom, B. L. Thomas. 1985. History of contamination of sediments in Commencement Bay, Tacoma, Washington. 43 pp.

OMA 15 M. Devine and D. Simpson. 1985. Impact of and recovery from sewage sludge dumping at the Philadelphia dumpsite. 37 pp.

OMA 16 D. L. Berg and J. S. Levinton. 1985. The biology of the Hudson-Raritan estuary, with emphasis on fishes. 180 pp.

OMA 17 K. E. Kohler and G. C. Han. 1985. Diagnostic modelling of continental shelf circulation in the New York Bight. 190 pp.

---

*Numbers in parentheses are NTIS (National Technical Information Service) accession numbers, which indicate that the volume is available from NTIS, U.S. Department of Commerce, Sills Bldg., 5285 Port Royal Road, Springfield VA 22161. [(703) 487-4600]. Price of paper copy varies; microfiche copy, $4.50.

NOAA Technical Memorandum NOS OMA 16

THE BIOLOGY OF THE HUDSON-RARITAN ESTUARY, WITH EMPHASIS ON FISHES

David L. Berg
Jeffrey S. Levinton

Department of Ecology and Evolution
SUNY at Stony Brook
Stony Brook, New York 11794

Rockville, Maryland
April 1985

UNITED STATES DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and Atmospheric Administration
Anthony J. Calio, Deputy Administrator

National Ocean Service
Paul M. Wolff, Assistant Administrator

Atlantic Office, Stony Brook, New York

Coastal and Estuarine Assessment Branch
Ocean Assessments Division
Office of Oceanography and Marine Assessment
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

CONTENTS

FIGURES

FIGURES (continued)

FIGURES (continued)

FIGURES (continued)

TABLES

TABLES (continued)

The Biology of the Hudson-Raritan Estuary, with Emphasis on Fishes

David L. Berg and Jeffrey S. Levinton

ABSTRACT. A number of studies that address various aspects of the ecology of the Hudson-Raritan estuary are reviewed and compared where possible. Special emphasis is directed at the species composition and abundance of fish within the estuary. Factors contributing to historical changes in finfish abundance are addressed. Fish densities and species composition are compared with other mid-Atlantic estuaries. Consideration is given to species distribution and abundance within the region and to factors contributing to historical changes in these parameters. Temporal and spatial patterns of abundance are examined for the 15 most numerous species. Fish species composition and patterns of abundance of the major species are generally typical of mid-Atlantic estuaries. However, the Lower Bay complex does appear to have lower overall fish densities and fewer species than the nearby Great Bay-Mullica River estuary of New Jersey. Benthic-feeding species are noticeably less abundant in the Lower Bay complex than in other local estuaries.

The plankton-nutrient cycle is summarized. The exceptionally high sewage-derived nutrient load does not limit primary production. It is governed instead by seasonal light and temperature changes.

Two major benthic surveys of the Lower New York Bay complex, conducted 15 years apart, are reviewed to assess temporal changes. Species richness and overall macrobenthic abundance declined substantially. Species indicative of overall disturbance were more numerous in the later survey. No causal relationship is established between this apparent decline and any natural or anthropogenic factor.

1. INTRODUCTION

This report summarizes the current knowledge of the biology of the Hudson-Raritan estuary. Because many studies have reviewed aspects of primary production and benthic distribution, these will be discussed only briefly. The biology, distribution, and abundance of the finfishes of the estuarine system will be emphasized in an effort to understand the potential for commercial exploitation, and more importantly, the current status of marine living resources in the estuary.

The Hudson-Raritan estuary shares many of its biotic characteristics with other estuarine systems on the East Coast of the United States. However, very large amounts of sewage-derived nutrients are released into the estuary. In fact, nutrient concentrations do not ever seem to limit primary productivity. In the Narrows, annual gross primary production surpasses that of any other estuary. Production seems to increase proportionately to seasonally increasing light and temperature (Malone, 1977a).

The estuarine system is also notable for high concentrations of anthropogenically introduced toxic substances. Raritan Bay harbors the highest estuarine metal concentrations in the world (Greig and McGrath, 1977). PCBs are found in varying concentrations in the bottom sediment throughout the estuary (e.g., Stainken and Rollwagen, 1979; MacLeod et al., 1981). Sediments of the Lower Bay are carbon rich; concentrations are substantially greater than those found in the adjacent continental shelf (Gross, 1970).

Given the levels of contimination, it is not surprising that the estuary probably harbors fewer species than more pristine water bodies (e.g. Franz, 1982). In the nineteenth century, the Lower Bay and Raritan Bay abounded in shad, smelt, crabs, and oysters, each of which constituted a major fishery. Pollution, habitat alteration and overfishing have taken their toll; none of these species is of major importance today.

2. HYDROLOGY

2.1. Circulation

2.1.1. Hudson River

The Hudson River Estuary (Fig. 1) receives most of its freshwater from the Hudson River. Other riverine contributions include those of the Raritan, Passaic, Hackensack, Shrewsbury, and Navesink Rivers. The estuarine (tidally influenced) portion of the Hudson River extends from the southern tip of Manhattan Island (Battery Park, km 0) to the Federal Dam near Albany (Troy, km 246). There are two major connections to the New York Bight; the Race in eastern Long Island Sound and the Sandy Hook-Rockaway Point transect in the Lower Bay. Semidiurnal tides of 1.4 m, 0.1 m, and 1.6 m mean, neap and spring tides respectively (NOAA, 1971), enter through the Narrows and move through the Upper Bay and Hudson River about 274 km. Throughout most of an "average" year, the salt front is generally confined to Haverstraw Bay (km 55-63) and southward during periods of high freshwater runoff, intruding as far north as West Point (km) and occasionally Newburgh (km 98) only during low flow (Texas Instruments, Inc. et al., 1977). The saline intrusion is always confined below km 129 even in such severe drought years as 1964 (Simpson, 1975; Texas Instruments, Inc. et al., 1977).

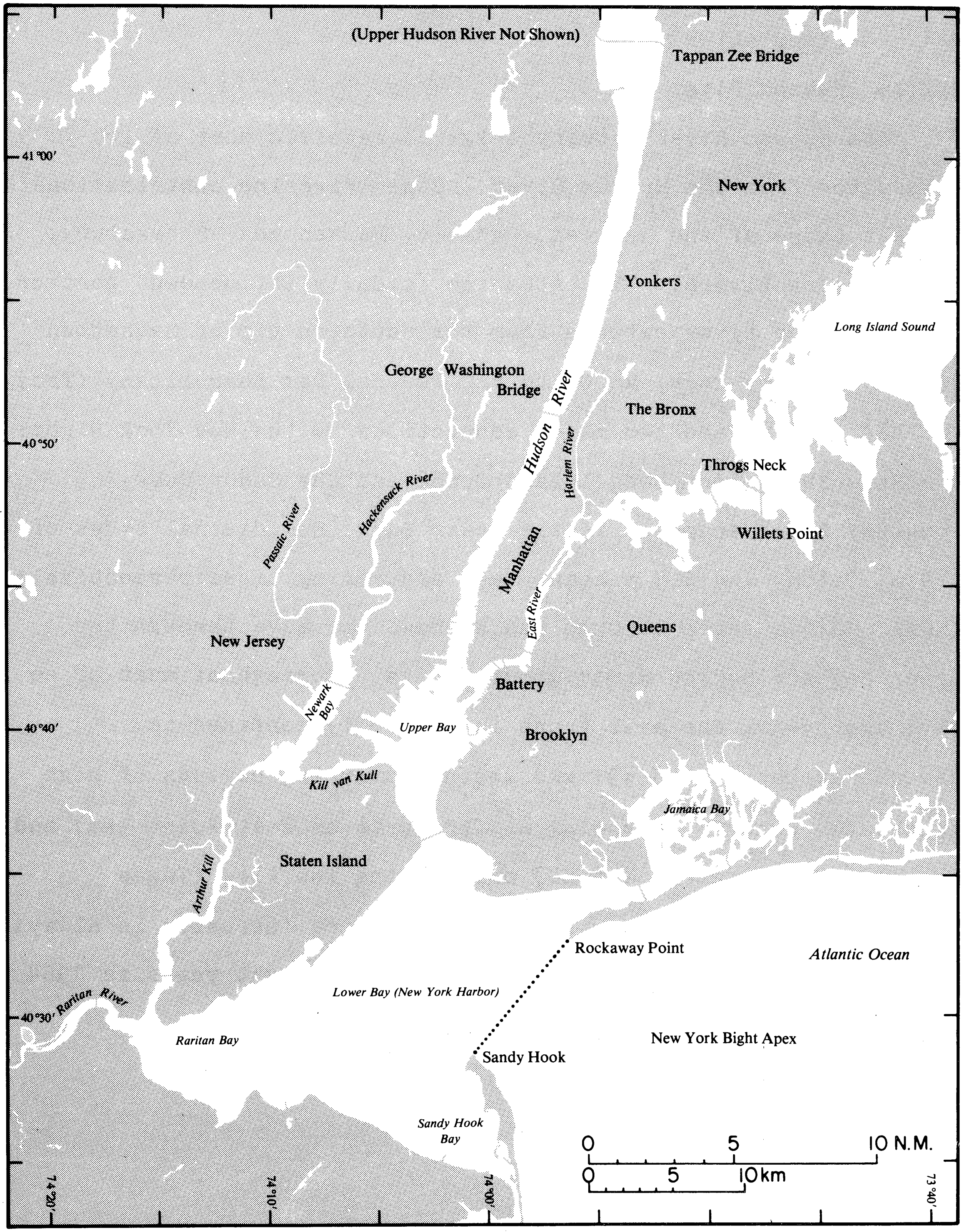


Figure 1. Hudson-Raritan Estuary Project study area.

Circulation patterns all over the Harbor are substantially affected by the seasonal cycle of Hudson River Runoff. The flow from the Hudson River drainage basin ($3.46 \times 10^4 km^2$) is subject to large irregularities (Giese and Barr, 1967). During a normal year, about half the runoff occurs during March, April, and May (Giese and Barr, 1967). Mean monthly runoff may vary by a factor of 10 from year to year. The runoff on an unusual day (up to $1.4 \times 10^4 m^3 sec^{-1}$) may be nearly an order of magnitude larger than the highest mean monthly runoff ($1.9 \times 10^3 m^3 sec^{-1}$). During late summer runoff, levels as low as 90 $m^3 sec^{-1}$ sometimes occur (Giese and Barr, 1967).

2.1.2. Lower Bay Complex

The Lower Bay complex of the New York Harbor consists of the Lower, Raritan, and Sandy Hook Bays. These waters mix and exchange with the waters of the Upper Bay to the north through the Narrows between Brooklyn and Staten Island and the sea to the south through the Sandy Hook (N. J.) - Rockaway Point (Brooklyn, N. Y.) transect. The Lower Bay complex is shallow (6.7 m average depth in Raritan Bay and 8.5 m in Lower Bay) and has an irregular submarine topography composed of numerous shoals, banks, and ship channels. The Lower Bay complex is about 40 km long with a surface area of 155 km^2 (National Marine Fisheries Service, 1971). Mixing of Hudson and Raritan freshwater and New York Bight seawater produces a large

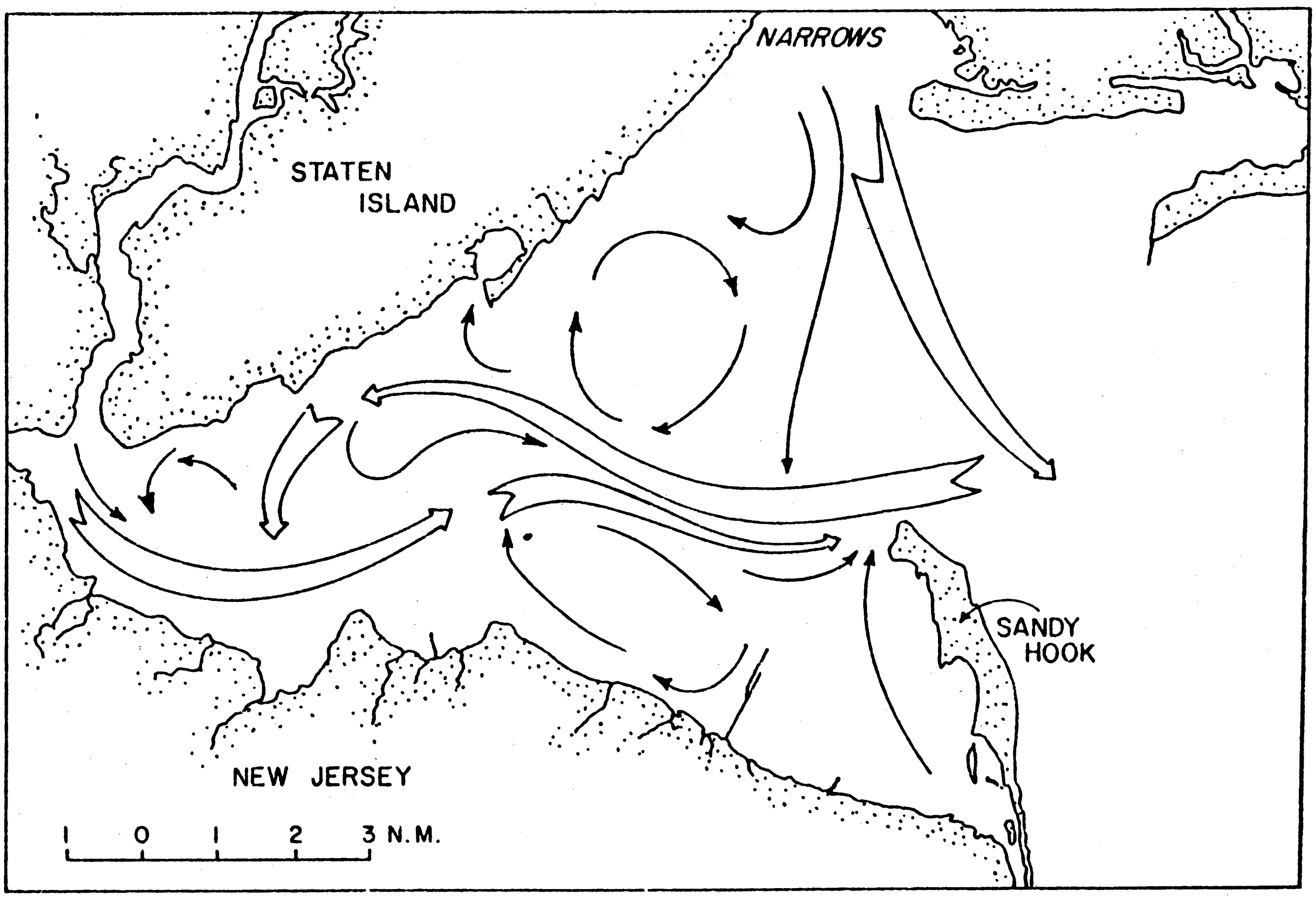
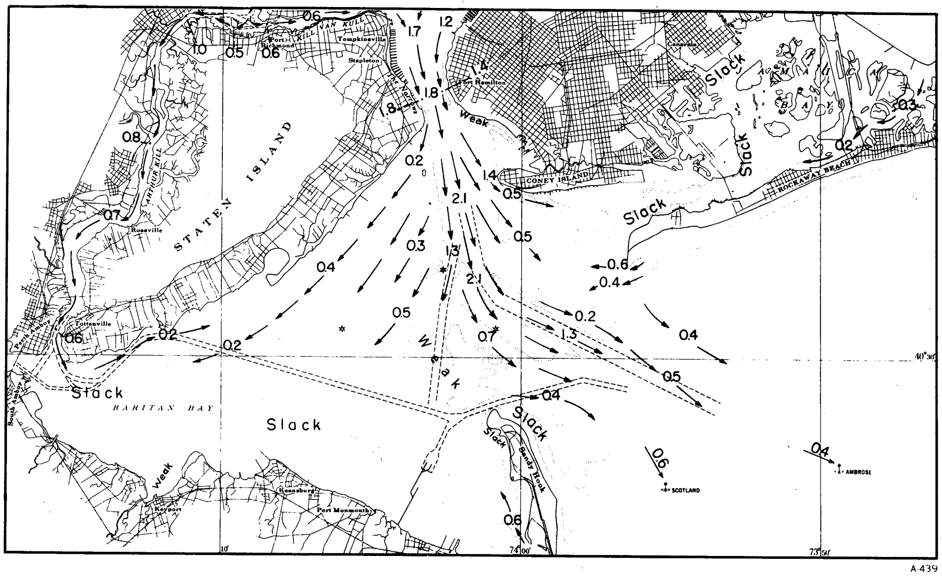
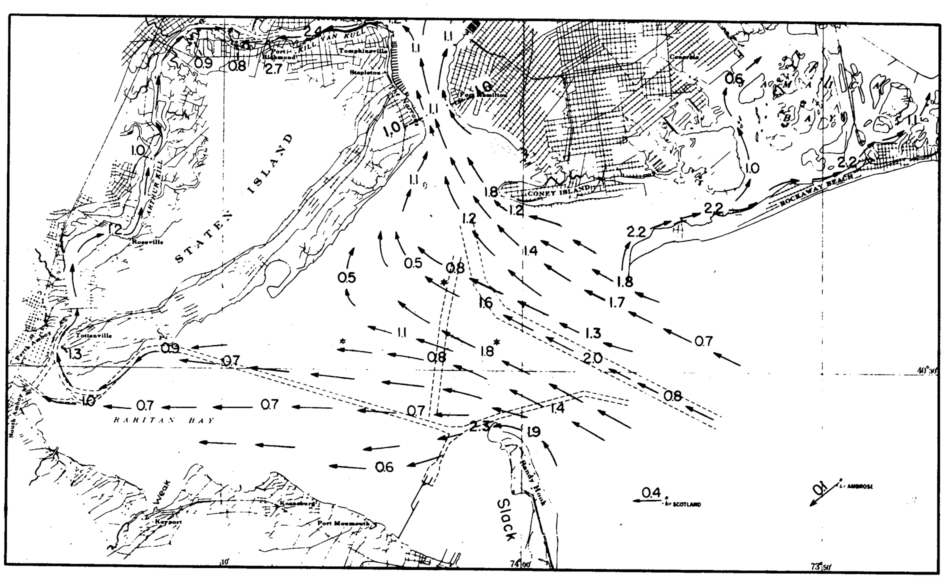


Figure 2. Net current flows in the Lower Bay complex (after Jeffries, 1962).

counterclockwise gyre (Jeffries, 1962). Raritan and Hudson River flows are separated by a clockwise eddy off Great Kills Harbor (Staten Island)(Fig. 2)(Ayers et al., 1949). Higher salinity water enters the Lower Bay during flood tide between the Ambrose Channel and Rockaway Pt. (Fig. 3) and continues in a southwesterly direction along the Staten Island shore (Brinkhuis, 1980). During ebb tide, the lower salinity water from Sandy Hook and Raritan Bays escapes around Sandy Hook into the New York Bight apex (Fig. 3). Lower Bay water is diluted primarily by Hudson River freshwater and flows out over the Ambrose Channel (Ayers et al., 1949). The nontidal circulation pattern in the Lower Bay complex has been described by Duedall et al. (1979) and Doyle and Wilson (1978). Less saline water leaves the Lower Bay near the surface, whereas a tongue of more saline N.Y. Bight water persists at depth in channels and depressions. There is a net nontidal flow of this saline water into the Lower Bay which mixes with overlying water by advection and turbulent diffusion (Kao, 1975; Doyle and Wilson, 1978). A slow net seaward drift of Lower Bay complex waters was suggested by Ayers et al. (1949), which involved mixing of outflowing waters with incoming masses, and little opportunity for significant flushing with each tidal cycle. A flushing time of 32-42 tidal cycles for maximum and minimum river flows was calculated by Ketchum (1951) for Raritan Bay. Sixty tides were required to flush

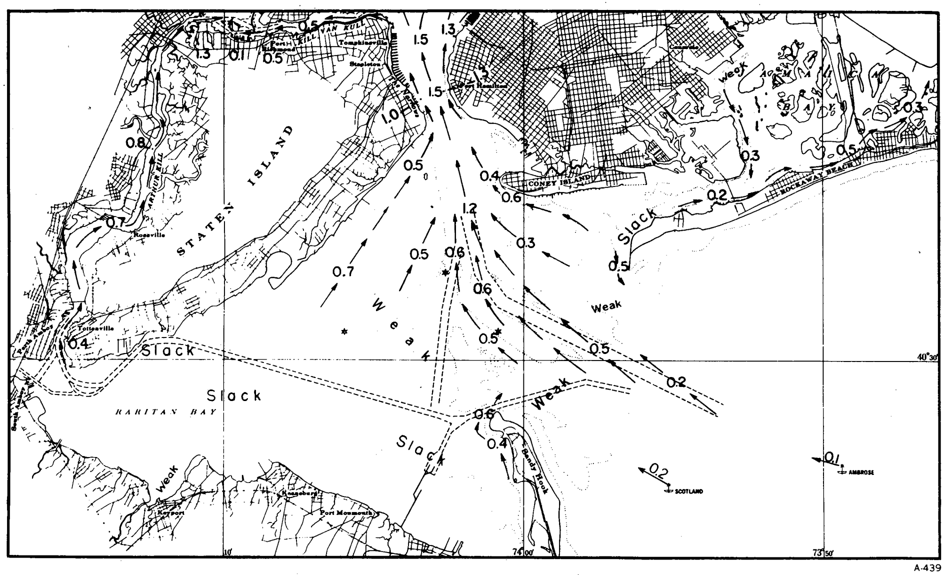


LOW WATER AT NEW YORK

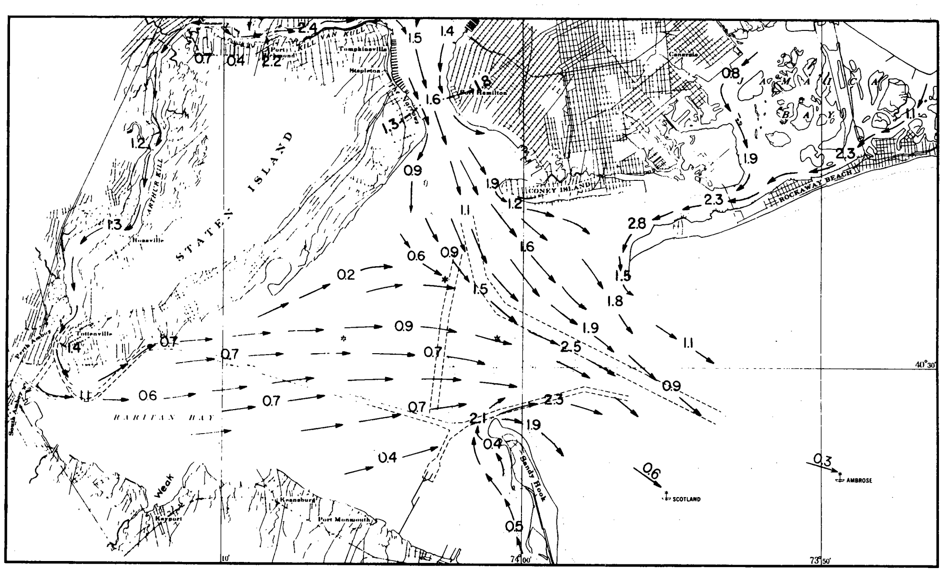


THREE HOURS AFTER LOW WATER AT NEW YORK

Figure 3. A) Tidal current charts of the Lower Bay complex and surrounding areas at low tide. (From National Marine Fisheries Service, 1971)



HIGH WATER AT NEW YORK



THREE HOURS AFTER HIGH WATER AT NEW YORK

Figure 3. B) Tidal current charts of the Lower Bay complex and surrounding areas at high tide. (From National Marine Fisheries Service, 1971)

river water through the estuary according to Ketchum's 1948 survey.

2.1.3. The Kills

The Arthur Kill separates Richmond County in New York from Union and Middlesex Counties in New Jersey. It is a tidal waterway about 21 km long and about 0.8 km wide. The Arthur Kill joins Raritan Bay to the south and Newark Bay to the north. Approximately 200 bulkheads and piers line the 50 km stretch of the Arthur Kill and contiguous Kill Van Kull. This area has been extensively dredged, filled, and bulkheaded. The Arthur Kill and Kill Van Kull drain into Raritan and Upper Bays respectively, and receive the discharge from the Passaic and Hackensack Rivers. Tidal currents are weak in the Arthur Kill, particularly in the northern end (Panuzio, 1966). Freshwater flow out of Newark Bay generally exits through the Kill Van Kull into the Upper Bay. The Arthur Kill is not a significant source of freshwater but has been described by Jeffries (1962) as a surge basin that contributes to mixing processes in Raritan Bay.

2.2. Dissolved oxygen

Surface and bottom dissolved oxygen concentrations in the HREP area reach minimal levels in August and September (Jeffries, 1962; Ichthyological Associates, Inc., 1974a,b,c,d,e,f; Texas Instruments, Inc. et al., 1970. Throughout much of the estuary, surface and bottom dissolved oxygen levels fall below 3 mg 1 particularly in the Hudson River along Manhattan Island (Texas Instruments, Inc. et al., 1977), the Arthur Kill (Raytheon, 1972; Ichthyological Associates, Inc., 1974a,b; Interstate Sanitation Commission, 1981), and the Lower Passaic and Hackenksack Rivers (Ichthyological Associates, Inc., 1974c,d,e,f). Bottom-water dissolved oxygen in the Lower Bay area ranges between 1.7 and 8.0 mg 1^{-1} in August (Thomas et al., 1976). East River and western Long Island Sound surface (1.5 meters) oxygen levels regularly drop below 3.0 mg 1^{-1} in August and September (Interstate Sanitation Commission, 1981). Seabed oxygen uptake rates are also highest in August (Thomas et al., 1976). Rates were highest in the Lower Hudson River (between Spuyten Duyvil and Upper New York Bay) and generally decreased seaward both in February and in August. Thomas et al (1976) attributes the high seabed oxygen consumption rates of the Lower Hudson to high organic loading. Fifty percent of the BOD load of the Hudson enters the river in this region (Mueller et al., 1976). Elevated rates of seabed oxygen uptake in Lower New York Bay are suggested by Thomas et al. (1976) to be a response to the large input of organic matter from primary productivity during August (O'Reilly et al., 1976). Thomas et al. (1976) estimates that only 3 to 6%

of the Lower Hudson River water can be accounted for by seabed oxygen uptake during the late summer. Similarly, the seabed of the Lower Bay was estimated to oxidize 6% of the total annual organic load of the Bay.

The primary factor contributing to dissolved oxygen levels in the Lower Hudson estuary is the discharge of enormous volume of sewage (Simpson et al., 1975). Of the total domestic waste discharge, 20% is not treated at all, and 27% receives only primary treatment. Even the remaining 53% of the domestic waste discharges are often treated much less efficiently than is expected of secondary sewage treatment (Mueller et al., 1976). The volume of sewage discharged to the estuary is about 10% of the Hudson River average discharge (Simpson et al., 1975). This illustrates the very high demand upon oxygen in the receiving waters.

3. PRIMARY PRODUCTION AND PHYTOPLANKTON

The two-layer circulation pattern of the Hudson-Raritan estuary must be considered in any discussioin of primary production. As discussed in the hydrography section, the estuary's nontidal circulation pattern fits the classic estuarine pattern. A deep-water saline intrusion extends as far as 129 km above the Battery; seaward surface flow of freshwater may extend as far south as 24 km north of the Battery.

Nutrient distribution in the Hudson-Raritan system may be regarded as unusual for an East Coast Atlantic estuary (Simpson et al., 1975). Nutrient chemistry and dissolved oxygen distribution is dominated by the enormous amount of sewage discharged into the estuary. The lower Hudson estuary received approximately 7.3 x $10^6 m^3 d^{-1}$ of domestic wastes (Mueller et al., 1976). Approximately two-thirds of the sewage discharge enters the estuary between 12.9 km below and 32.2 km above the Battery (Fig. 4). Unlike most other estuaries, biological activity does not seem to reduce nutrient concentrations or affect their distribution very much (Simpson et al., 1975; Malone, 1977a; Garside et al., 1976). Rather, nutrient distribution (e.g., phosphate) seems to act as a conservative oceanographic property (Fig. 5).

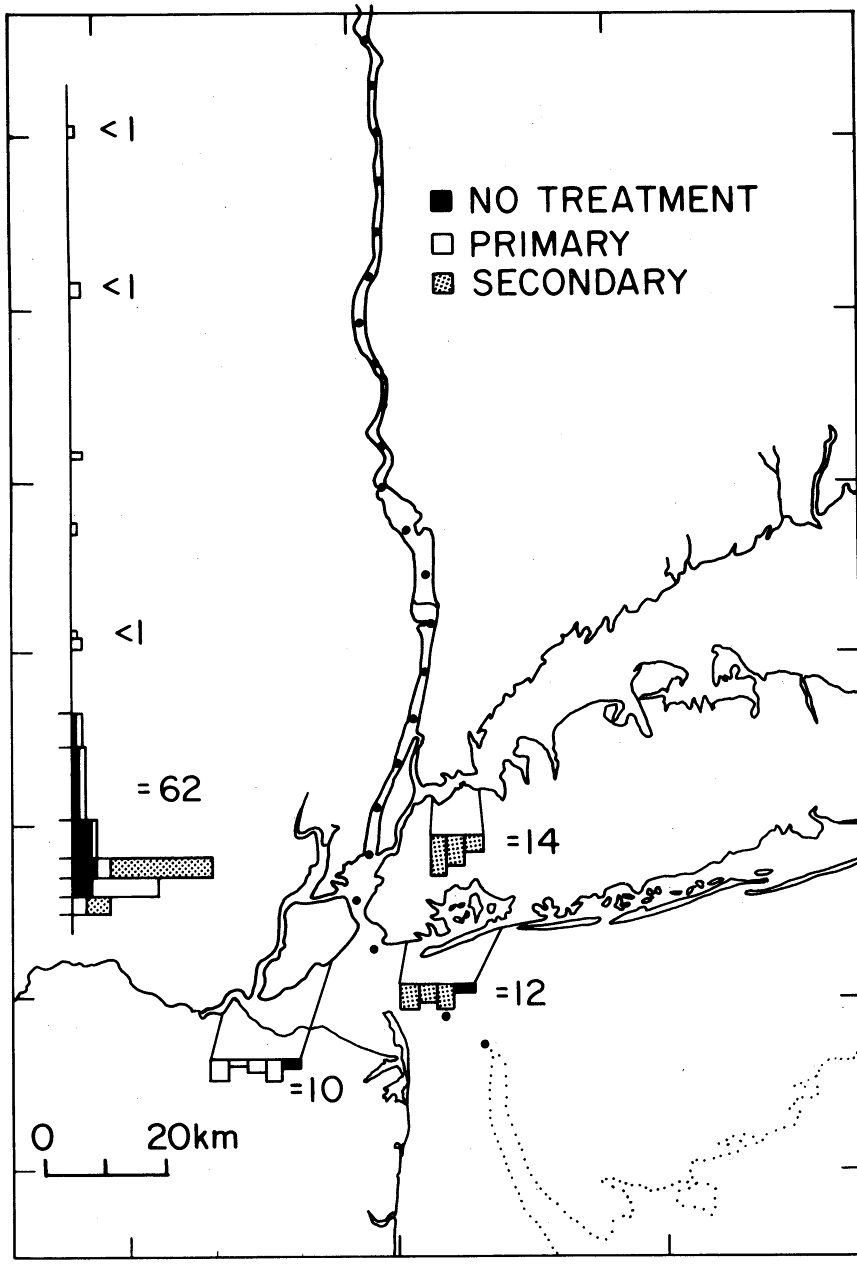


Figure 4. Volumes of sewage discharged to the Hudson Estuary (m^3/sec). The total volume discharged at the Narrows is 62 m^3/sec. Discharges to Jamaica Bay (12 m^3/sec), Arthur Kill and Raritan Bay (10 m^3/sec) enter downstream of the Narrows. The Upper East River discharges (14 m^3/sec) leave the system presumably via Long Island Sound. (From Simpson et al., 1975)

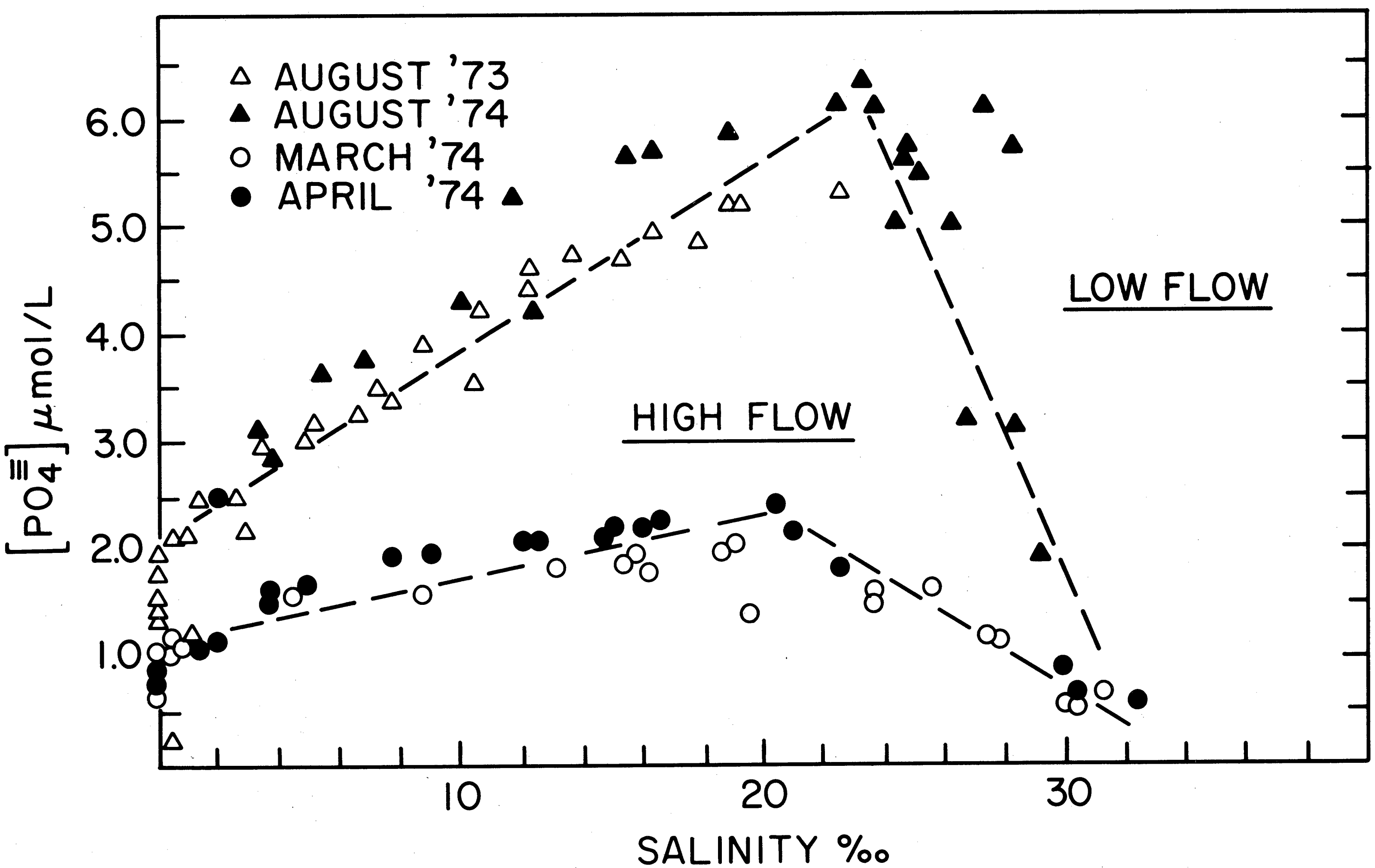


Figure 5. Molybdate-reactive phosphate as a function of salinity in the Hudson Estuary. The average high flow (1200 m^3/sec) salinities within Upper New York Bay are lower (15-20°/oo) than during low flow (<300 m^3/sec) when they range between 20°/oo and 26°/oo. (From Simpson et al., 1975)

Phytoplankton productivity seems to be directly proportional to chlorophyll a concentrations throughout the estuary (O'Reilly et al., 1976; Sirois and Fredrick, 1978). In the winter, primary productioin is dominated by net phytoplankton; nannoplankton, however, dominate summer production. Light and temperature seem to be the major limiting factors in the amount of production (Malone, 1977a); in the Lower Bay, productiion steadily increases (Fig. 6) to a peak in summer months. Dissolved ammonia varies directly with temperature. In the winter, it is likely that much of the net phytoplankton present in the lower reaches of the estuary is imported via estuarine flow of deeper saline waters from the New York Bight. Despite the high nutrient concentrations in the lower part of the estuary, netplankton growth rates in the winter are apparently too low to exceed flushing rates of the surface layer (Malone, 1977a).

The gross primary production of the Hudson River and upper reaches of New York harbor is comparable to that of other East Coast estuaries; annual production is most likely in the range of 100-200 gC $m^{-2} y^{-1}$ (Sirois and Fredrick, 1978). However, Lower New York Bayu has substantially higher productivity. At a station in the Narrows, O'Reilly et al. (1976) estimate annual gross primary production at 817 gC $m^{-2} y^{-1}$ (Fig. 7). This may be related to the substantial amount of nutrient-rich water that passes through the narrows. At this station,

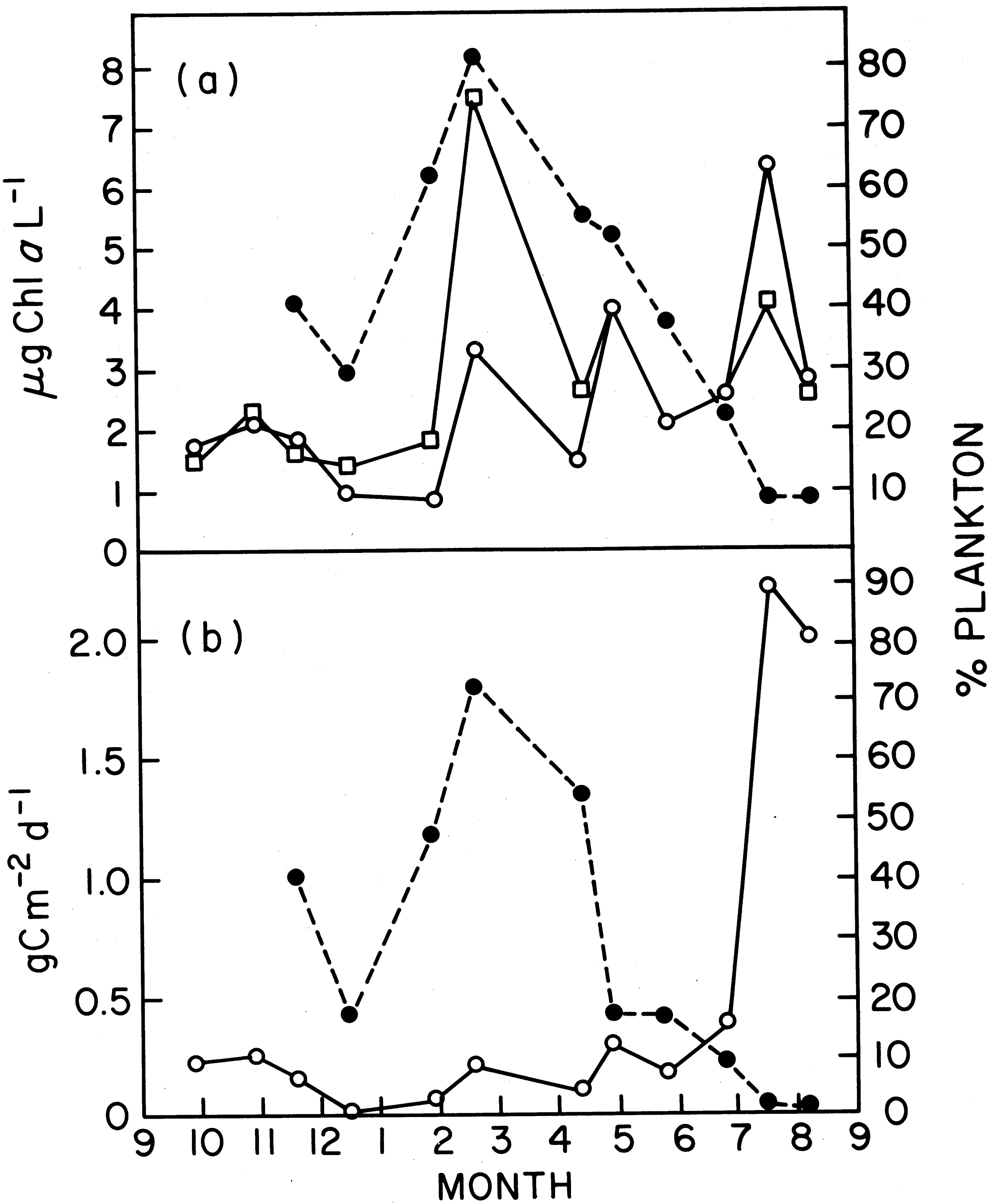


Figure 6(a) Monthly variations in mean photic zone chlorophyll a (O), near bottom chlorophyll a (□) and percent netplankton chlorophyll a (●) in the Upper Bay

(b) Monthly variations in primary productivity (gC $m^{-2}d^{-1}$, O) and percent netplankton productivity (●) in the Upper Bay

(From Malone, 1977)

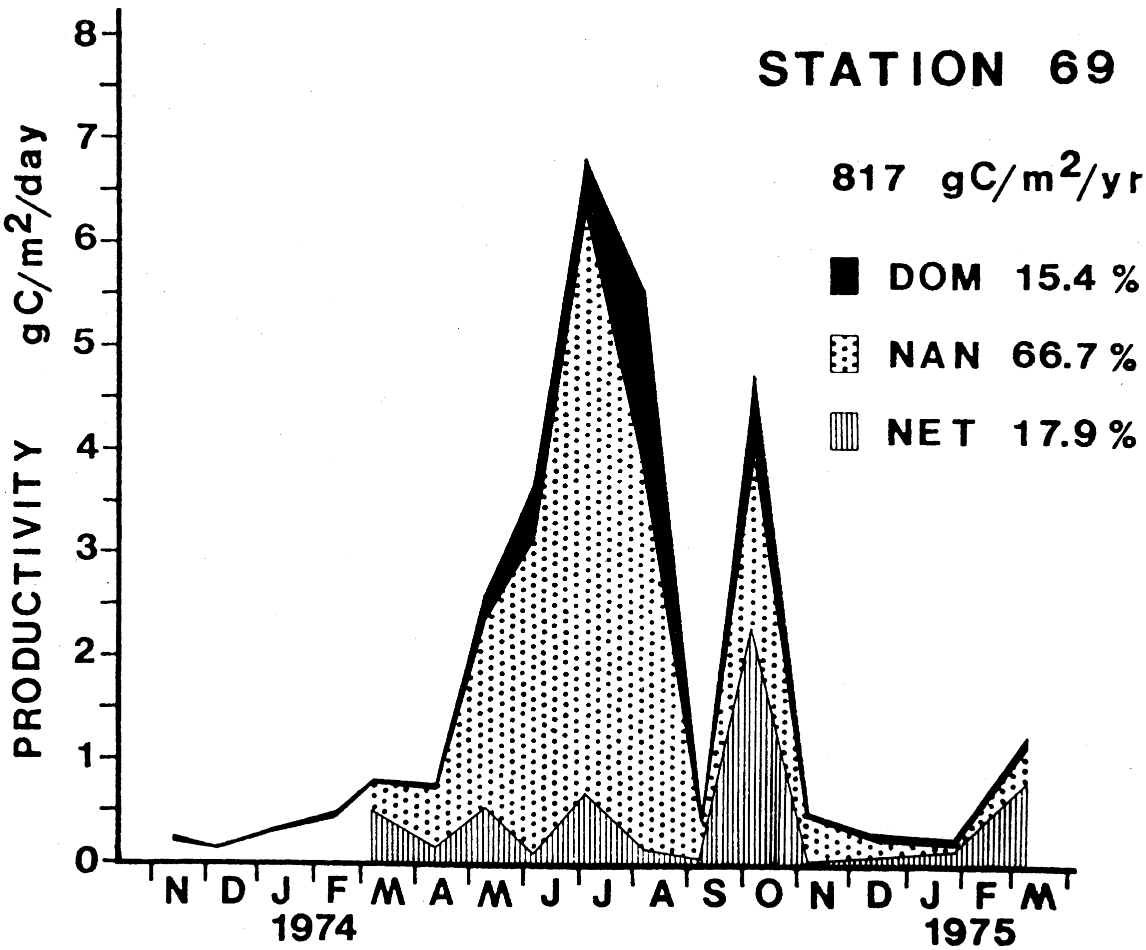


Figure 7. Annual cycle of netplankton (NET) - nannoplankton (NAN) productivity and dissolved organic matter (DOM) release rates in the Lower Bay. (From O'Reilly et al., 1976)

production peaks in June and July and is dominated by nannoplankton. This pattern is similar to that in Newark Bay (McCormick and Quinn, 1975).

Extracellular release of dissolved organic matter by primary producers in the Lower Bay is at least 2 times greater than that of Georgia estuaries (O'Reilly et al., 1976). Thus, the total amount of material produced via primary production is significantly greater than the particulate value of 100-100 gC $m^{-2}y^{-2}$; values of particulate plus dissolved production should range from 435 to 493 gC $m^{-2}y^{-1}$. Maximally, ca. 25% of the total primary production is released as dissolved organic matter. Much of this may be taken up by planktonic bacteria and contribute to decreases in dissolved oxygen.

The taxonomic composition of the phytoplankton has been reported for various regions of the Hudson-Raritan estuary (Patten, 1962; McCarthy, 1965; Kawamura, 1966; Fredrick et al., 1976; Malone, 1977a). In one of the most comprehensive surveys, Olsen and Cohn (1979) report the presence of 332 species in the Lower Bay and New Jersey coastal waters. Bacillariophyceae (diatoms) comprise 168 species; Dinophycea are the second most diverse, having 92 species. The Chlorophyceae contribute eleven species or only 3% of the total. However, this group dominates primary production in the summer. In particular, Nannochloris dominates summer blooms throughout the Hudson-Raritan estuary.

Species occurrence in the lower Hudson River follows the classical pattern for temperate lakes (Storm and Heffner, 1976). Diatoms dominate the river microflora during the colder months, whereas green and blue-greens dominate in the summer. *Cyclotella glomerata* was the dominant diatom in the river, whereas unidentified coccoid forms comprise the green algal component. Like the Upper Bay and Lower Bay regions, the river phytoplankton are not limited by nutrient availability.

4. ZOOPLANKTON

The composition of the zooplankton is complex, as might be expected for an estuarine system with strong mixing with the Lower Bay and New York Bight apex. Detailed studies have been carried out in Raritan Bay and adjacent waters (e.g., Jeffries, 1962; Sage and Herman, 1972). As is the case for phytoplankton, estuarine and tidal flow strongly influence the distribution of zooplankton. Seawater entering the Lower Bay on flood time is deflected toward the northern shore; this water mixes with the Raritan River discharge in the western part of the Raritan Bay and departs along the southern shore (Fig. 2). In accordance with this pattern, species that typically occur in inshore shelf waters (e.g., the copepod (*Pseudocalanus minutus*) tend to occur at stations on the northern side of Raritan Bay, whereas typical estuarine species (e.g., *Acartia tonsa*) dominate in the western and southern portions of the Bay (Jeffries, 1962). Relative frequency of occurrence of non-indigenous copepods was 22% greater in flood-dominated areas, relative to ebb-dominated stations.

Zooplankton seasonal abundance is quite variable from year to year (Fig. 8). In Sandy Hook Bay, zooplankton numbers peak anywhere from May to September (Sage and Herman, 1972). It is by no means clear whether zooplankton abundance is related to phytoplankton

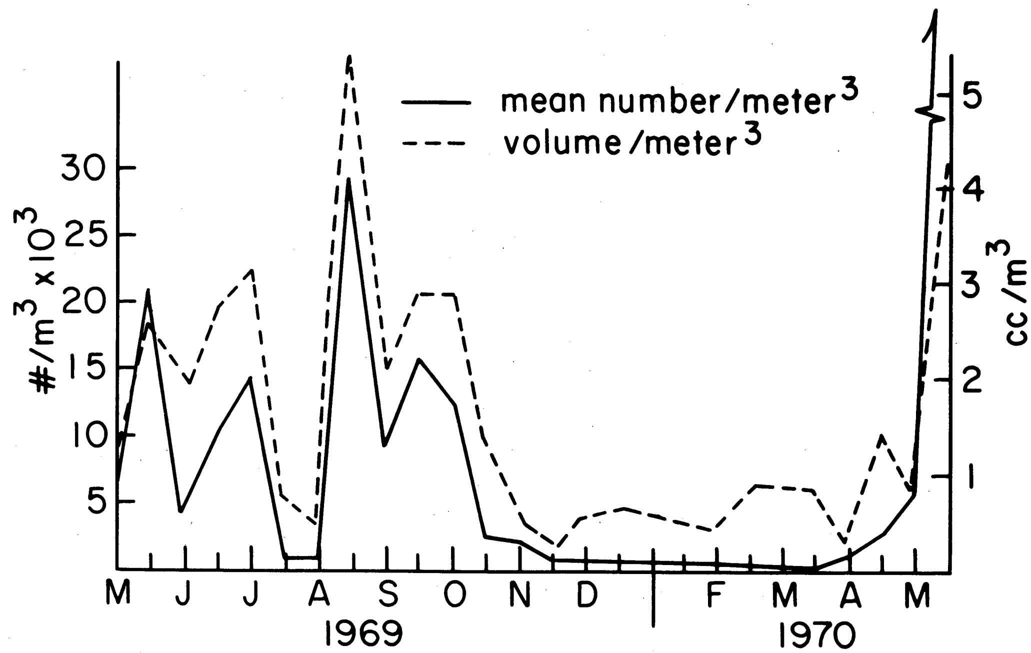


Figure 8. Mean number and volume of zooplankton per cubic meter in the Sandy Hook Bay (From Sage and Herman, 1972)

seasonal patterns. In the Arthur Kill, zooplankton sampled at the Exxon Bayway Refinery intake (Ichthyological Associates, Inc., 1976) show peaks in May and July-September. Maximum abundance in Sandy Hook Bay was ca. 50,000 organisms m^{-3} ; in the Arthur Kill, maximum abundance was ca. 120,000 individuals m^{-3} .

As might be expected for an estuarine system, taxonomic composition is both spatially and temporally variable. Generally, calanoid copepods dominate most surveys of Raritan Bay and the Arthur Kill (Sage and Herman, 1976; Ichthyological Associates, 1974a,b,c,d,e,f). However, Sandy Hook Bay was dominated by harpacticoid copepods in May 1970 (over 50%). In the Arthur Kill, polychaete larvae are an important component of the meroplankton in summer; larvae of other invertebrates are also abundant. In waters of lower salinity, such as in the Navesink and Shrewsbury Rivers, the rotifer *Synchaeta littoralis* may dominate (Yamazi, 1966). Rotifers are also abundant in the Arthur Kill (Fig. 9), as occasionally are oligochaetes.

In summary, zooplankton composition and abundance patterns follow those expected for a typical estuarine system in eastern North America. Mixing with oceanic waters results in the introduction of nonindigenous species in the northern part of the Raritan Bay.

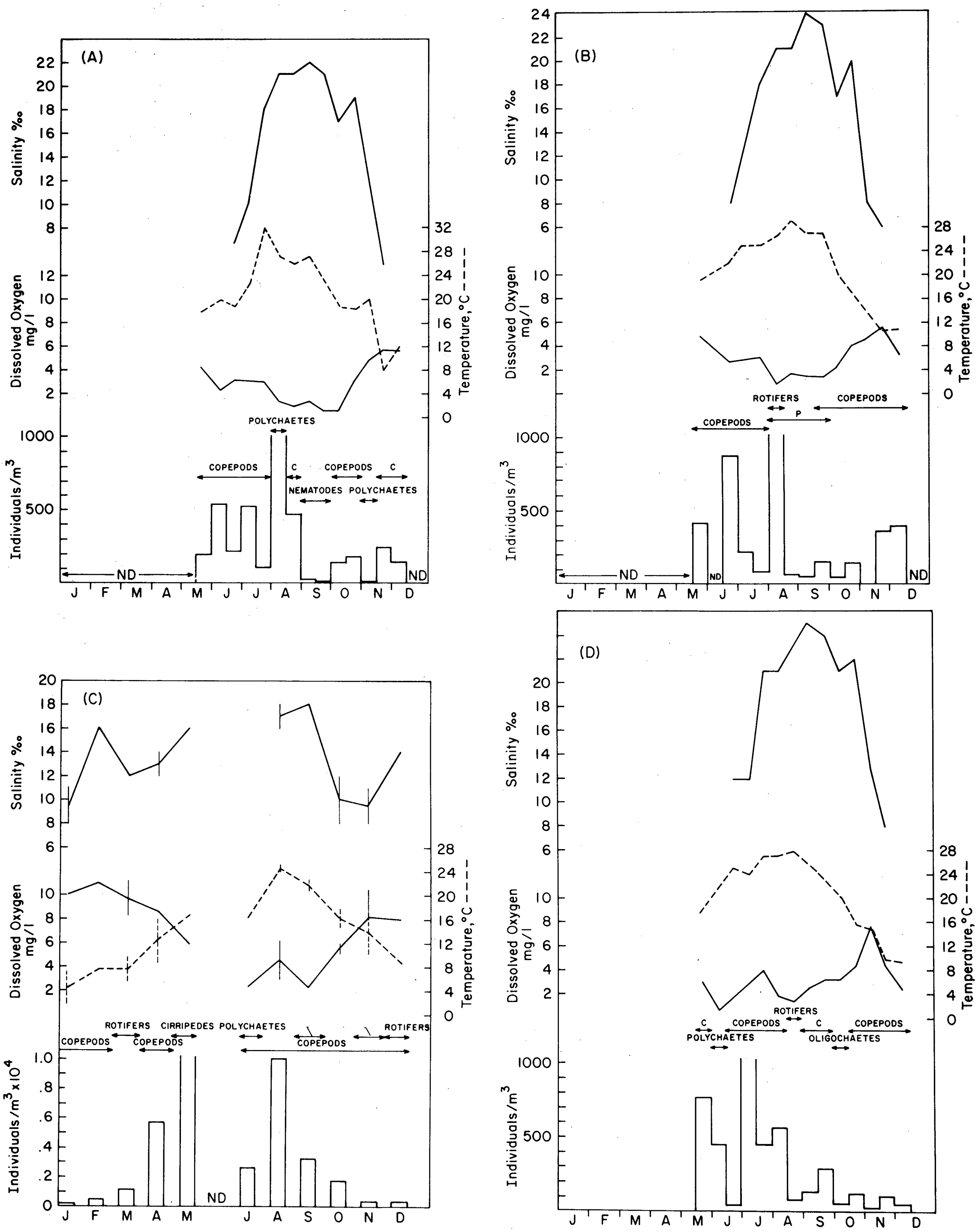


Figure 9. Dominant zooplankton ($\#/m^3$), temperature, salinity and dissolved oxygen at four stations in the Arthur Kill. (From the data of Ichthyological Associates, Inc., 1974a,b: 1976)

5. BENTHOS

The benthos of the Hudson-Raritan estuary have been relatively well studied. A summary of previous studies is presented in Brinkhuis (1980) and an analysis of community structure and trends over time can be found in Diaz and Boesch (in press). Therefore, our account will be relatively brief. We shall divide analyses of the benthos into general studies and those that focus on commercially important species.

Collections of various naturalists have permitted analyses of species lists from as early as the latter part of the nineteenth century. Franz (1982) compares changes from 1887 to 1920. Using those species of mollusks that are commonly taken in shallow-water samples, 57 species were to be found in Raritan Bay waters in the late nineteenth century. This list is comparable to cleaner estuaries today, such as Fisher's Island Sound and Great South Bay. However, a 1920 study (Jacot, 1920) already showed a marked decline in species richness. Several of the missing species (e.g., *Anachis avara*, *Bittium alternata*, *Laevicardium mortoni*, *Solemya velum*, *Nucula proxima*) are associated most commonly with eelgrass beds and their absence may therefore be related simply to loss of habitat. The deposit-feeding bivalve *Yoldia limatula* is usually associated with shallow water silty sediments; its decline may relate to pollution, but the evidence is not convincing, since no specific factor has been identified.

More recent collections of macrobenthos in Raritan Bay permit some understanding of short-term changes in the estuary. Dean (1975) studied the macrobenthos from 1957-1960, before and after the establishment of sewage treatment in the Raritan River. Samples were collected with either a Van Veen or Peterson grab and were sieved on a 1.5-mm mesh. Despite differences of sampling gear, coverage of stations, and mesh size, some interesting conclusions may be drawn.

Dean (1975) analyzed selected species to examine changes in species richness before and after the installation of a trunk sewer line in the lower Raritan Valley in 1958. Of the stations examined, one showed no change, four averaged a 30% decrease, while 6 others averaged a 96% increase. It is not clear that these changes, which appear to generally indicate an increase, necessarily related to pollution abatement. Diaz and Boesch (in press) subjected Dean's data to multivariate analysis and could find no strong changes in community structure before and after the installation of the sewer line. *Mya arenaria*, *Ensis directus*, and *Ilyanassa obsoleta* increased in abundance near the sewage outfall. However, these increases seemed to reflect changes throughout the bay, rather than any localized effect.

Although changes before and after the establishment of the sewage outfall are probably equivocal for the saline portion of Raritan Bay, Dean and Haskin (1964) present convincing evidence that substantial improvement occurred in the Raritan River itself. Dissolved oxygen, total animal abundance and species richness all increased substantially in stations taken upriver (salinities of ca. 1-10 o/oo). The isopod *Cyathura polita* (Fig. 10) and the mud crab *Rhithropanopeus harrisi* both increased substantially in these areas (Dean and Haskins, 1964).

Comparisons of Dean's 1957-1974 study show a marked decrease of both species richness and density. Figures 11 and 12 show changes in these parameters. These maps were produced by the computer SYMAP program (Dougenik and Sheehan, 1976). A general deterioration is noticeable. This change cannot be ascribed to sampling differences; Dean's gear and mesh size would tend to collect fewer species and individuals from the same areas. Increases in abundance of the polychaetes *Streblospio benedicti* and *Nephtys incisa* in the 1973 survey might indeed reflect the smaller mesh size of McGrath's (1974) study. Several mollusks, however, show a spectacular decline. The deposit-feeder and scavenger gastropods, *Ilyanassa obsoleta* (Fig. 13) and *Nassarius trivitatus* disappeared or greatly declined, respectively. The soft-shell clam, *Mya arenaria* was abundant throughout Raritan Bay in 1957-1960, but was relatively sparse in 1973-1974 (Fig. 14).

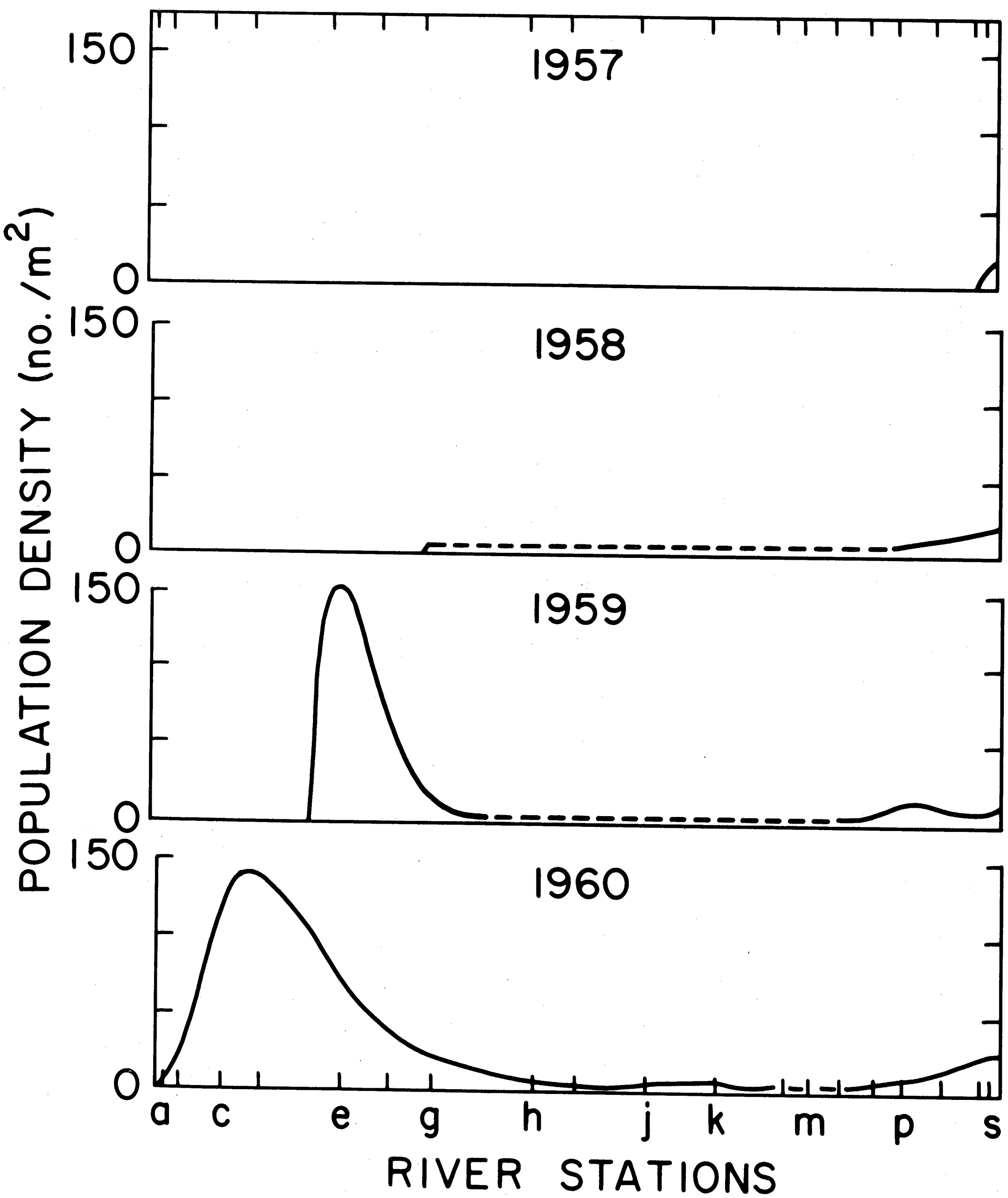


Figure 10. Quantitative distribution of the isopod *Cyathura* in the Raritan River, 1957-1960. (From Dean and Haskin , 1964)

Some major changes in species composition occurred in the interim between the two sampling periods. Tables 1 and 2 show species lists for the 15 most frequent species in both surveys. Of greatest interest is the switch from Mya arenaria (Fig. 14) to Mulinia lateralis (Fig. 15) in the number one rank. Mulinia lateralis seems to have sporadic recruitment and can be indicative of major disturbance, such as sediment dumping or bottom erosion (Calabrese, 1971; Rhoads, 1975). Thus a noncommercial species indicative of disturbance has replaced a commercially important species. Similarly, the razor clam, Ensis directus, has declined from a rank of 10 to a rank of 53 (Table 1).

The distribution of macrobenthos in Raritan Bay seems to follow the classic sediment-related pattern found in other studies of the Atlantic coast of the U.S. (e.g., Sanders, 1956, 1958; Sanders et al., 1965). McGrath (1974) distinguished between sand and mud assemblages. The sand communities were dominated by the polychaete Streblospio benedicti and Tellina agilis. The mud bottom community was sparse, but was dominated by Mulinia lateralis. Though the cause may be unknown, it can safely be said that dominance by Mulinia probably indicates some major disturbance, relative to other estuaries in the region. Comparable sediments in Long Island Sound (e.g., Sanders, 1956) and southwest Long Island (Steimle and Stone, 1973) are dominated by species

Table 1. The 15 most abundant species in the 1957-60 survey of the Lower Bay Complex (Dean, 1975) and their rank in the 1973-1974 survey of McGrath (1974).

		1957-1960			1973-1974			
RANK	SPECIES	REL.* ABUND.	TOTAL #/m²	% OCC.	RANK	REL.* ABUND.	TOTAL #/m²	% OCC.
1.	*Mya arenaria*	1690	1926	88	45	0.05	0.78	6.1
2.	*Ampelisca*	588	987	60	--	--	--	--
3.	*Gemma gemma*	54	1696	3.0	--	--	--	--
4.	*Polydora ligni*	21	45	46	3	13	55	24
5.	*Mulinia lateralis*	17	42	41	1	51	80	63
6.	*Nassarius obsoletus*	15	32	48	98	<0.001	0.04	1.7
7.	*Unciola serrata*	13	57	23	34	0.12	1.6	7.8
8.	*Balanus improvisus*	13	70	18	5	6.2	34	18
9.	*Mytilus edulis*	10	125	8.0	18	0.72	4.9	15
10.	*Ensis directus*	6.9	17	41	53	0.01	0.32	3.5
11.	*Nereis succinea*	5.1	12	42	14	1.4	7.7	18
12.	*Heteromastus filiformis*	3.9	14	28	21	0.42	2.3	18
13.	*Cyathura polita*	2.9	10	28	--	--	--	--
14.	*Glycera americana*	2.9	10	30	16	1.0	4.1	24
15.	*Pectinaria gouldii*	2.8	10	29	12	2.4	6.8	36

*RELATIVE ABUNDANCE = (total number/m^2 x (percent occurrence).

Table 2. The 15 most abundant species in the 1973-1974 benthic survey of the Lower Bay Complex (McGrath, 1974) and their rank in the 1957-1960 survey of Dean (1975).

		1973-1974			1957-1960			
RANK	SPECIES	REL.* ABUND.	TOTAL $\#/m^2$	% OCC.	RANK	REL.* ABUND.	TOTAL $\#/m^2$	% OCC.
1.	*Mulinia lateralis*	51	80	63	5.0	17	42	41
2.	*Streblospio benedicti*	14	35	39	20	1.2	6.9	17
3.	*Polydora ligni*	13	55	24	4.0	21	45	46
4.	*Acteon punctostriatus*	7.3	56	13	--	--	--	--
5.	*Balanus improvisus*	6.2	34	18	8.0	13	70	18
6.	*Sabellaria vulgaris*	6.0	35	17	27	0.0	5.0	9.0
7.	*Telina agilis*	6.0	16	37	28	0.4	3.2	13
8.	*Tharynx* sp.	5.8	29	20	34	0.3	3.0	10
9.	*Spio setosa*	4.0	18	23	16	2.2	9.1	24
10.	*Nephtys incisa*	2.9	6.3	45	36	0.2	1.8	11
11.	*Nassarius trivittatus*	2.7	6.7	41	18	1.9	8.8	22
12.	*Pectinaria gouldii*	2.4	6.8	36	15	2.8	9.5	29
13.	*Mercenaria mercenaria*	1.6	6.2	26	24	0.8	3.6	22
14.	*Nereis succinea*	1.4	7.7	18	11	5.1	12	42
15.	*Peloscolex gabriellae*	1.2	8.9	13	--	--	--	--

*RELATIVE ABUNDANCE = (total number/m^2) x (percent occurrence).

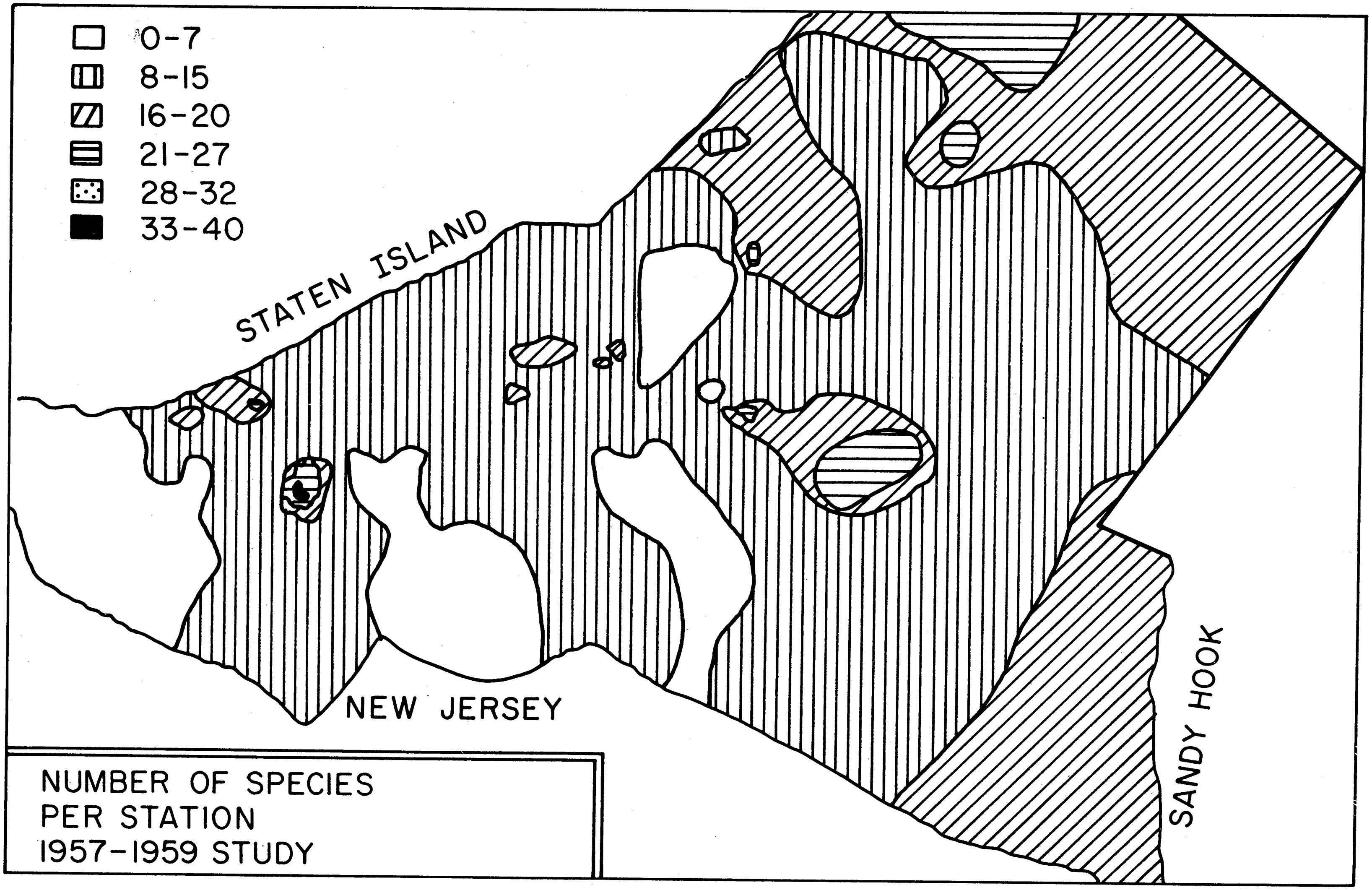


Figure 11. A) Benthic species richness (species per station) in the Lower Bay complex, 1957-1959. (From the data of Dean, 1975)

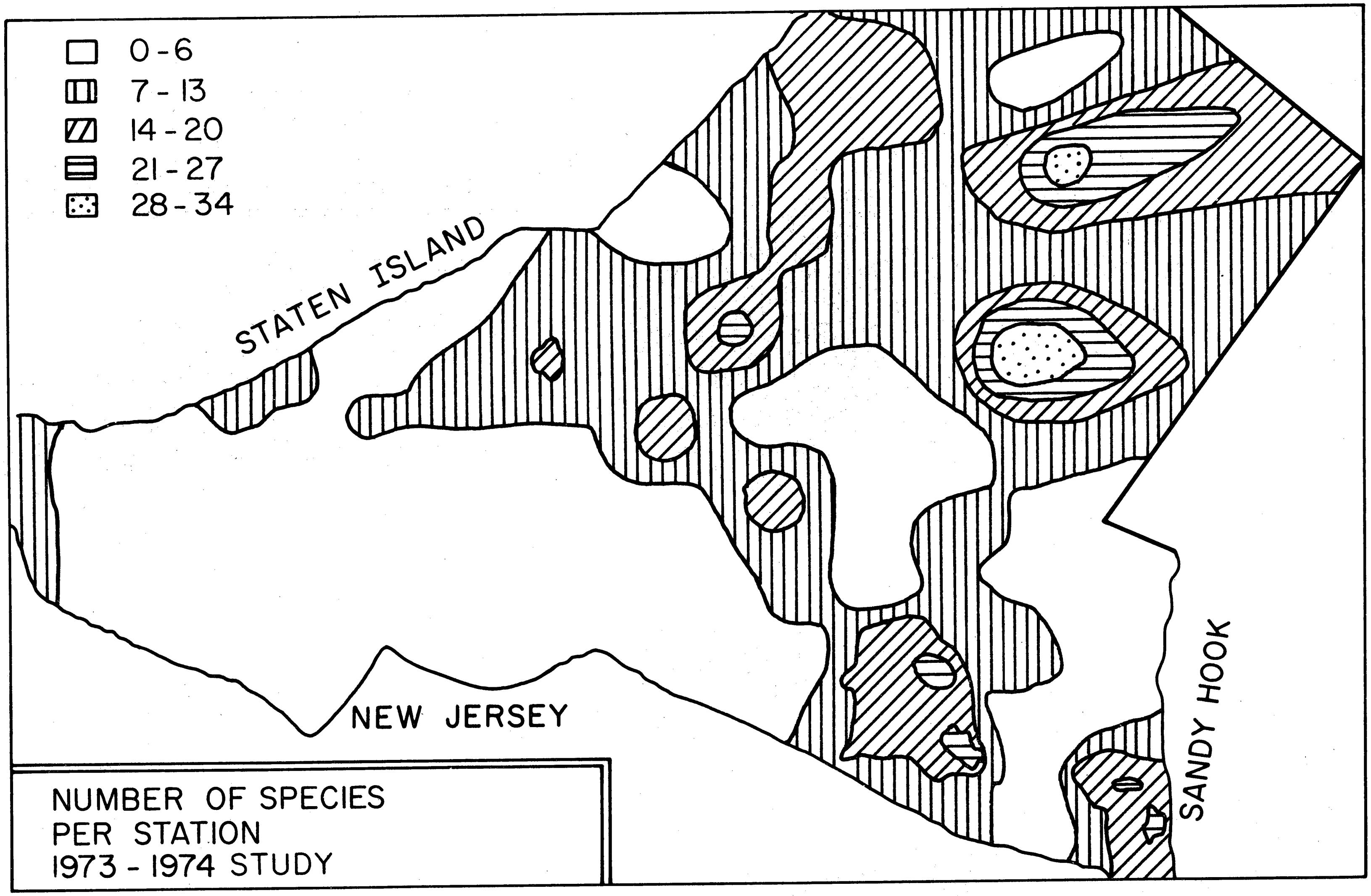


Figure 11. B) Benthic species richness (species per station) in the Lower Bay complex, 1973-1974. (From the data of McGrath, 1974)

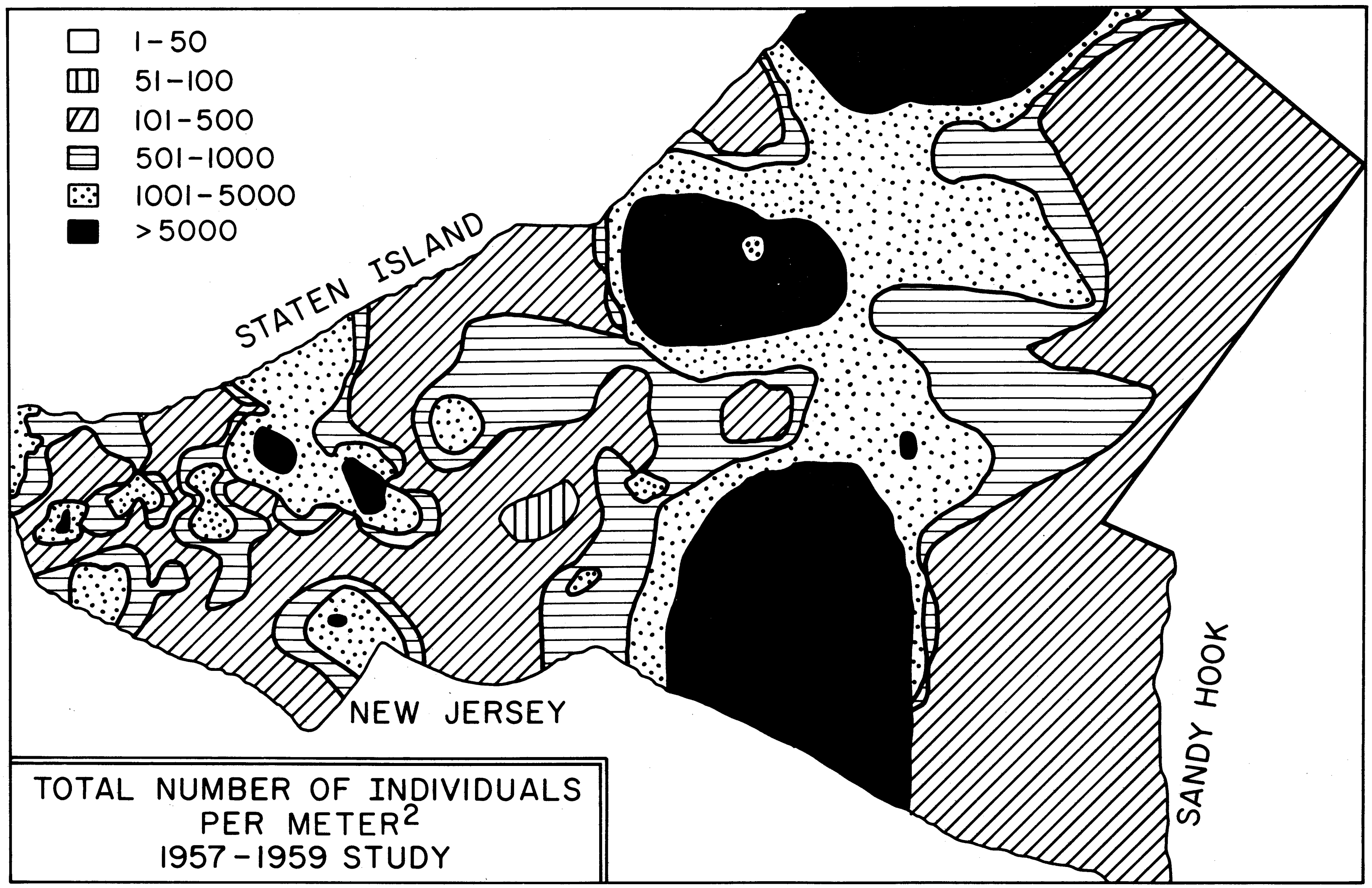


Figure 12. A) Benthic population density (# individuals per meter^2) in the Lower Bay complex, 1957-1959. (From the data of Dean, 1975)

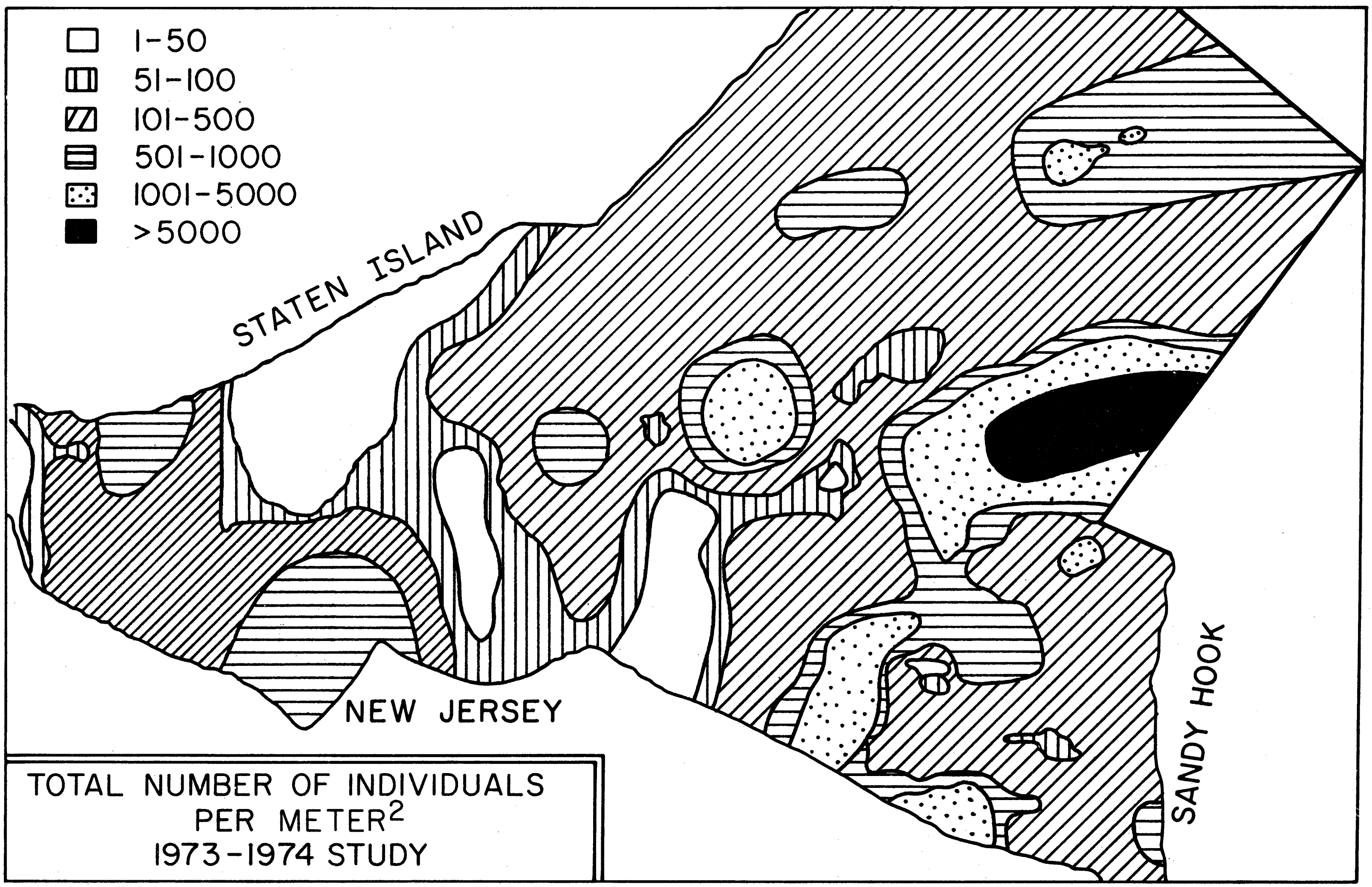


Figure 12. B) Benthic population density (# individuals per meter^2) in the Lower Bay complex, 1973-1974. (From the data of McGrath, 1974)

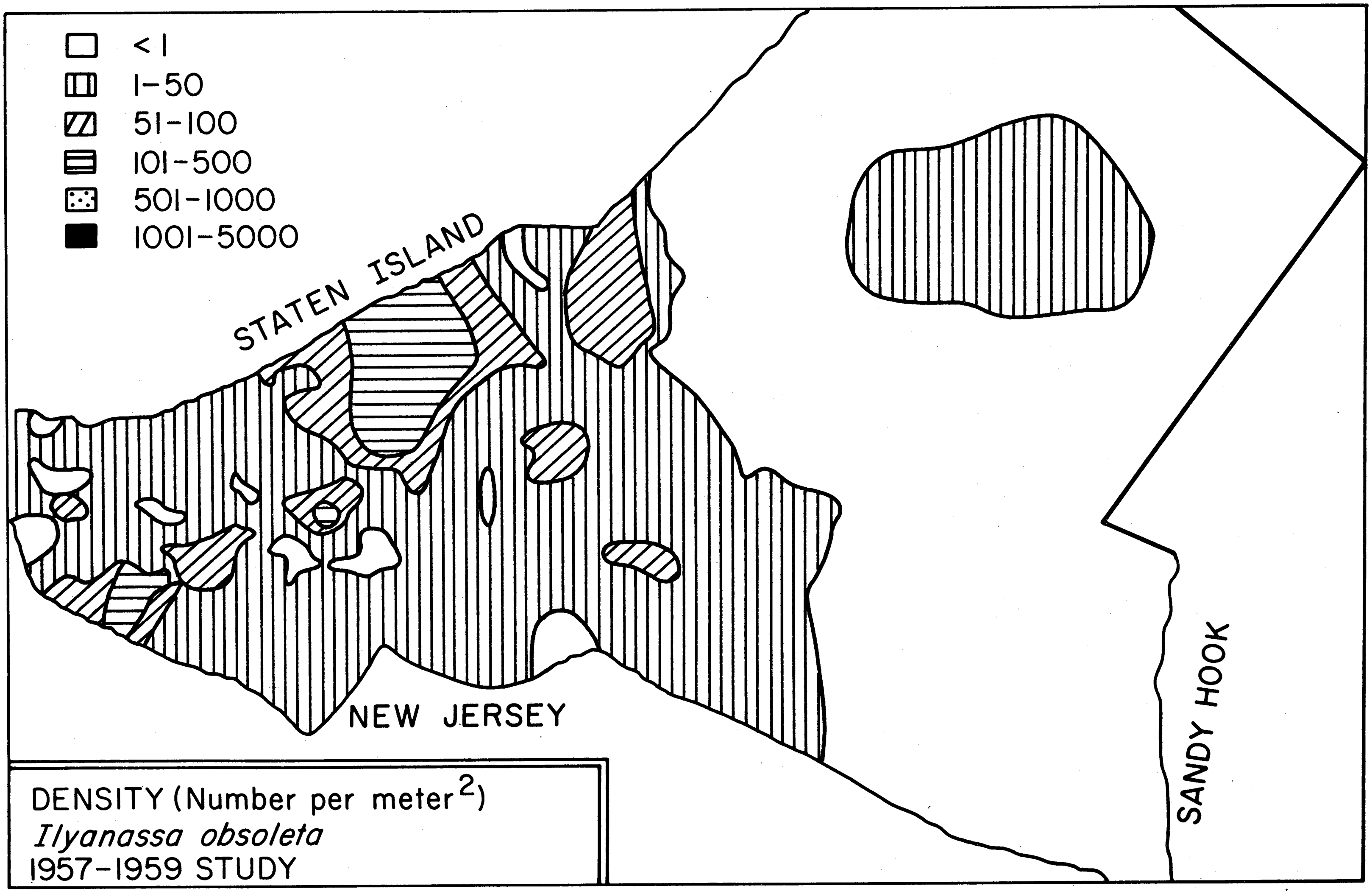


Figure 13. A) Ilyanassa obsoleta density (#/m^2) in the Lower Bay complex, 1957-1959. (From the data of Dean, 1975)

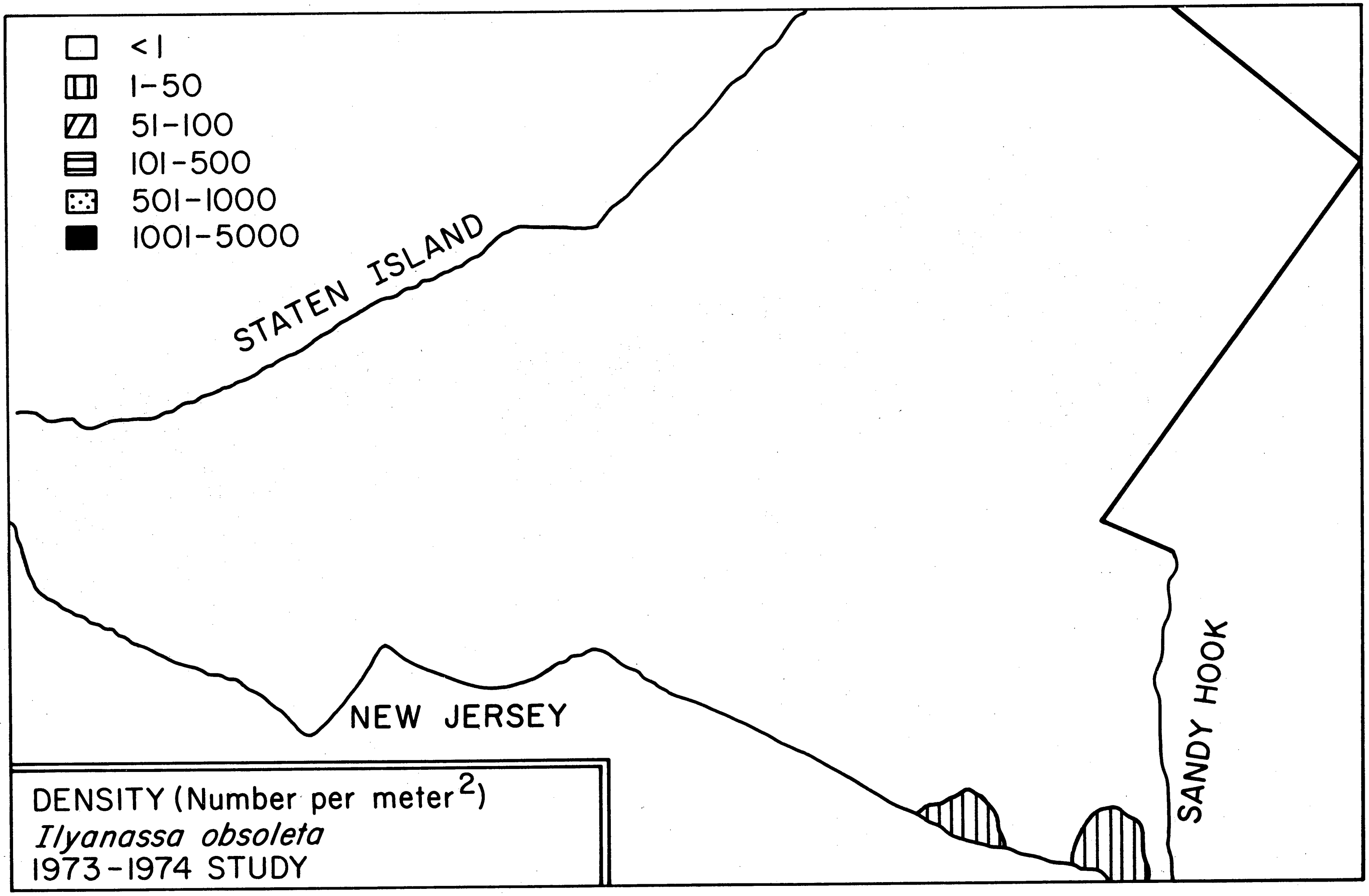


Figure 13. B) Ilyanassa obsoleta density (#/m^2) in the Lower Bay complex, 1973-1974. (From the data of McGrath, 1974)

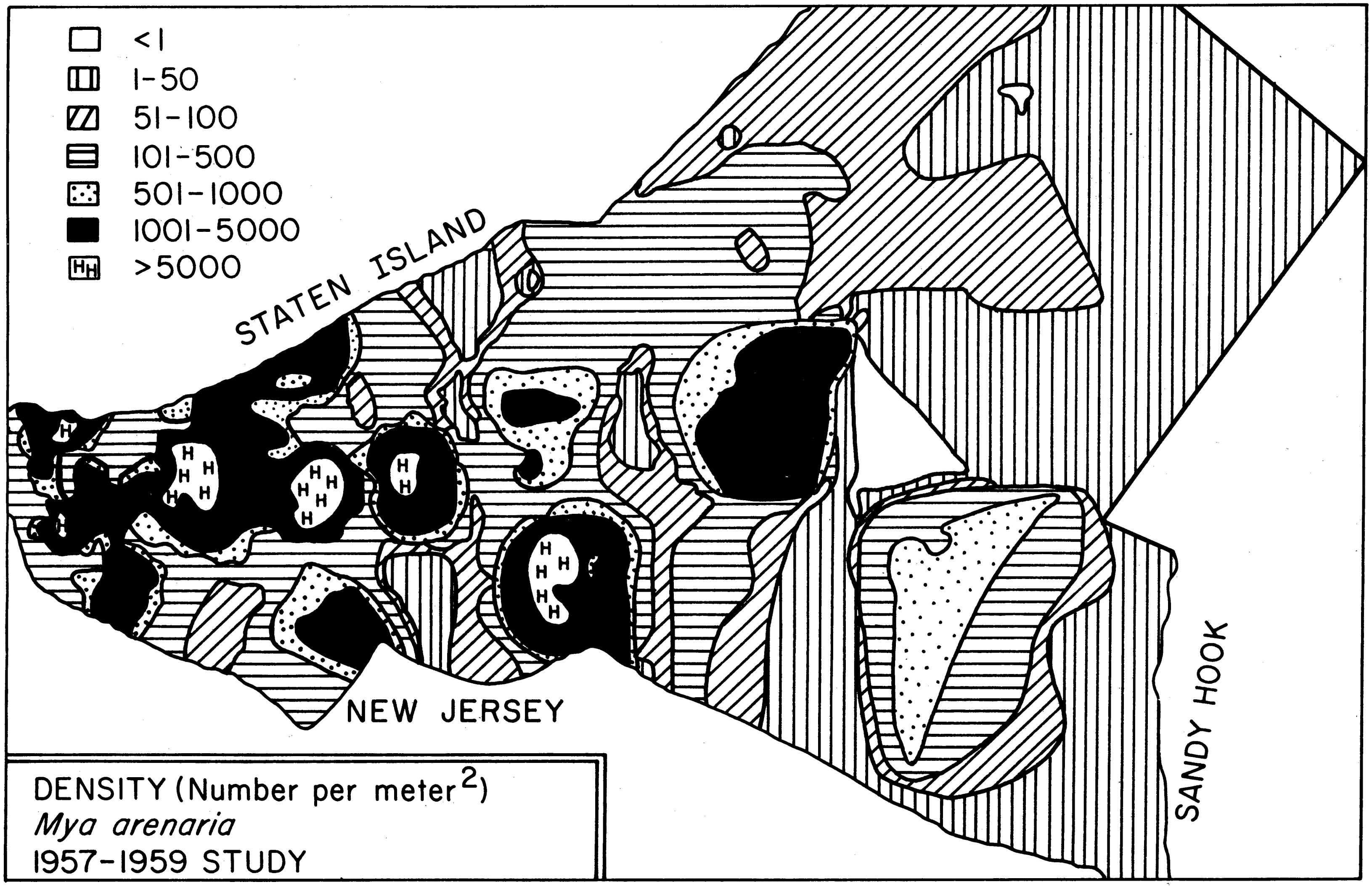


Figure 14. A) Mya arenaria density (#/m^2) in the Lower Bay complex, 1957-1959. (From the data of Dean, 1975)

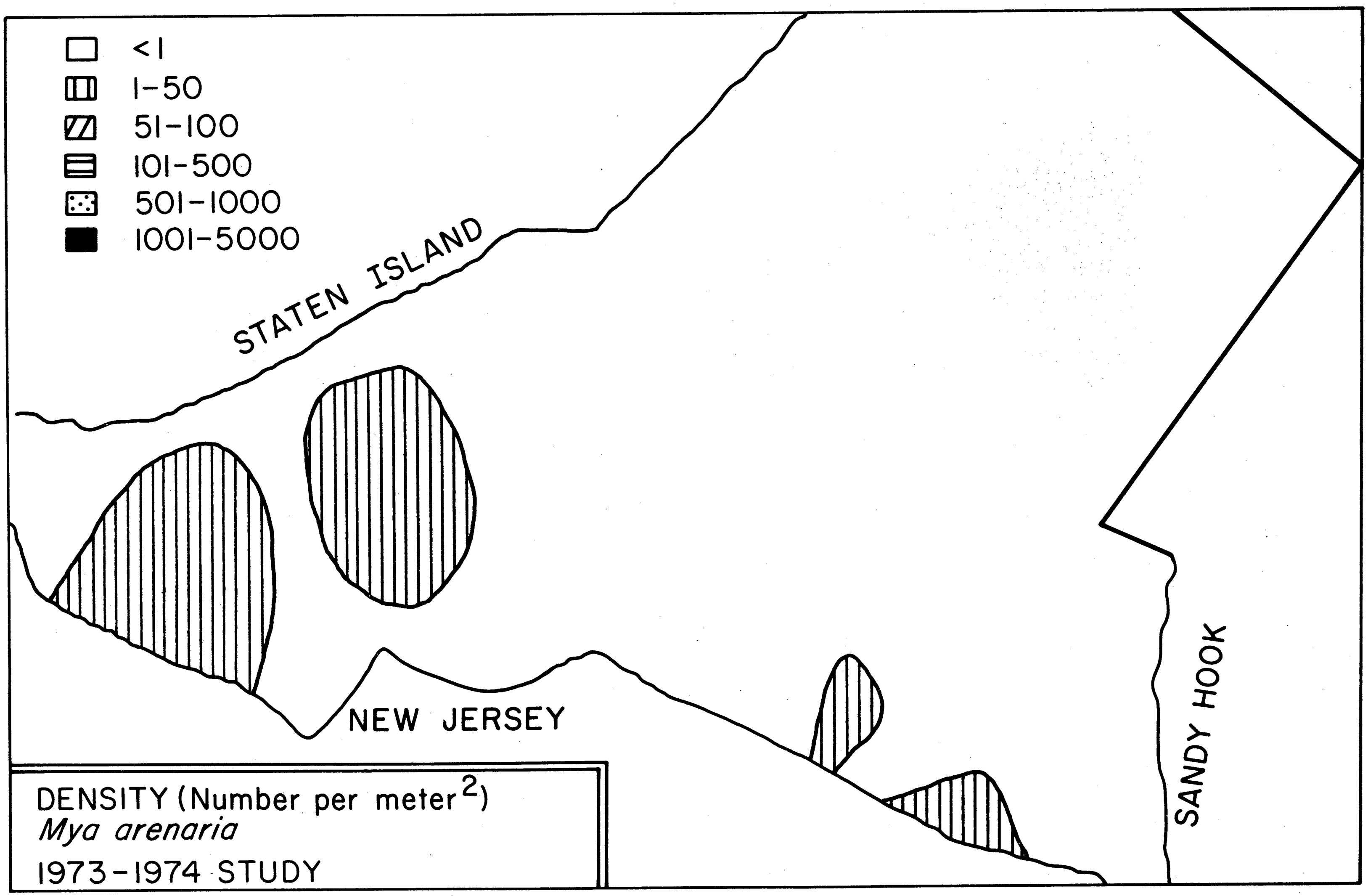


Figure 14. B) *Mya arenaria* density (#/m^2) in the Lower Bay complex, 1973-1974. (From the data of McGrath, 1974)

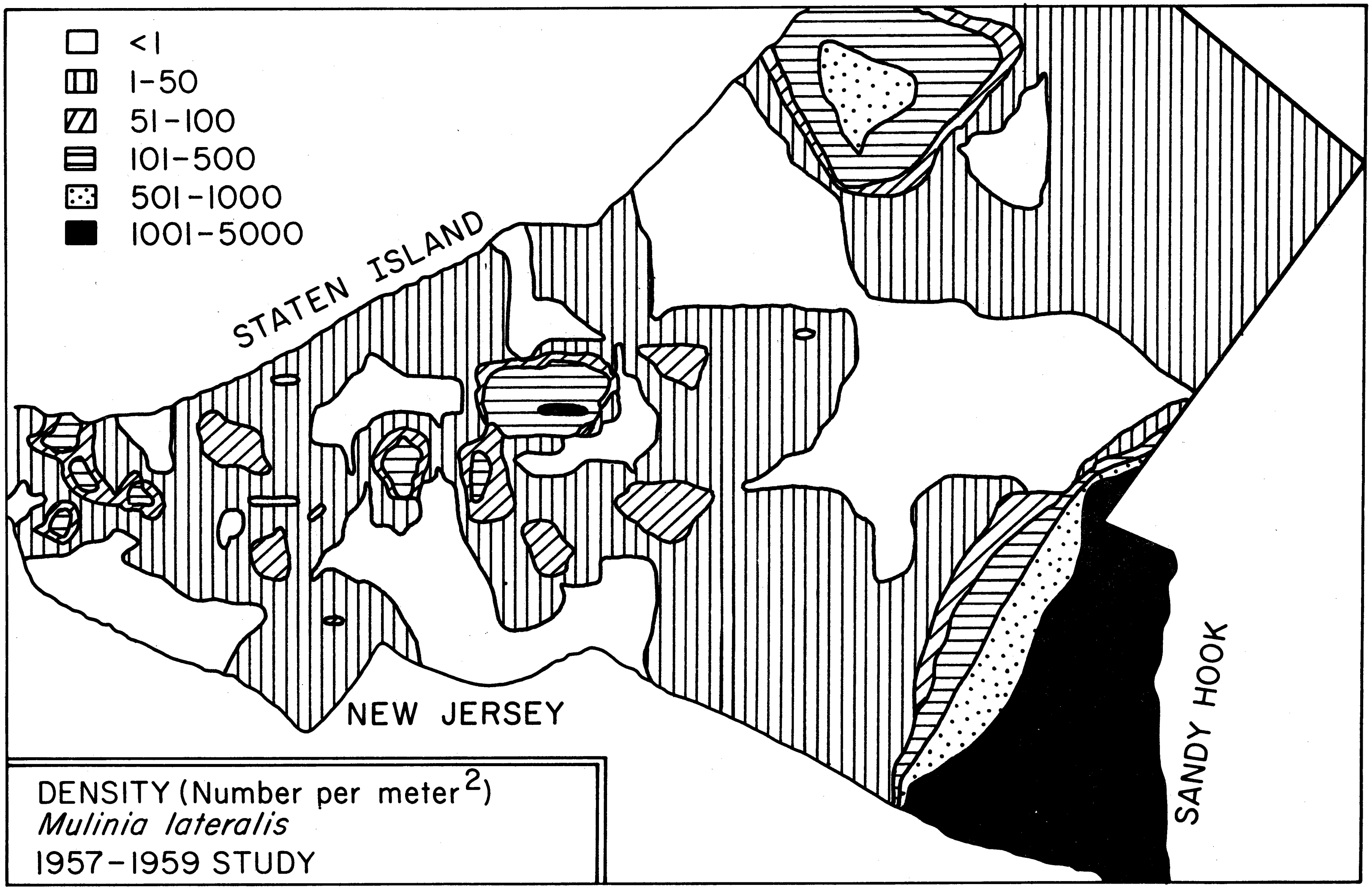


Figure 15. A) Mulinia lateralis density (#/m^2) in the Lower Bay complex, 1957-1959. (From the data of Dean, 1975)

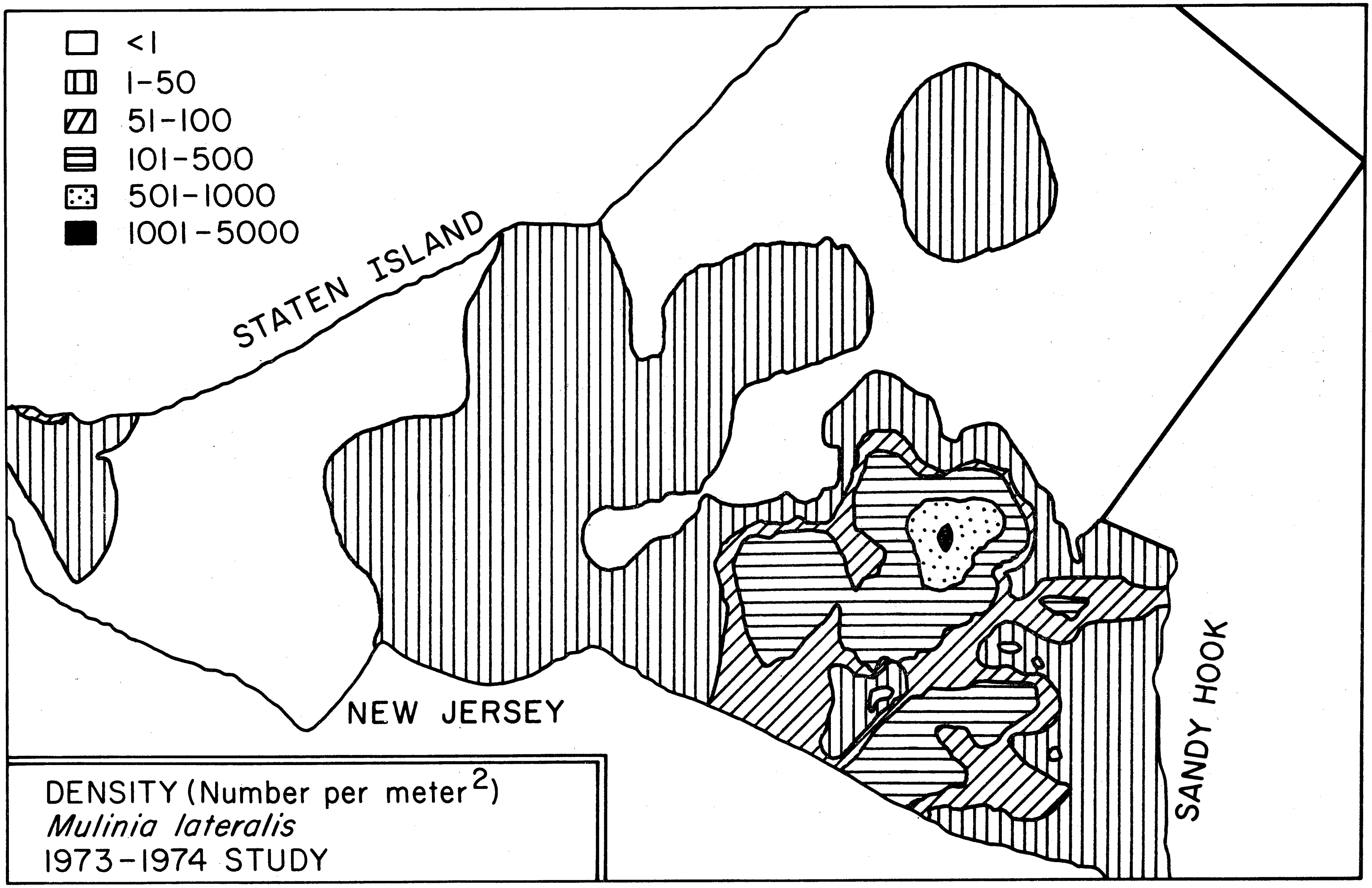


Figure 15. B) Mulinia lateralis density (#/m^2) in the Lower Bay complex, 1973-1974. (From the data of McGrath, 1974)

of the genus *Nucula*. The work of D. C. Rhoads and colleagues (e.g., Levinton, 1970; McCall, 1977) shows that *Nucula* and *Mulinia* represent disturbed versus undisturbed environments. In contrast, sand assemblages of Raritan Bay are not that different from comparable sediments in other nearby estuaries.

We may conclude from the comparison of the studies of Dean and McGrath that a substantial decline of species richness, abundance, and qualitative composition has occurred between 1957-1960 and 1973-1974. This change occurred despite a similarity in bottom sediments. This leaves little room for easy explanation, as many other variables were not measured between the two studies. For example, no complete account of nutrient supply to the bottom exists. Therefore, it is by no means safe to say that the change must, of necessity, be due to an anthropogenic source. It is true, however, that the relative paucity of the mud community may be used as a vehicle for further study. Figure 16 shows the distributioon of lead and zinc throughout Raritan Bay. Of note is the high correlation of metal abundance with the peak of *Mulinia* abundance in the southwest portion of the Bay. At present, no extensive multifactorial study exists to examine the fine-scale spatial structure of anthropogenic and environmental parameters as they relate to the biota. Such a study is sorely needed to understand the complexities of distribution.

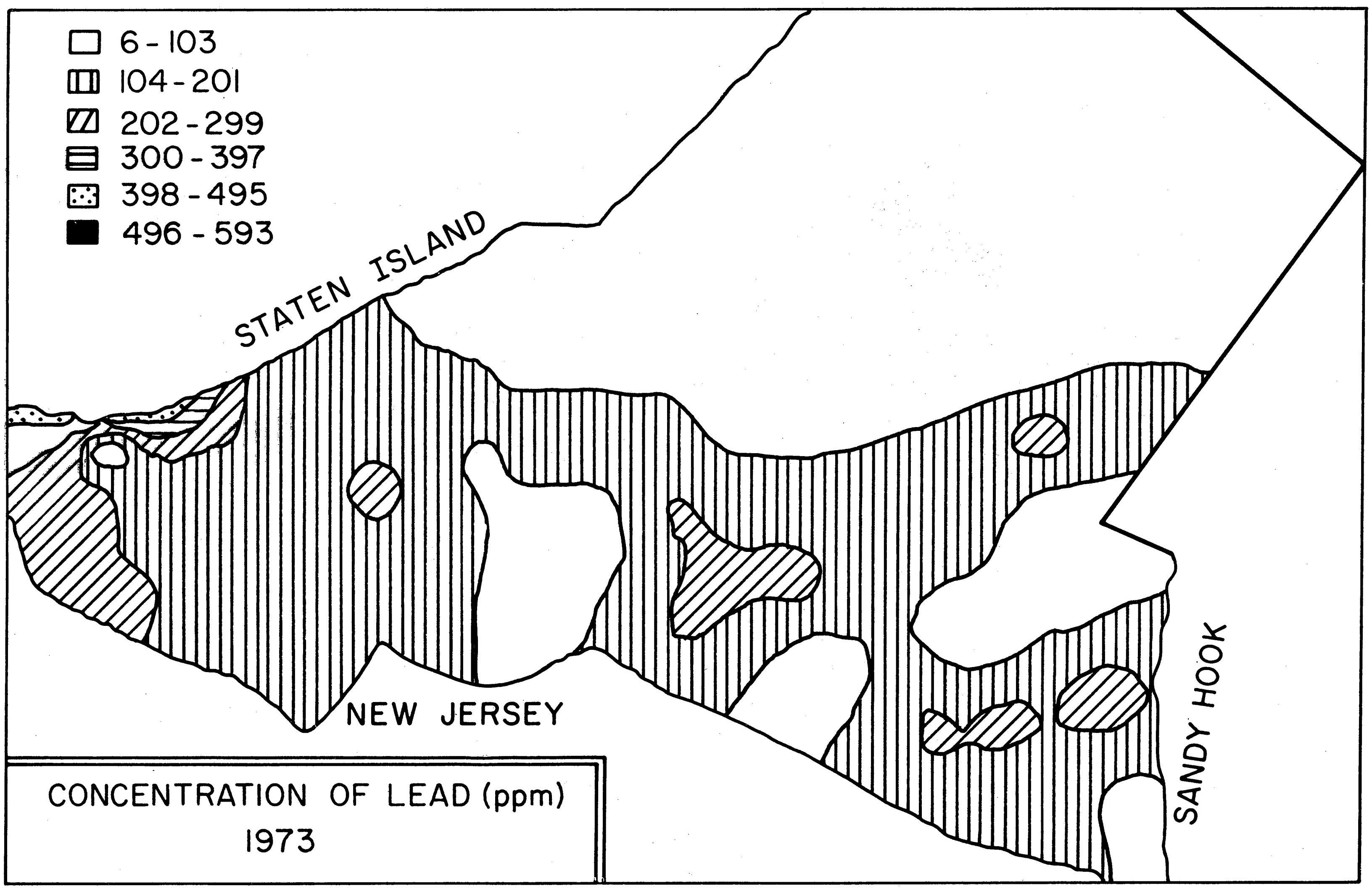


Figure 16. A) Concentration of lead (ppm) in the Lower Bay complex. (From the data of McGrath, 1974)

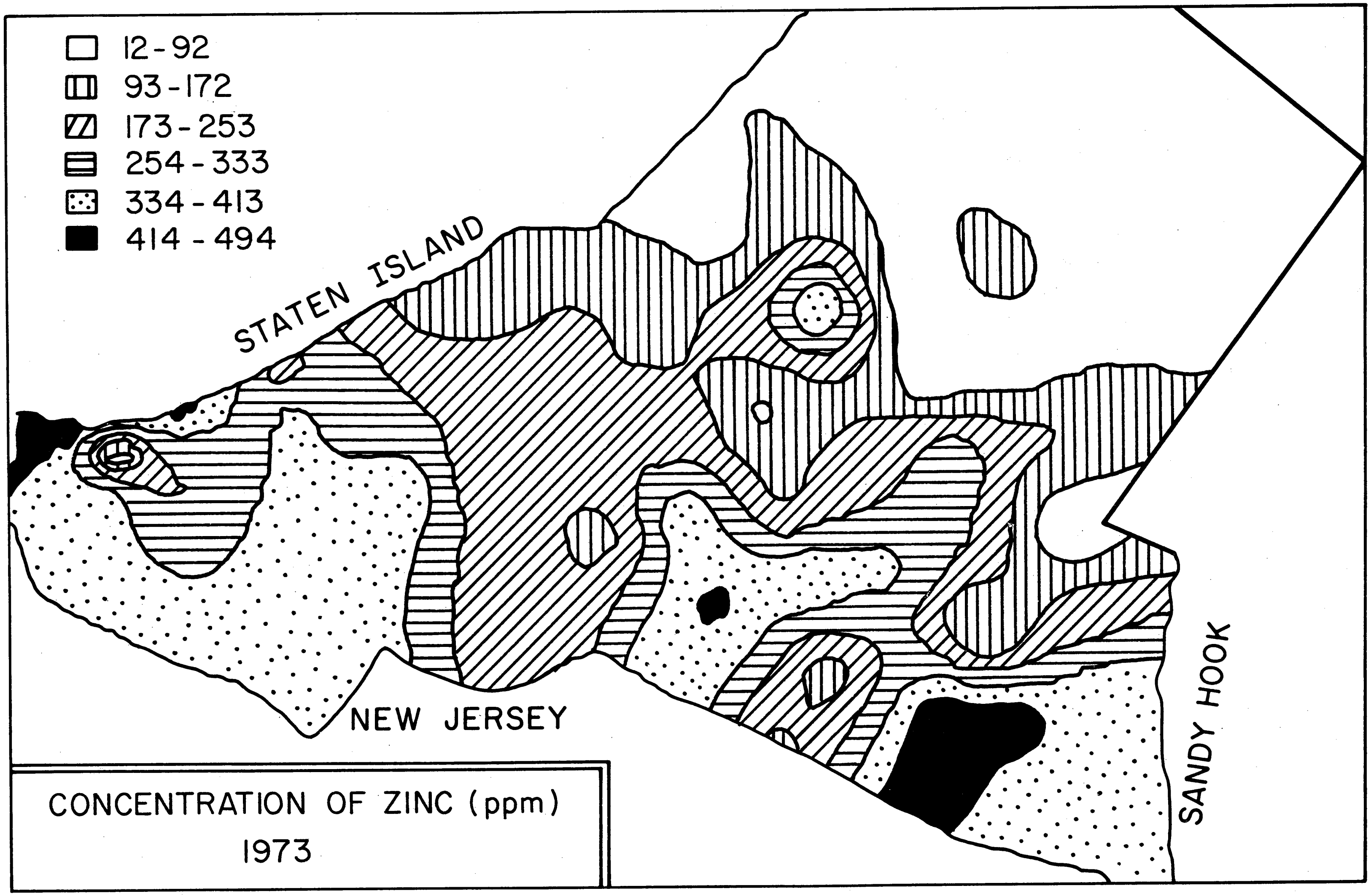


Figure 16. B) Concentration of zinc (ppm) in the Lower Bay complex. (From the data of McGrath, 1974)

Some sampling has been done in the Arthur Kill and other narrow waterways leading into Raritan Bay. The Federal Water Pollution Control Administration (FWPCA) (de Falco, 1967) sampled 10 stations in the Arthur Kill; abundance was generally less than five individuals per square meter. In the Kill Van Kull, abundance and species diversity increased in the direction of New York Bay. Densities were still low at ca. 500 m^{-2}. In both Kills, *Polydora ligni* was a dominant organism, as might be expected from the commonness of fine sands with some silt. Oil was noticed in bottom sediments throughout the Kills.

Studies by Ichthyological Associates, Inc. (1974a) at the Sewaren site in the Arthur Kill (surveys in 1972 and 1973 show substantially higher faunal densities at 1400 m^{-2}. *Mulinia lateralis* and the polychaete *Nereis arenaceodonta* were the dominant organisms. A study of the benthos near the Kearny generating station on the Hackensack River (Ichthyological Associates, Inc. 1974c) shows higher densities as well (average 5814 m^{-2}). The difference in results from the FWPCA study may relate to sampling gear.

A 1972 survey of the Hudson River macrobenthos (Ristich et al., 1973) shows substantially greater densities. Numbers as high as 6×10^4 m^{-2} were encountered in several stations below the Tappan Zee Bridge. The isopod *Cyathura polita* was common; this seems significant as it seems to have responded strongly to pollution abatement in 1957-1960 (Dean and Haskin, 1964). In general, the dominant species in salinities from 5-30 $^{0}/_{100}$ were those expected for undisturbed estuaries of the region (see discussion in Diaz and Boesch, in press).

Data on commercially important benthos seem restricted to the molluscs. As mentioned above, Franz (1982) documents changes in the molluscan fauna of the estuary between the nineteenth century and the present. Where sedimentary conditions were conducive, oyster (*Crassostrea virginica*) constituted a viable commercial fishery; they no longer do. Oyster beds were probably overexploited in the nineteenth century. By 1905, oyster beds in New York Bay were limited mainly to the southeastern shore of Staten Island. Pollution and siltation, from the establishment of shipping channels and dredging, probably contributed to the decline. Franz (1982) makes a case for human sewage as a primary agent of decline of the oyster stocks.

Hard-shell clams have been surveyed extensively in Raritan Bay. The studies of Dean and McGrath show a general peak of abundance on the south shore of Staten Island and north of Sandy Hook Bay. Except for one station in Sandy Hook Bay, the hard-shell clam shows a substantial decline in the period from 1960 to 1973. The

1963 FWPCA survey shows that the distribution of "sub-legal" hard clams is more widespread than "necks" which occur most abundantly close to the Staten Island shore (Fig. 17). Hendrickson (1970) found a peak near Seguine Point in 1970.

In summary, oysters seem to have declined drastically since the nineteenth century. In more recent years, the soft-shell clam has changed from being a dominant to a rare species in the Bay. The hard-shell clam occurs most commonly near the south shore of Staten Island, most particularly near Seguine Point.

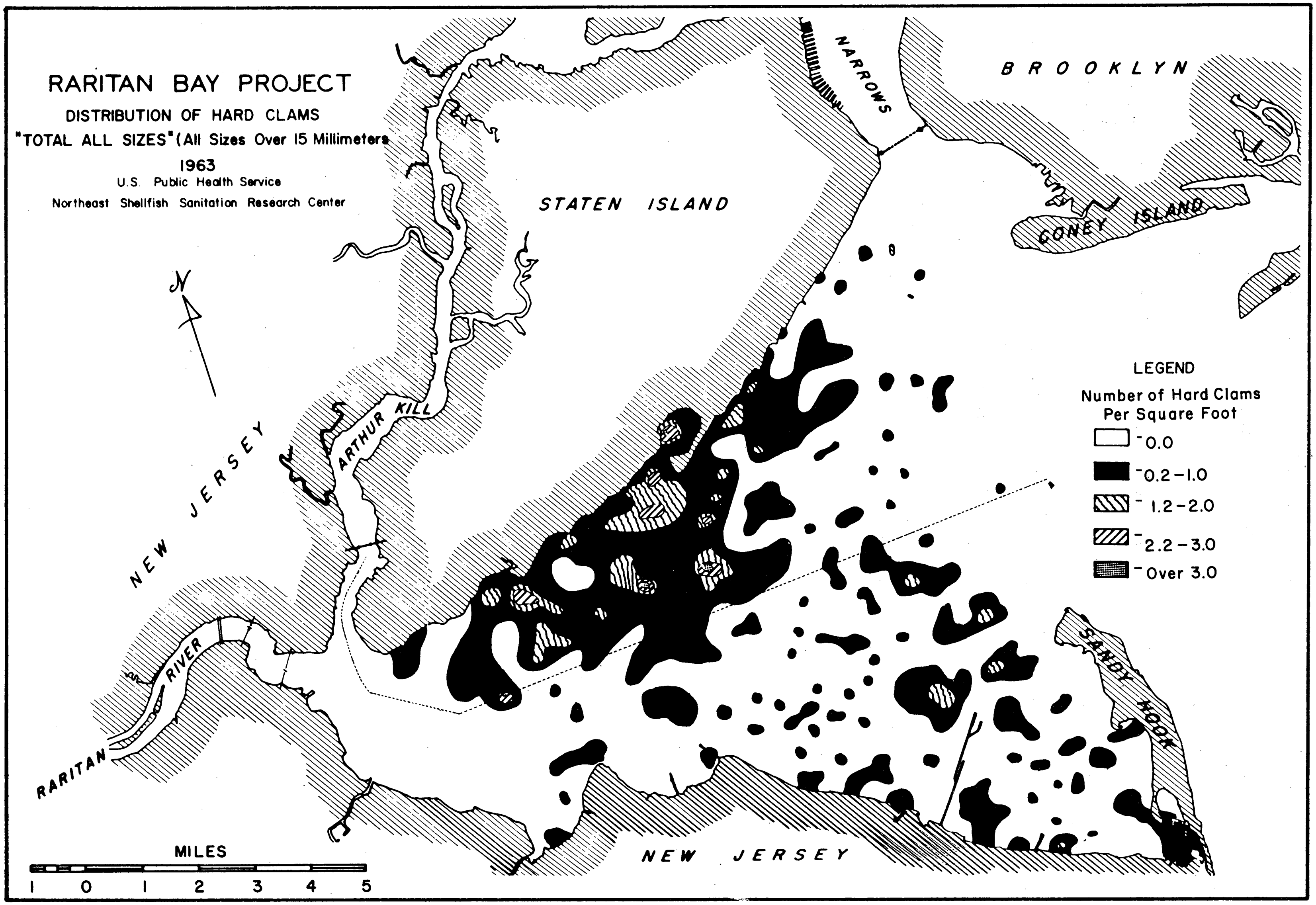


Figure 17. A) Distribution of hard clams (all sizes greater than 15 mm) in the Lower Bay complex in 1963. (From de Falco, 1967)

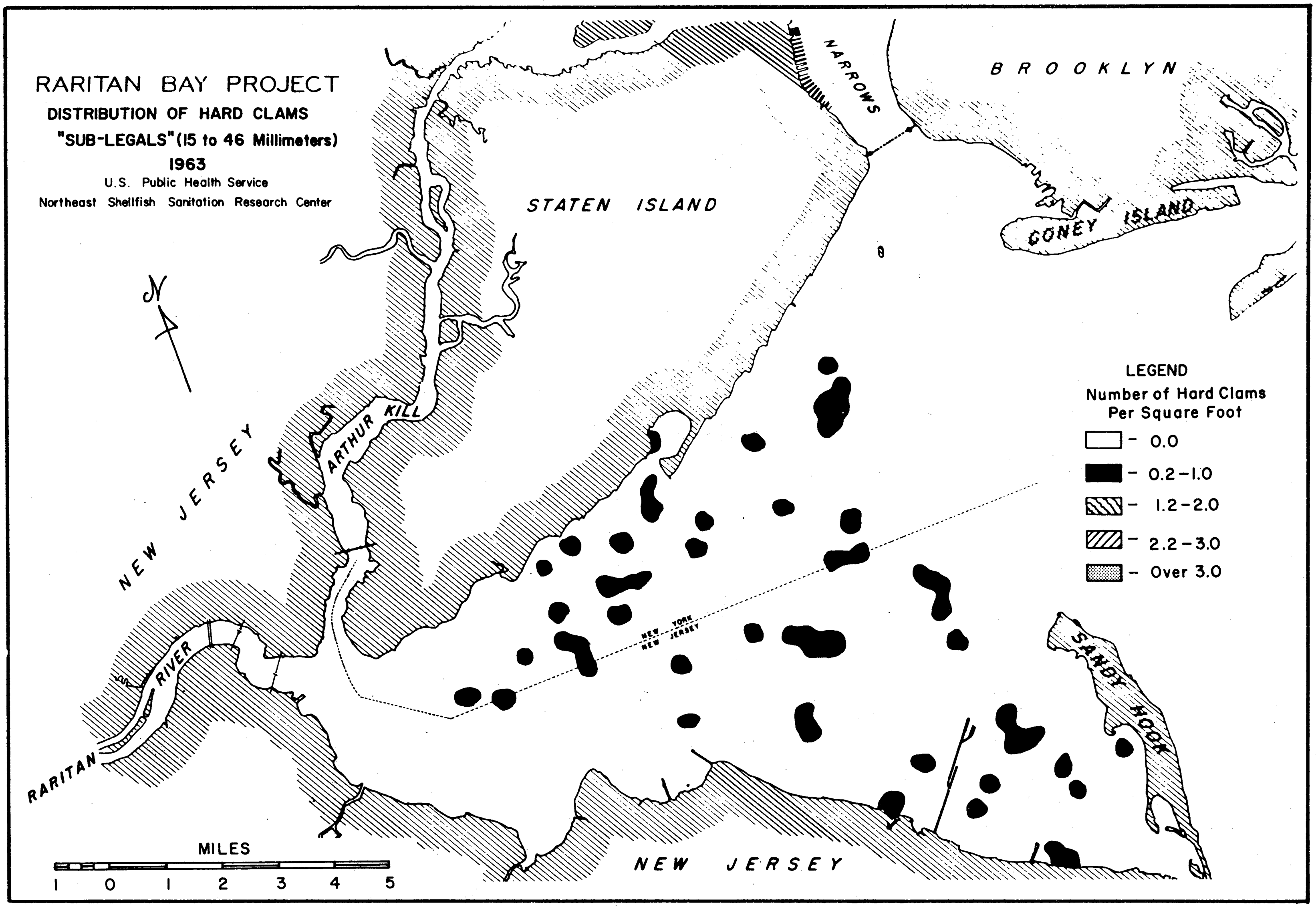


Figure 17. B) Distribution of hard clams (15-46 mm) in the Lower Bay complex in 1963. (From de Falco, 1967)

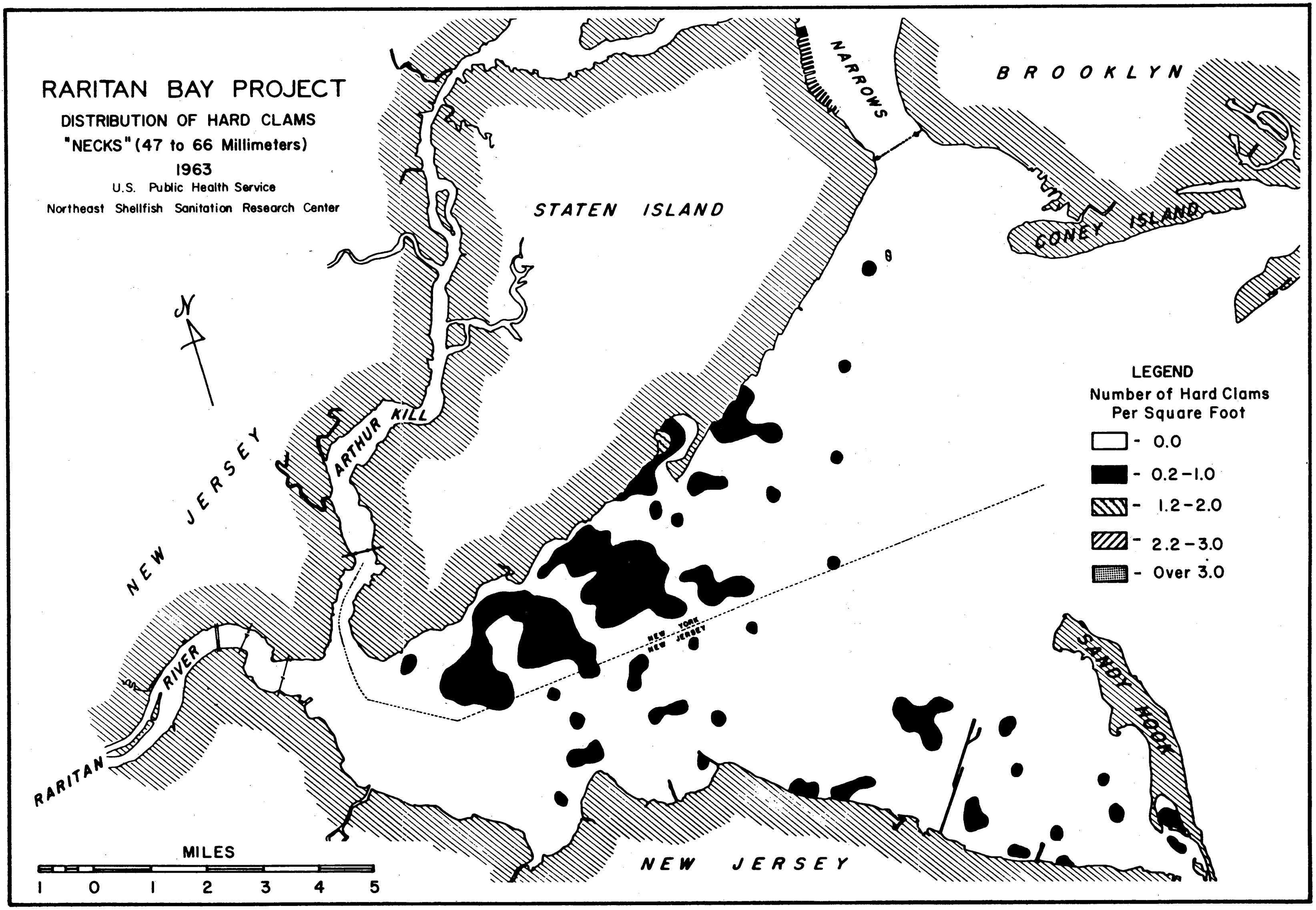


Figure 17. C) Distribution of hard clams (47-66 mm) in the Lower Bay complex in 1963. (From de Falco, 1967)

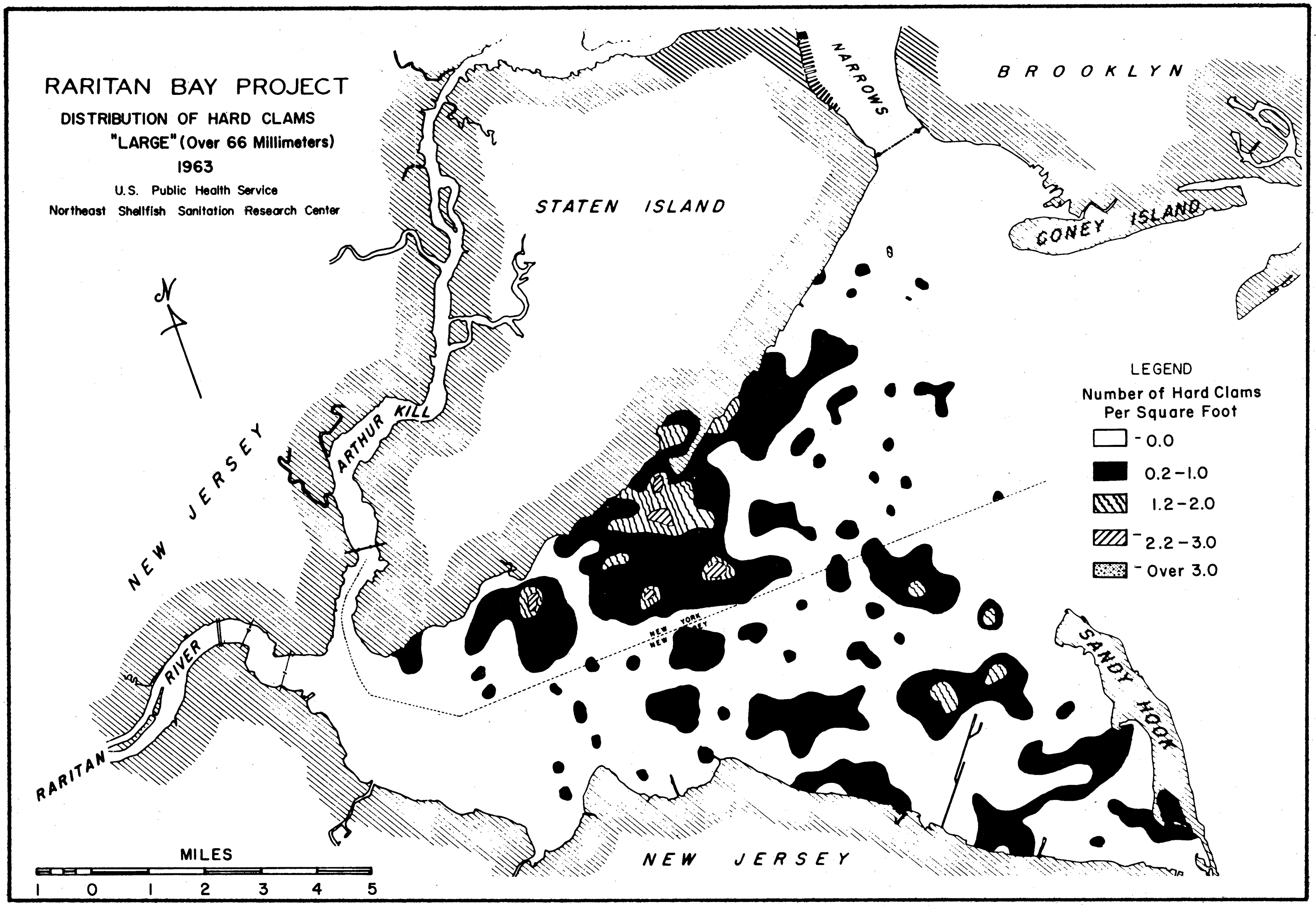


Figure 17. D) Distribution of hard clams (over 66 mm) in the Lower Bay complex in 1963. (From de Falco, 1967)

6. FISH

6.1. Conditions contributing to historical changes

Temporal and spatial comparison of finfish abundance are complicated by the diversity of collection gear and the near impossibility of standardization. Included in this summary are data from commercial landings, otter trawl, seine and plankton net collections, and impingement on cooling water intake screens. Commercial statistics are influenced by changing fishing effort, which is a function of market conditions, fuel costs, and catch limits. Furthermore, these data include both estuarine and offshore catches. Nonetheless, this type of information is often the only method of estimating historical trends. In contrast to recent years, Monmouth County finfish landings at the turn of the century were higher (Table 3). Several species taken then are no longer taken, or seen only sporadically, including croaker, spot, sheepshead, and Spanish mackerel (National Marine Fisheries Service, 1971). Esser (1982) summarizes long-term changes in some finfishes of the Hudson-Raritan estuary. He found that significant fluctuations and a general decline have occurred in the commercial catch of American shad. The sturgeon fishery that flourished in the Hudson River during the 1800s had declined by the early 1900s. The smelt fishery experienced its height in the early 1800s in the Raritan River, but had already

Table 3. Some finfish landings, Monmouth County, N.J. (lbs x 1000). (From National Marine Fisheries Service, 1971)

SPECIES	1897	1898	1901	1967	1968	1969	1970
Cod	2222	1200		0.9	23	17	18
Drum	2.5	2.0	12	0.2	0.3	0.4	
Eel	217	240	120	1.7	3.3	2.9	1.1
Flounder	747	824	111	90	53	64	53
Kingfish	6.7	6.1	11	0.7	0.7	0.7	0.4
Mackerel	24	17	2.9	5.5	37	18	69
Shad	167	124	7.1	12	40	50	19
Scup	514	316	251.3	92	51	7.3	1.8
Sea bass	997	903	580	2.8	0.1	0.1	1.4
Weakfish	5500	7281	1118	4.5	2.7	9.1	16
Tautog	288	314	0.8	5.9	3.3	3.5	4.0

declined by the late 1800s. Of those species reviewed by Esser (1982), only the striped bass population appeared to have increased in recent years. Several other species, including bluefish, scup and flounder, appear to be caught in lower numbers than at the turn of the century (Table 3). However, because they are caught both in the Estuary and in the ocean, the combined statistics make it difficult to estimate the estuarine harvest alone. Although natural fluctuations in fish populations may mask anthropogenic effects, the populations of several commercially important species have undoubtedly been seriously influenced by the industrialization of the estuary begun early last century. The impacts of urbanization on fish species include: reduction of suitable spawning and nursery areas, diminished water quality, and decreased food supply. In the following pages, data collected in the Hudson-Raritan estuary in the past decade will be examined first by regions within the estuary and subsequently by major species.

6.1.1. Physical factors

Bulkheading and filling much of the harbor shoreline have eliminated many of the small coves and bays that were suitable as nursery areas. Shoreline changes, channel improvements and stong currents have been cited as the factors responsible for the lack of a significant fisheries resource in the lower East River (Hazen and Sawyer, 1980). Similarly, Arthur Kill shallow water habitats have been virtually eliminated by bulkheads, piers, and landfill operations. Physical disturbances in the Hudson River have been suggested as important factors in the decline of certain populations (Esser, 1982). The decrease in available spawning and nursery areas is of consequence not only to resident species, but it may also reduce the spawning success of Hudson River anadromous species (e.g., shad, sturgeon, striped bass, and alewife) and those that migrate into the lower estuary for spawning (e.g., weakfish, scup, and winter flounder).

6.1.2. Water quality

Water quality deterioration is perhaps most severe in the Raritan Bay-lower Hudson estuarine system. Pearce (1979, p.9), reviewing the current status of the area, likened it to "an enormous septic system collecting contaminants from the metropolitan New York area as well as from areas as far removed as Albany and the Mohawk Valley...." The Lower Bay system receives urban and industrial wastes from the Hudson, Passaic, Hackensack, and Raritan Rivers. Flushing of the Bay is slow, approximately 32-42 tidal cycles or 16-21 days (Jeffries, 1962). Dilution from oceanic waters is slow, and pollutants may accumulate in the water column, sediments, and organisms. The Arthur Kill is characterized on its western shore by a concentration of petroleum and chemical industries, which use the waterway as a heat and process-effluent receiving station. The eastern shore on Staten Island is heavily used as a dumping ground. Oil spill residues and "sanitary" landfill operations are severe impacts on both shorelines. Trunk sewers now bring large amounts of domestic wastes from inland communities for "primary" treatment before discharge into the Kill (Raytheon, 1972). This factor, along with inadequate flushing, result in very low levels of dissolved oxygen, particularly in summer. Sluggish water movement and cooling waste water discharge has also raised water temperatures to over 30°C in much of the Arthur Kill and as high as 40° C in some tributaries (Ichthyological Associates, Inc., 1976).

Although it has been difficult to isolate causative agents in the multitude of pollutants, several investigators have associated fish diseases with sewage and metal pollution. Mahoney et al. (1973) reported severe fin rot disease among at least 22 species of marine and euryhaline fishes of the area. Of 1,152 bluefish examined in 1967, 70% were diseased. Summer and winter flounder and weakfish were also heavily infected. In another study of winter flounder alone, the Raritan Bay system and the less polluted Great Bay of central New Jersey were compared (Ziskowski and Murchalano, 1975).

In 1973, 15% of the 451 fish from Raritan Bay had fin erosion, whereas only 2.2% of 480 fish from Great Bay were diseased. Mahoney et al. (1973) tentatively attributed the fin rot disease to bacterial populations enhanced by organic enrichment of the habitat. Alternatively, the fish may have suffered some environmental stress which increased their susceptibility to bacterial infection. Disease incidence tended to parallel the seasonal temperature regime, reaching highest levels from July to September. Heavy metal pollutants have been found to increase susceptibility to bacterial infection in some fish species (Pippy and Hare, 1969).

Water column concentrations of mercury, zinc, cadmium, and lead have been reported "far in excess of background" (McCormick and Koepp, pg. 17, 1978). Zinc and lead reached parts per thousand levels in Arthur Kill sediments (McCormick and Koepp, 1978). Copper concentrations of $65 \mu g l^{-1}$ observed in the waters of the Raritan and Lower New York Bays were the highest reported to date for estuarine waters (Waldhauer et al., 1978). Metals may be lethal in certain concentrations, but also affect growth, reproduction, and physiological processes at sublethal levels. Pringle (1968) found copper fatal to sticklebacks down to $20 \mu g l^{-1}$. Methylmercury and cadmium in concentrations found in the estuary produce severe abnormalities in embryological development, and death in killifish (Fundulus heteroclitus) (Weis and Weis, 1977a and 1977b). Avoidance and behavior modification are other responses to metal concentrations typical of this area (e.g., Stephenson and Taylor, 1975). Atlantic salmon have been shown to avoid sublethal concentrations of copper as low as 2.4 $\mu g l^{-1}$ (Sprague cited in Waldhauer et al., 1978).

6.1.3. Food availability

The availability of food is a significant factor in the distribution of fish. Benthic organisms are important in the diet of many fish (e.g., spot, silver hake, tomcod, white perch, flounder). The bottom community of much of the lower estuary is very sparsely populated. McGrath (pg. 12, 1974) stated that "the most striking characteristic of the benthic fauna of Raritan Bay is its impoverishment." Macrofauna density is considerably lower than other areas both on this coast and elsewhere. Consequently, those species with a preference for certain benthic food organisms might be expected to be distributed accordingly.

Zooplankton densities and species composition in the Hudson-Raritan estuary are comparable to other mid-Atlantic estuaries (see Zooplankton section). Planktivorous fish species (e.g., the herrings, bay anchovy, menhaden, mummichog, weakfish) are probably not limited by food availability. Foraging species such as the bay anchovy, mummichog, silversides, and herrings, represent some of the most abundant fish of the estuary. The density of these species may be sufficient to meet the requirements of the larger carnivorous species such as the bluefish and striped bass. The usually high phytoplankton density in the lower estuary (see Phytoplankton section) may be a boon to filter-feeding species and secondarily to zooplanktivorous fish. However, the annually recurring blooms of phytoflagellates in the lower New York Bay and adjacent waters may also adversely affect fish populations. Although many of the occurrences may be benign in nature, some have been assigned a possible role in fish mortality (Ogren and Chess, 1969). Aside from the direct effects of red tide toxins, the death and decay of blooms may cause localized or regional oxygen depletions. These blooms have been strongly suggested to be associated with urban hypertrophication (Mahoney and McLaughlin, 1977).

6.2. Species distribution and abundance

6.2.1. The Lower Bay complex

The Lower Bay complex consists of the Raritan Bay, Lower Bay, and Sandy Hook Bay. Studies of demersal fish abundance were conducted by Wilk et al. (1977), from June 1974 to June 1975 and by Wilk and Silverman (1976), from

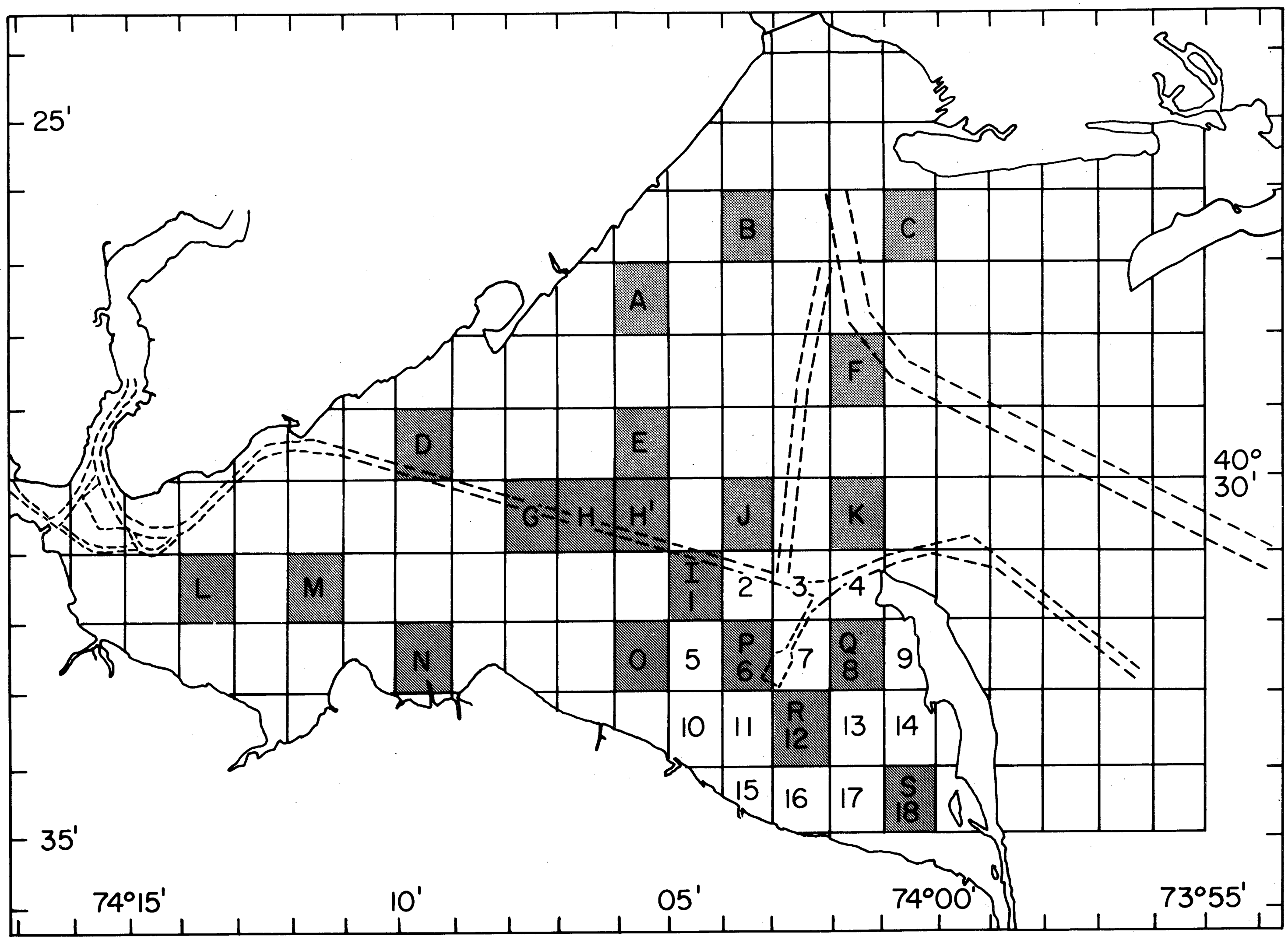


Figure 18. Sampling grids for the demersal finfish surveys of Wilk et al. (1977) and Wilk and Silverman (1976)

July to October, 1970. Fish collections were made with the same otter trawl, towed for 10 minutes (1970) and 15 minutes (1974-1975). The 1970 study sampled 18 quadrants of the Sandy Hook Bay, each measuring 1' lat. x 1' long., except where interrupted by land (Fig. 18). In 1974-1975, the Lower Bay complex was divided into similar-sized blocks. However, the authors did not specify which quadrants, or how many, were sampled within the area. Station coordinates were identified, but no indication was made whether tows began or ended there or in which direction they proceeded. Several station coordinates fell between blocks. It was therefore necessary to assign stations to sampling blocks based on the given coordinates and water depths and assuming the tows began there and a more or less equal number of tows were made per block (Figure 18). Analysis of the data does not include several stations where a larger trawl was used. The following discussion will emphasize the 1974-1975 study over the 1970 study, as it covered a greater area over a full year.

A total of 55 species (Table 4) were identified from the Lower Bay complex, representing a mean annual abundance of 131 fish per 15-minute tow. The bay anchovy alone accounted for 58% of the total. The 15 species with a mean annual density greater than one per 15-minute tow made up 96% of the total density. Peak densities

Table 4. Species rank, seasonal distribution, percent of total and percent occurrence of fish taken in the Lower Bay complex by otter trawl, 1974-1975. (From Wilk et al., 1977)

		NUMBERS PER TRAWL												
RANK	SPECIES	JAN	FEB	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	TOTAL # /TRAWL	% OF TOTAL	% OC-CUR.*
1.	Bay anchovy	0.07	--	0.08	--	50	0.73	23	287	354	9.4	76	58	27
2.	Silver anchovy	--	--	--	--	--	--	0.13	--	92	--	11	8.4	8.7
3.	Blueback herring	16	3.4	12	3.9	45	--	--	--	0.05	1.8	9.7	7.4	30
4.	Winter flounder	1.4	.08	.62	3.2	4.0	4.9	1.2	3.1	13	17	5.4	4.1	53
5.	Alewife	8.6	28	2.5	1.5	--	0.20	--	--	0.84	13	5.0	3.8	32
6.	Red hake	0.64	0.15	0.15	28	0.96	0.20	--	--	0.05	0.63	3.1	2.3	20
7.	Atlantic menhaden	19	1.7	0.08	0.56	2.8	0.07	--	--	0.95	1.6	2.6	2.0	26
8.	American shad	20	1.0	--	1.6	--	--	--	--	0.05	3.3	2.4	1.8	24
9.	Weakfish	--	--	--	--	0.04	1.4	2.9	12	6.5	1.5	2.3	1.8	28
10.	Windowpane	0.21	0.15	0.38	3.6	1.0	0.33	0.13	0.23	5.5	5.7	2.0	1.5	35
11.	Butterfish	--	--	--	0.13	3.9	0.07	0.80	2.7	6.8	0.16	1.7	1.3	21
12.	Atlantic silverside	0.50	--	--	4.6	4.5	--	--	--	0.47	2.5	1.5	1.1	22
13.	Summer flounder	--	--	--	0.06	0.57	2.7	5.7	1.8	1.5	0.11	1.2	0.91	21
14.	Silver hake	1.1	0.15	0.38	3.4	--	--	--	--	--	5.2	1.1	0.84	21
15.	Bluefish	--	--	--	--	0.13	1.4	0.80	1.8	5.8	0.11	1.1	0.82	16

Table 4. Species rank, seasonal distribution, percent of total and percent occurrence of fish taken in the Lower Bay complex by otter trawl, 1974-1975.

		NUMBERS PER TRAWL												
RANK	SPECIES	JAN	FEB	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	TOTAL # /TRAWL	% OF TOTAL	% OC-CUR.*
16.	Scup	--	--	--	--	0.30	1.1	--	6.2	0.05	2.2	0.92	0.70	11
17.	American sandlance	3.1	3.5	--	--	--	--	--	--	0.84	0.05	0.66	0.50	5
18.	Little skate	--	--	--	--	--	7.1	--	--	--	--	0.66	0.50	0.6
19.	Spotted hake	0.14	--	0.08	1.3	0.30	--	--	--	--	3.8	0.64	0.49	11
20.	Atlantic herring	2.2	3.5	0.62	0.38	0.17	--	--	--	--	--	0.59	0.45	17
21.	White hake	--	--	--	--	2.4	--	--	--	--	--	0.35	0.27	2.5
22.	Striped searobin	--	--	--	--	--	2.9	0.07	--	0.42	--	0.33	0.25	5.6
23.	Smallmouth flounder	0.07	--	--	--	--	--	--	--	1.5	0.32	0.23	0.17	5
24.	Smooth dogfish	--	--	--	--	--	1.5	0.20	0.15	--	--	0.18	0.13	5
25.	Tautog	--	--	--	0.44	0.04	0.07	0.13	--	0.68	0.21	0.18	0.13	8.1
26.	Cunner	--	--	--	--	--	--	--	--	0.05	1.1	0.13	0.10	1.2
27.	Northern kingfish	--	--	--	--	--	--	--	1.2	0.05	--	0.10	0.08	3.7
28.	Northern pipefish	--	--	--	0.06	--	--	--	0.08	0.47	0.05	0.08	0.06	3.1
29.	Northern searobin	--	--	0.08	--	--	0.13	0.07	0.31	0.11	0.05	0.07	0.05	2.5
30.	Silver perch	--	--	--	--	--	--	--	--	0.53	--	0.06	0.05	2.5
31.	Spot	--	--	--	--	--	--	0.07	0.08	0.26	--	0.04	0.03	2.5
32.	Grubby	0.21	--	--	--	--	0.07	--	--	--	0.11	0.04	0.03	3.7
33.	Black sea bass	--	--	--	--	0.04	--	--	0.31	0.05	--	0.04	0.03	1.9
34.	Lined seahorse	--	--	0.08	--	--	--	--	--	0.16	--	0.025	0.02	2.5
35.	Striped bass	--	--	--	0.06	--	0.13	--	--	0.05	--	0.025	0.02	2.5

Table 4. Species rank, seasonal distribution, percent of total and percent occurrence of fish taken in the Lower Bay complex by otter trawl, 1974-1975.

		NUMBERS PER TRAWL												
RANK	SPECIES	JAN	FEB	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	TOTAL # /TRAWL	% OF TOTAL	% OC-CUR.*
36.	Atlantic moonfish	--	--	--	--	--	--	--	0.23	0.05	--	0.025	0.02	2.5
37.	Northern stargazer	--	--	--	--	--	--	--	--	0.16	--	0.02	0.01	1.9
38.	Longhorn sculpin	--	0.08	0.15	--	--	--	--	--	--	--	0.02	0.01	1.2
39.	Striped anchovy	--	--	--	--	--	--	0.07	--	--	--	0.006	0.005	0.6
40.	Spotfin butterflyfish	--	--	--	--	--	--	--	0.08	--	--	0.006	0.005	0.6
41.	Gulf Stream flounder	--	--	--	--	--	--	--	0.08	--	--	0.006	0.005	0.6
42.	Conger eel	--	--	--	0.06	--	--	--	--	--	--	0.006	0.005	1.2
43.	Threespine stickleback	0.07	--	--	--	--	--	--	--	--	--	0.006	0.005	0.6
44.	Atlantic croaker	--	--	--	--	--	--	--	--	0.05	--	0.006	0.005	0.6
45.	Planehead filefish	--	--	--	--	--	--	--	0.08	--	--	0.006	0.005	1.2
46.	White perch	--	--	--	--	--	--	--	--	--	0.05	0.006	0.005	0.6
47.	White mullet	--	--	--	--	--	--	0.07	--	--	--	0.006	0.005	0.6
48.	Shorthorn sculpin	--	--	--	--	--	--	--	0.08	--	--	0.006	0.005	0.6
49.	Pigfish	--	--	--	--	--	--	--	--	0.05	--	0.006	0.005	0.6
50.	Inshore lizardfish	--	--	--	--	--	--	--	--	0.05	--	0.006	0.005	0.6
												131.367	100.00	
	Number individuals per trawl	73	42	17	52	117	25	35	317	494	69			
	Number of species	16	11	13	17	19	18	15	16	33	24			

$$* \text{ \% occurrence} = \frac{\text{\# Stations where present}}{\text{Total \# stations}} \times 100\%$$

Total # Stations = 161

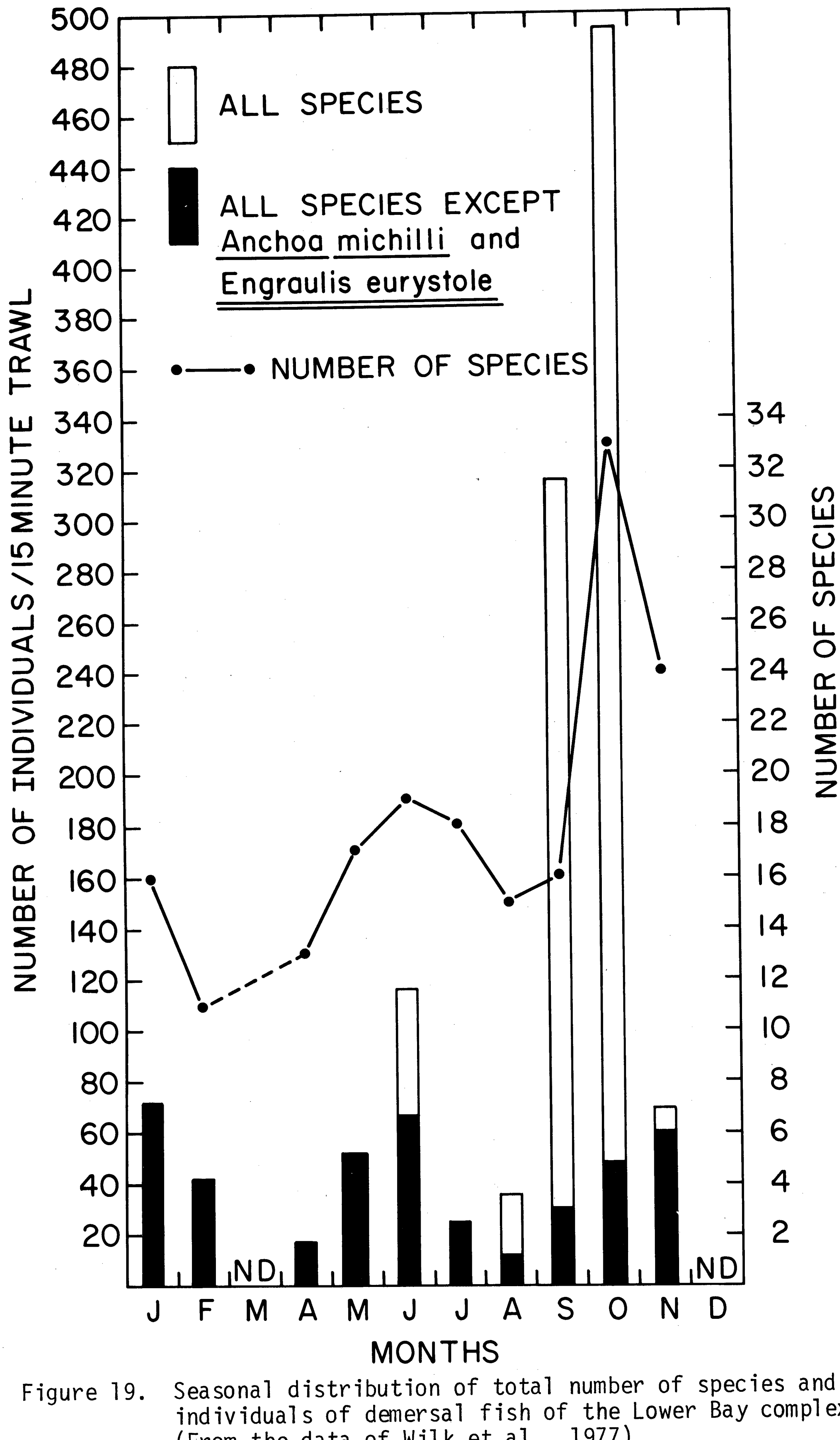


Figure 19. Seasonal distribution of total number of species and individuals of demersal fish of the Lower Bay complex. (From the data of Wilk et al., 1977)

occurred in late spring and the late fall-early winter (Fig. 19). These are the times of year when migratory species move into and out of the estuary. The lowest number of fish occurred in August when temperature is maximal and dissolved oxygen minimal (Swartz and Brinkhuis, 1978). Freshwater discharge is also at a seasonal low (Simpson et al., 1975), and hence the residence time of Lower Bay complex water and its associated pollutant load is highest.

The number of species present in the Lower Bay complex was lowest in February (11) and generally increased through the year to a peak in October (33) (Fig. 19). There was a decline in the summer months which may be related to the water quality conditions discussed above. The minimal value in February most likely reflects the absence of migratory species which have moved offshore to warmer waters, and those fish which are dormant or inactive in the winter months. The late fall peak in species numbers is probably due to the migration of summer residents out of the estuary and the appearance of some north-south offshore migrants in the estuary.

The mean annual distribution of fish within the Lower Bay complex is shown in Fig. 20. The regions of lowest fish densities were found to be on either side of the Ambrose Channel (areas C and F, Fig. 18). The low numbers found there may be directly related to the very

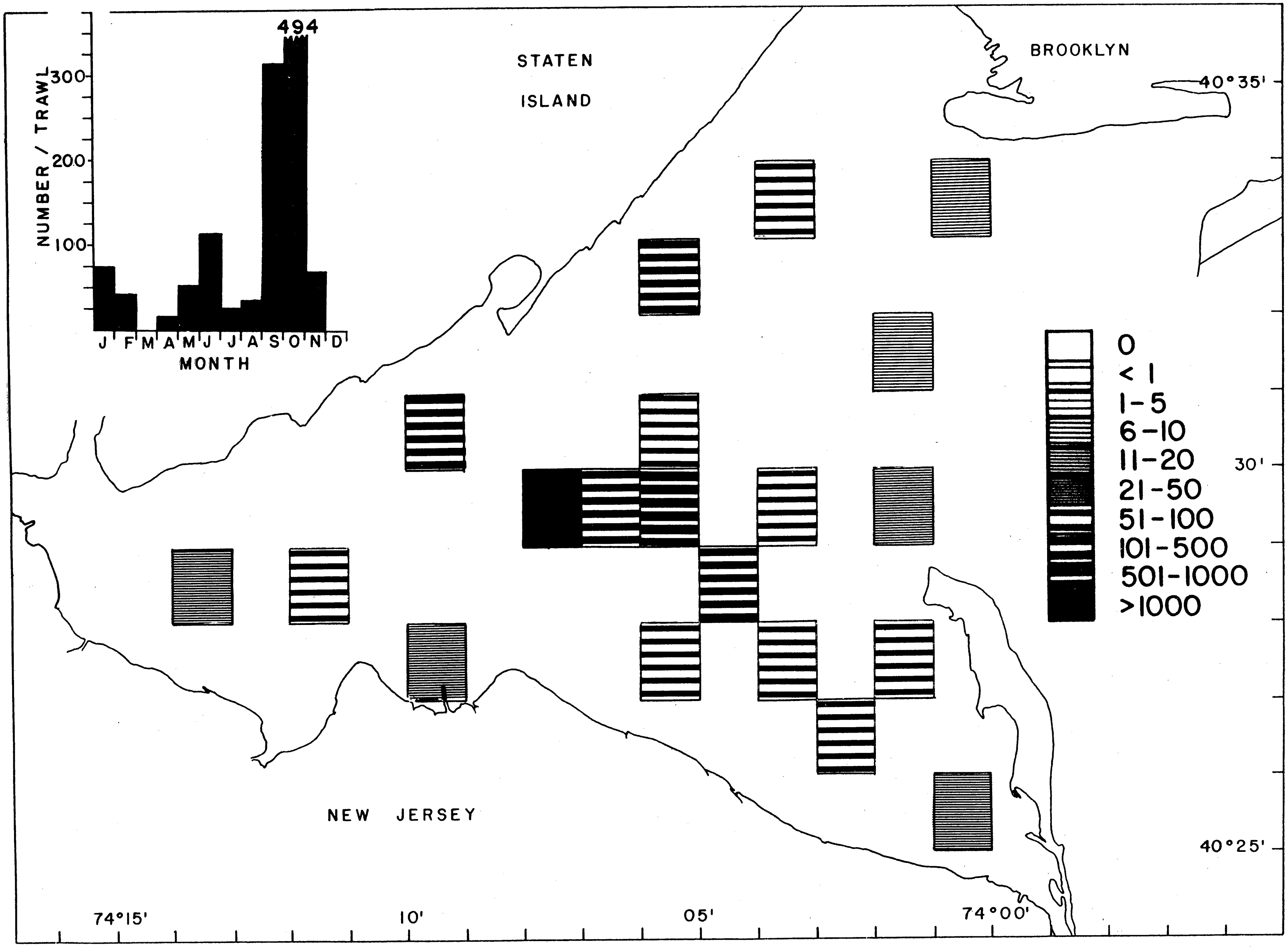


Figure 20. Mean annual distribution of demersal fish densities in the Lower Bay complex. (From the data of Wilk et al., 1977)

high current velocities that sweep fish away (Fig. 3) or may be a consequence of net avoidance due to the water movement. The central bay (areas G, H and H_1, Fig. 18) had the greatest number of fish. A net influx of offshore water flows at depth through the Raritan Bay Reach channel (Fig.2). This channel passes through the five areas of maximum abundance (areas D, G, H, H_1, and I, Fig. 18) suggesting that there may be a preference for oceanic waters over bay or riverine waters.

Further examination of the spatial distribution reveals some seasonal changes in fish densities (Fig. 20). In summer, the majority of species and individuals are centered in the Sandy Hook Bay. The western and northern portions are especially low in diversity and abundance. Freshwater discharge from the Hudson River and Raritan River-Arthur Kill areas is at its annual low during summer. Pollutants are therefore more concentrated during this season. The density of fish in the Sandy Hook Bay may reflect a preference for the relatively "clean" waters of the Navesink and Shrewsbury Rivers that empty into the Bay.

In fall, the distribution across the Lower Bay complex is complicated by the passage of migratory species out of the estuary. The areas of highest numbers of species and individuals are in the central bay. This area may be slightly warmer than other Lower Bay complex areas in the fall (Jeffries, 1962). Passage of offshore water into the Lower Bay complex is primarily through this area (Fig. 2). Thus, an influx of zooplankton from the fall population increase in the New York Bight may concentrate fish near the greatest food source.

In winter, fish numbers are greatest in the central Bay and Sandy Hook Bay. By spring, the greatest densities occur near the apexes of the Lower Bay complex "triangle," near the mouths of the various freshwater sources of the Lower Bay complex. The riverine water warms earlier and plankton blooms may occur sooner in the season there than in oceanic water.

6.2.2. Arthur Kill-Hackensack River

The Arthur Kill-Hackensack and Passaic River System was sampled extensively by Ichthyological Associates, in 1972 and 1973. The studies were prepared for the PSE & G Company of New Jersey to assess the impacts of several power-generating stations in the area. Fish were collected in seines, otter trawls, plankton nets, and on intake screens. Though certain collection methods may be more appropriate for some species than others, samples of fish impinged on cooling water intake screens are derived from very large volumes of water.

Nineteen species were impinged in 1973 in densities greater than 0.01/1000 m^3 (Table 5). The mummichog (Fundulus heteroclitus) accounted for greater than 50% of

Table 5. Fish impinged on intake screens of Arthur Kill, Passaic River, and Hackensack River generating stations in densities greater than $0.01/1000m^3$ in 1973. (From the data of Ichthyological Associates, Inc., 1974a,b,c,d,e,f)

	SPECIES	SEWAREN $\#/1000m^3$	%	LINDEN #/1000m	%	KEARNY #/1000m	%	HUDSON #/1000m	%	BERGEN #/1000m	%	MEAN DENSITY	% OF TOTAL
1.	Mummichog	0.061	7.8	1.1	51.4	2.9	79	1.3	80	3.2	77	1.7	70
2.	Blueback herring	0.056	7.2	0.52	25	0.12	3.3	0.15	9.5	--	--	0.17	6.9
3.	Goldfish	--	--	--	--	0.005	0.15	--	--	0.81	19	0.16	6.7
4.	Bay anchovy	0.43	55	0.13	6.1	0.004	0.10	0.01	0.7	--	--	0.11	4.7
5.	Alewife	0.03	3.8	0.21	9.7	0.082	2.2	0.03	1.7	--	--	0.069	2.8
6.	White perch	0.002	0.31	0.024	1.1	0.080	2.1	0.037	2.3	0.10	2.5	0.049	2.0
7.	Spot	0.09	11	0.006	0.3	0.027	0.73	0.03	1.6	--	--	0.030	1.2
8.	Threespine stickleback	0.008	1.1	0.039	1.9	0.085	2.3	0.002	0.15	0.001	0.01	0.027	1.1
9.	Tomcod	--	--	0.004	0.18	0.11	3.1	0.006	0.35	--	--	0.025	1.02
10.	Bluegill	--	--	--	--	0.091	2.4	0.001	0.05	--	--	0.018	0.73
11.	Striped bass	0.001	0.15	0.015	0.7	0.051	1.4	0.008	0.50	--	--	0.015	0.61
12.	Smelt	0.002	0.3	0.003	0.12	0.056	1.5	0.003	0.2	--	--	0.013	0.53
13.	Weakfish	0.029	3.7	0.001	0.06	0.027	0.7	0.002	0.15	--	--	0.012	0.49
14.	American shad	0.004	0.5	0.024	1.1	0.004	0.1	0.015	1	--	--	0.009	0.37
15.	Atlantic menhaden	0.015	2.0	0.016	0.8	--	--	0.001	0.05	--	--	0.006	0.24
16.	American eel	--	--	0.010	0.5	0.004	0.1	0.007	0.45	0.011	0.3	0.006	0.24
17.	Carp	--	--	--	--	0.002	0.05	--	--	0.021	0.5	0.005	0.20
18.	Crevalle jack	0.011	1.4	0.001	0.06	0.002	0.05	0.002	0.10	--	--	0.003	0.12
19.	Black crappie	--	--	--	--	--	--	0.001	0.05	0.012	0.3	0.003	0.12
	# individuals > $0.01/1000m^3$	0.71	91	2.1	98	3.7	99	1.5	97	4.2	100	2.5	100
	# species > $0.01/1000m^3$	8		10		11		7		6			
	Total # species	26		24		23		26		9			

Table 6. Fish taken in otter trawls in the Arthur Kill-Hackensack River in 1973 (number/trawl). (From the data of Ichthyological Associates, Inc., 1974a,b,c,d,e,f)

	Species	Sewaren	Linden	Essex	Kearny	Hudson	Bergen	Upper Hackensack	TOTAL
1.	Mummichog	5.4	9.8	13	1.9	12	4.7	8.5	7.9
2.	White perch	0.04	--	--	0.02	--	--	8.6	1.2
3.	Goldfish	--	--	--	--	--	--	7.9	1.1
4.	Spot	3.5	--	--	--	0.02	--	--	0.50
5.	Bay anchovy	3.0	--	0.18	0.05	--	--	--	0.46
6.	Carp	--	--	--	--	--	0.02	1.2	0.17
7.	Alewife	0.40	--	0.12	0.33	0.07	--	--	0.13
8.	American eel	0.02	--	0.02	0.04	0.02	--	0.74	0.12
9.	Tomcod	--	--	0.23	0.04	0.37	--	--	0.09
10.	Blueback herring	0.32	--	0.07	0.11	0.04	--	--	0.08
11.	Shad	0.21	--	0.02	0.04	--	--	--	0.04
12.	Atlantic herring	0.14	--	--	--	--	--	--	0.02
13.	Yellow perch	--	--	--	--	--	--	0.11	0.02
14.	Northern pipefish	0.04	--	--	0.04	--	--	--	0.01
15.	Silver hake	0.04	--	0.02	--	--	--	--	0.009
16.	Striped bass	0.02	--	--	--	--	--	--	0.003
17.	Bluefish	0.02	--	--	--	--	--	--	0.003
18.	Largemouth bass	--	--	0.02	--	--	--	--	0.003
	TOTAL #1 Trawl	13	9.8	14	2.6	12	4.7	27	12
	TOTAL # Species	13	1	9	9	6	3	6	18

Table 7. Mean annual density, rank, and temporal occurrence of fish larvae taken with a 0.5m plankton net in the Arthur Kill-Passaic and Hackensack Rivers in 1973. (From the data of Ichthyological Associates, Inc., 1974a,b,c,d,e,f)

RANK	SPECIES	SEWAREN (#/1000m³)	LINDEN	EXXON	ESSEX	KEARNY	HUDSON	BERGEN	UPPER HACKENSACK	TOTAL
1.	*Pseudopleuronectes americanus*	25	77	102			0.37			26
2.	*Anchoa mitchilli*	100	14	65		2.6				23
3.	*Ammodytes americanus*		87	21	0.41	0.75				14
4.	*Morone americana*	0.41			1.2				98	12
5.	*Microgodus tomcod*	19	56		1.2	1.1	0.37			9.7
6.	*Fundulus* spp.	0.81	6.8	11.2	0.82	4.2	8.2	5.4	2.5	5.0
7.	*Anguilla rostrata**	2.0	22	0.81	3.3	3.8	1.9			4.2
8.	*Myoxocephalus aenaeus*	0.81	28	0.81		0.38				3.7
9.	*Clupea harengus*	0.81	29							3.7
10.	*Gobiidae*	1.2	6.2	0.81	0.82		1.1			1.3
11.	*Bairdiella chrysura*		8.1							1.0
12.	*Cynoscion regalis*	2.8		0.20						0.38
13.	*Alosa* spp.	2.4		0.10	0.41					0.37
14.	*Menidia* spp.	2.4		0.10	0.41					0.37
15.	*Brevoortia tyrannus*	0.81				0.75	0.37			0.24
16.	*Etheostoma olmstedi*								1.9	0.24
17.	*Cyprinus carpio*							0.49	1.3	0.22
18.	*Syngnathus fuscus*	0.81		0.20						0.13
19.	*Trinectes maculatus*			0.71						0.09
20.	*Paralichthys dentatus*	0.41								0.05
21.	*Scopthalmus aquosus*			0.20						0.03
22.	*Tautoga onitis*			0.20						0.03
23.	*Tautogolabrus adspersus*			0.10						0.01
24.	*Enchelyopus cimbrius*			0.10						0.01
	TOTAL (#/1000m³)	162	366	204	8.6	14	12	5.9	105	110
	# species	15	10	16	8	7	6	2	4	24

*juveniles

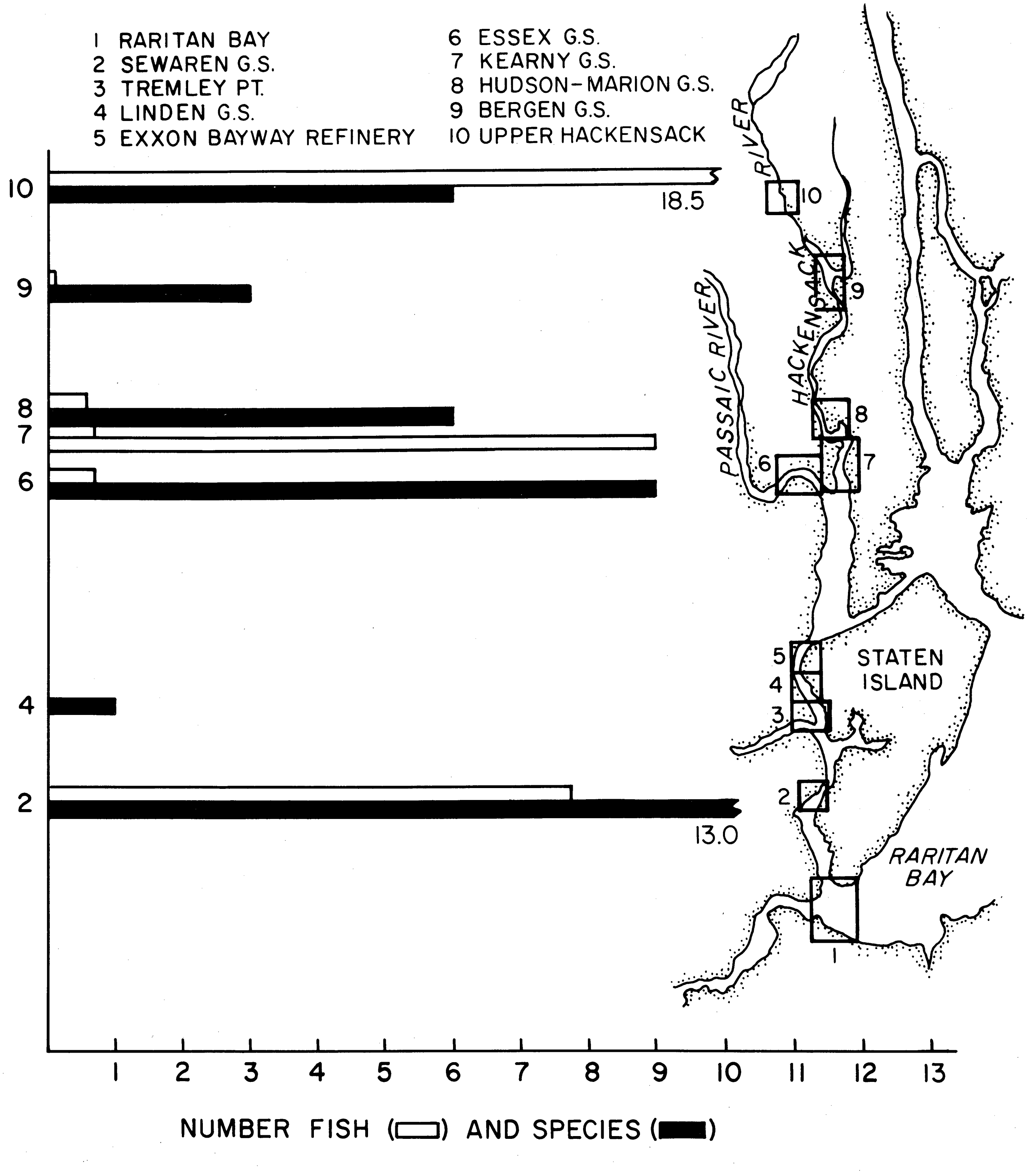
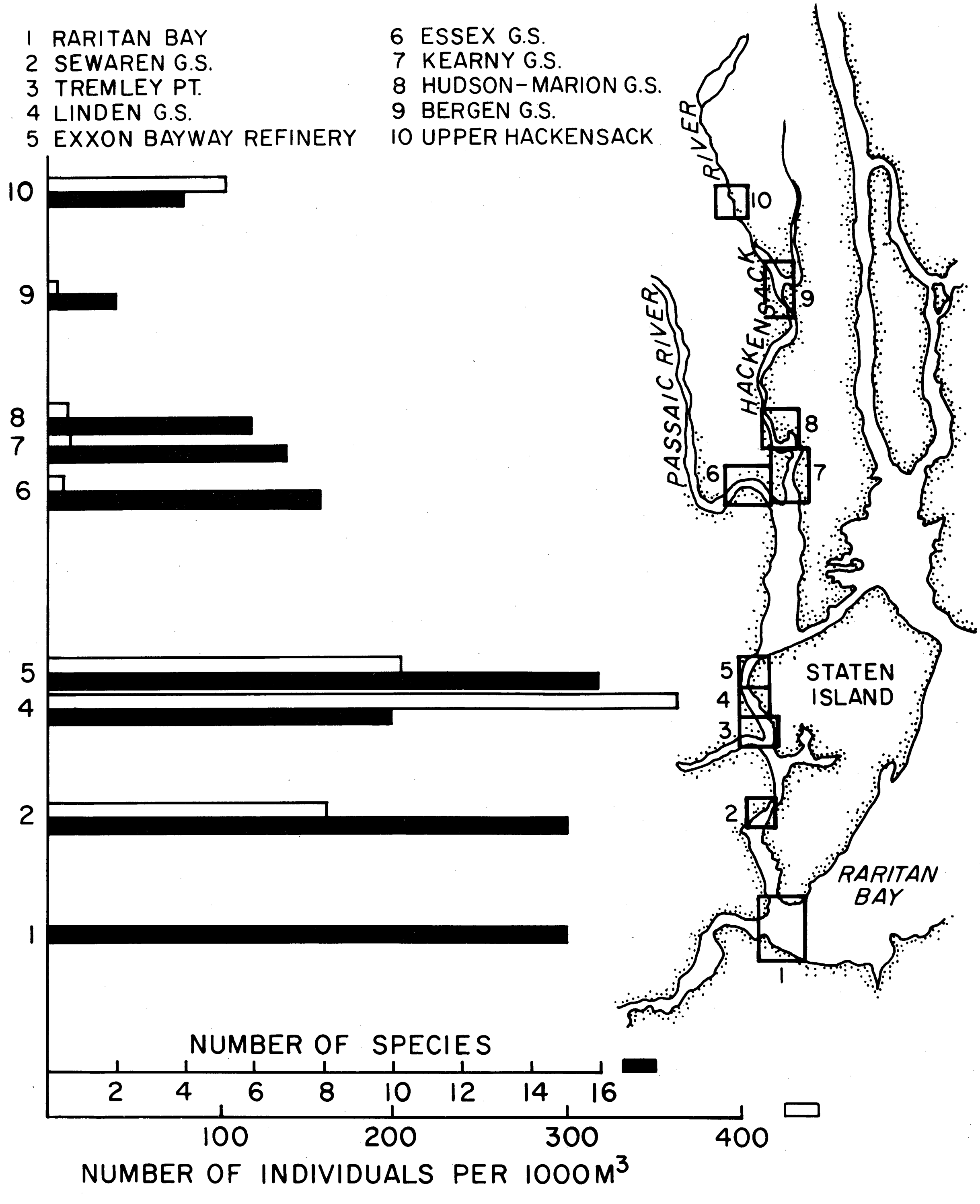


Figure 21. Number of species and individuals of finfish in the Arthur Kill-Hackensack River-Passaic River Estuary taken in five-minute otter trawls in 1973. (From the data of Ichthyological Associates, Inc., 1974a,b,c,d,e,f)



FISH LARVAE AND JUVENILES

Figure 22. Number of species and individuals of finfish larvae and juveniles in the Arthur Kill-Hackensack River-Passaic River Estuary impinged on cooling water intake screens in 1973. (From the data of Ichthyological Associates, Inc., 1974a,b,c,d,e,f, 1976)

the total densities at all stations but Sewaren. The mummichog, blueback herring (Alosa aestivalis), goldfish (Carrassius auratus) and bay anchovy (Anchoa mitchilli) together represented close to 90% of the total density of fish (Table 8).

Otter trawl collections in 1973 included a total of 18 species. Fundulus heteroclitus averaged 66% of the total number and higher than 95% at Linden, Hudson and Bergen stations (Table 6). The greatest number of species (13) was found at Sewaren, whereas the most individuals occurred in the Upper Hackensack (Fig. 21).

Plankton net tows yielded 24 species of fish larvae and juveniles (Table 7). Almost half the total number were winter flounder (Pseudopleuronectes americanus), and bay anchovy (Anchoa mitchilli). These species along with the following comprised 92% of the total catch: sandlance (Ammodytes americanus), white perch (Morone americana), tomcod (Microgadus tomcod), mummichog (Fundulus heteroclitus), American eel (Anguilla rostrata), grubby (Myoxocephalus aenaeus), and Atlantic herring (Clupea harengus). A greater number of individuals and species was found in the Arthur Kill than the Hackensack River or head of the Newark Bay (Fig.22). Though sampling was incomplete in the winter months, the sand lance (Ammodytes americanus) was the dominant species from January through early March. From late March through early May, winter flounder (Pseudopleuronectes

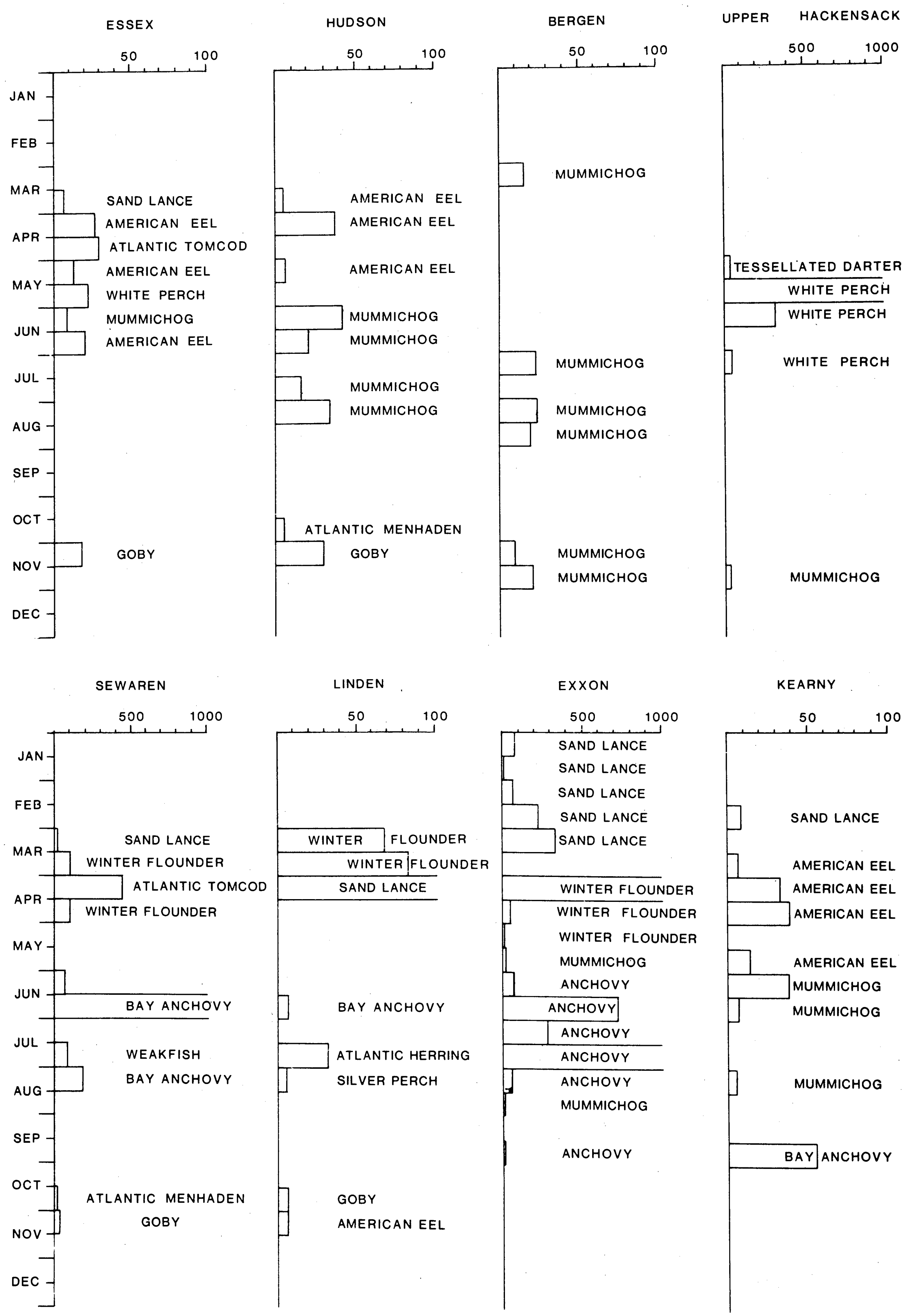


Figure 23. Seasonal distribution of larval and juvenile finfish densities in the Arthur Kill-Hackensack River-Passaic River Estuary in 1973. Dominant species are indicated for each month. (From the data of Ichthyological Associates, Inc., 1974a,b,c,d,e,f, 1976)

americanus) larvae were most abundant in the Arthur Kill, and American eel (Anguilla rostrata) elvers were dominant in the head of the Newark Bay (Fig. 23). In June, July and early August, bay anchovy (Anchoa mitchilli) larvae dominated the ichthyoplankton in the Arthur Kill, whereas the mummichog (Fundulus heteroclitus) appeared most frequently in the head of Newark Bay. In the late summer, early fall months when temperatures are highest and oxygen levels lowest, few or no ichthyoplankton were collected in the entire area. The late fall catch was primarily goby larvae (Gobiidae)(Fig. 23). In the Hackensack River, the mummichog was the dominant species in all catches near the river mouth. White perch larvae were the major species in the Upper Hackensack.

The seasonal distribution of adults, based on impingement collections, can be categorized by spawning habitat (Table 8, Fig. 24). Fresh and brackish water resident species were most numerous at the Bergen and Kearny stations. Those species whose maximum densities occurred in winter (Morone americana and Fundulus heteroclitus) and summer (Carrassius auratus, Cyprinus carpio and Pomoxis nigromaculatus) were most numerous at Bergen. Species that reached peak densities in fall (Lepomis machrochirus and Gasterosteus aculeatus) occurred primarily near Kearny.

Anadromous fish with winter peaks in abundance

Table 8. Seasonal distribution of adult fish in the Arthur Kill-Hackensack River by residence and spawning habits. From cooling-water intake screen collections in 1973. (From the data of Ichthyological Associates, Inc., 1974a,b,c,d,e,f.)

RESIDENCE, SPAWNING HABIT	MAXIMUM DENSITY	
1. Residents	AREA*	SEASON
a. Fresh Water		
Goldfish *(Carrasius auratus)*	B, K	Summer
Carp *(Cyprinus carpio)*	B, K	Summer
Black crappie *(Pomoxis nigro-maculatus)*	B, H	Summer
Bluegill *(Lepomis macrochirus)*	K, H	Fall
White perch *(Morone americana)*	B, K	Winter
b. Brackish Water		
Threespine stickleback *(Gasterosteus aculeatus)*	K, L	Fall
Mummichog *(Fundulus heteroclitus)*	B, K	Winter
2. Migratory		
a. Anadromous and Catadromous		
Smelt *(Osmerus mordax)*	K	Winter
Tomcod *(Microgadus tomcod)*	K	Winter
Striped bass *(Morone saxatilis)*	K	Winter
Blueback herring *(Alosa aestivalis)*	L, K	Spring, Fall
Alewife *(Alosa pseudoharengus)*	L, K	Spring, Fall
Shad *(Alosa sapidissima)*	L, H	Spring, Fall
American eel *(Anguilla rostrata)*	L, B	Spring, Fall
b. Nursery		
Bay anchovy *(Anchoa mitchilli)*	S, L	Spr. Summ. Fall
Menhaden *(Brevoortia tyrannus)*	L, S	Spr. Summ. Fall
Crevalle jack *(Caranx hippos)*	S, K	Fall
Spot *(Leiostomus xanthurus)*	S, K	Fall
Weakfish *(Cynoscion regalis)*	S, K	Fall

*near the following generating stations: B = Bergen, K = Kearny, H = Hudson, S = Sewaren.

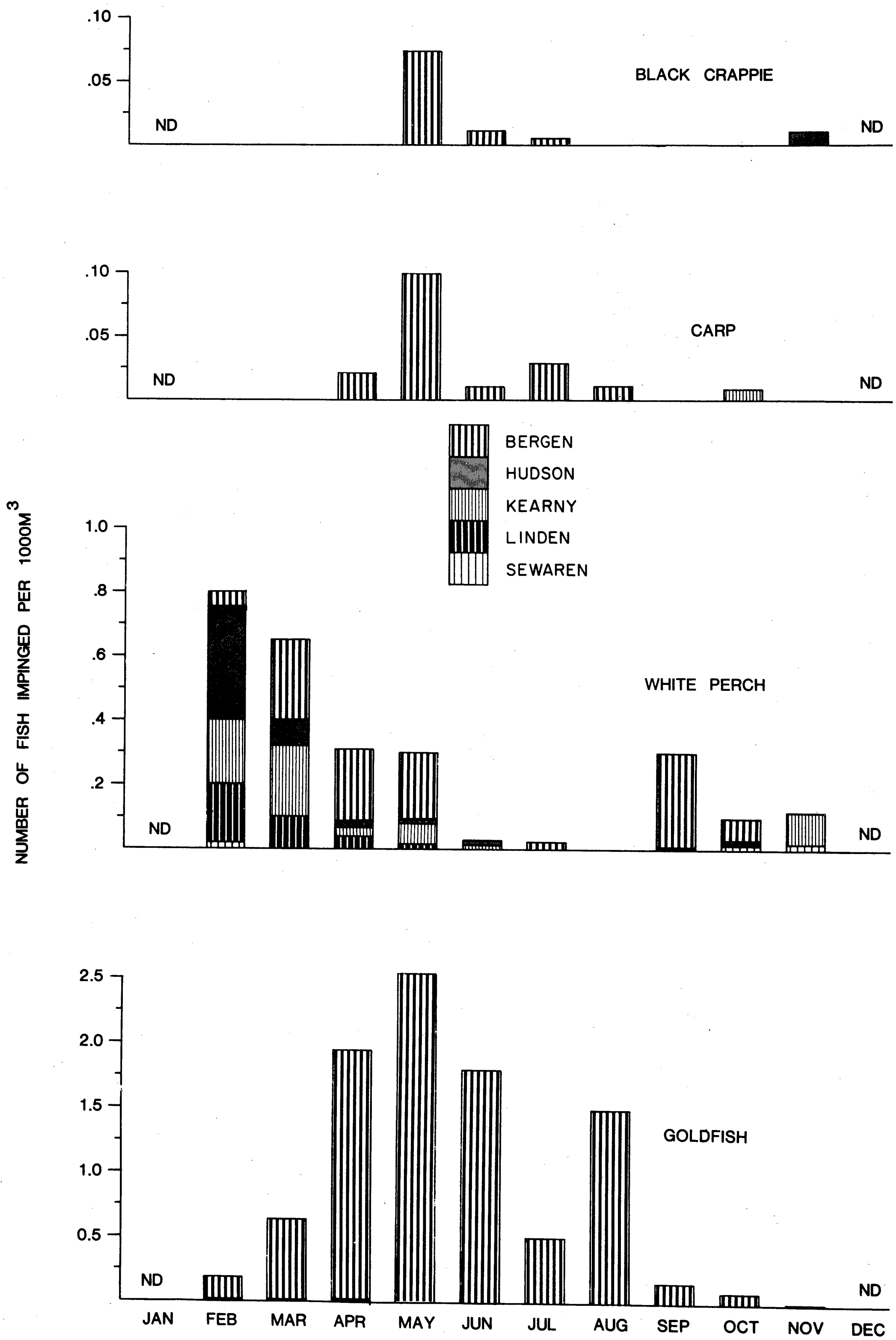


Figure 24. A) Seasonal and spatial distribution of freshwater resident finfish impinged on the cooling water intake screens of Arthur Kill-Hackensack River-Passaic River power generating stations in 1973. (From the data of Ichthyological Associates, Inc., 1974a,b,c,d,e,f)

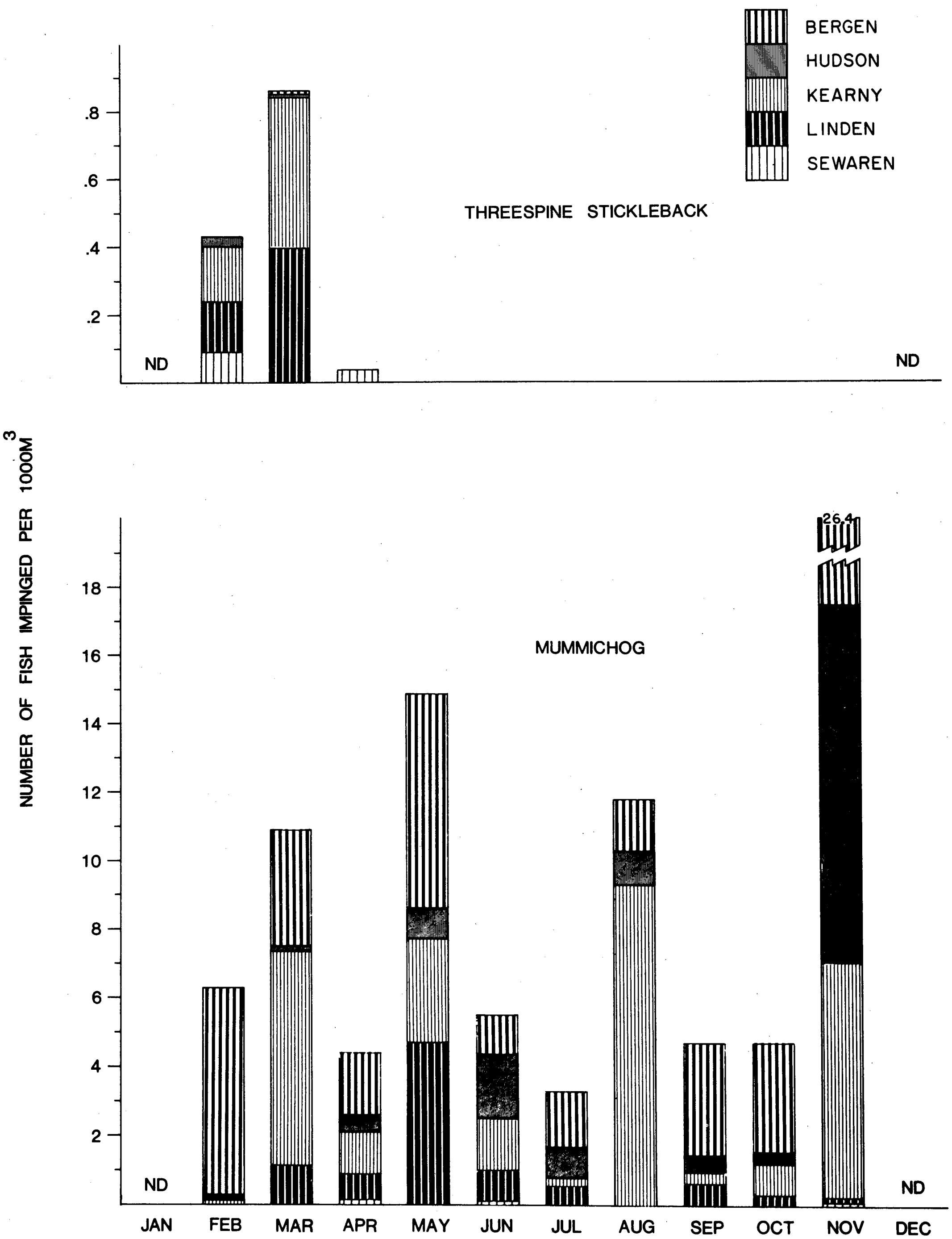


Figure 24. B) Seasonal and spatial distribution of brackish water resident finfish impinged on the cooling water intake screens of Arthur Kill-Hackensack River-Passaic River power-generating stations in 1973. (From the data of Ichthyological Associates, Inc., 1974a,b,c,d,e,f)

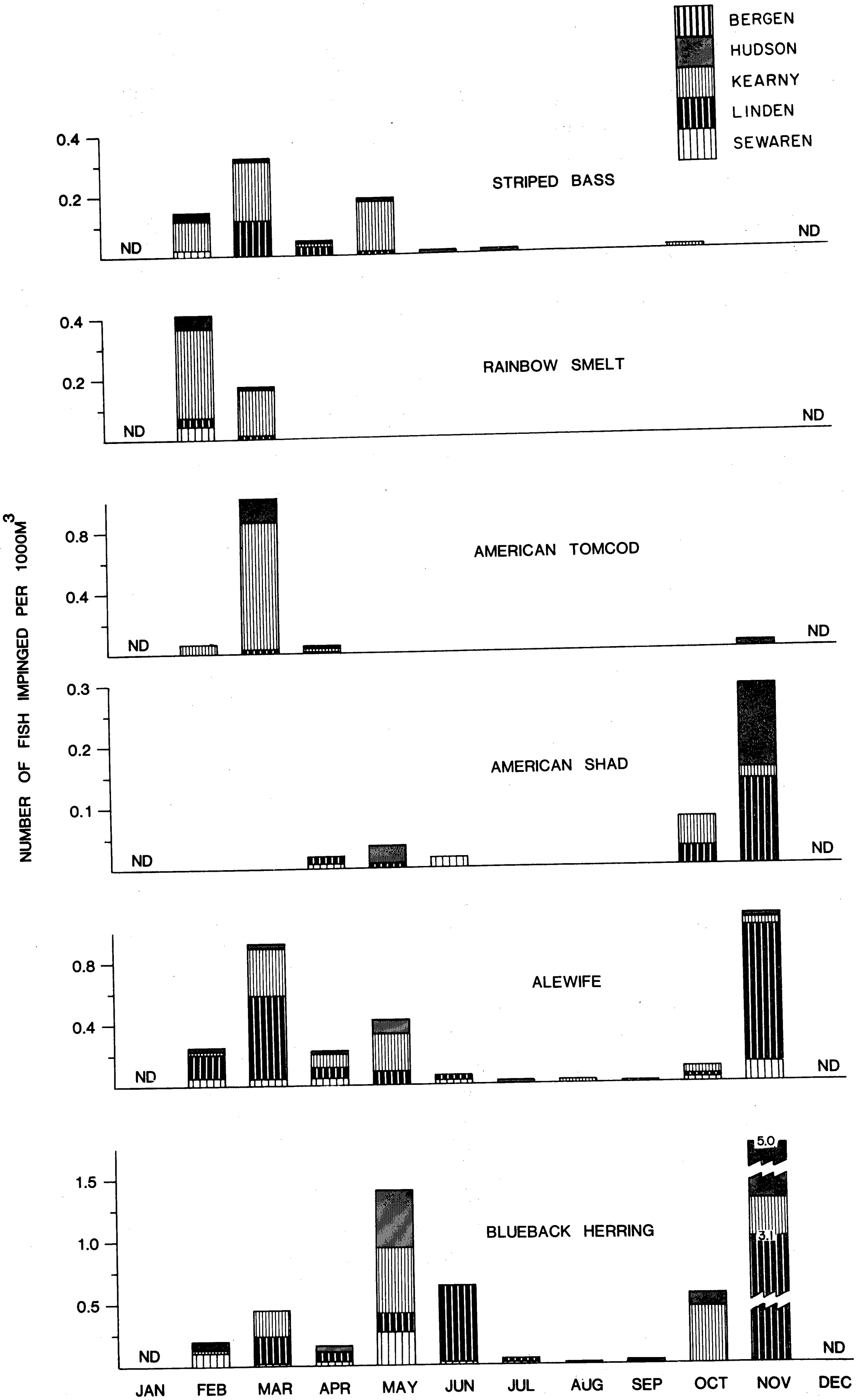


Figure 24. C) Seasonal and spatial distribution of anadromous finfish impinged on the cooling water intake screens of Arthur Kill-Hackensack River-Passaic River power-generating stations in 1973. (From the data of Ichthyological Associates, Inc., 1974a,b,c,d,e,f)

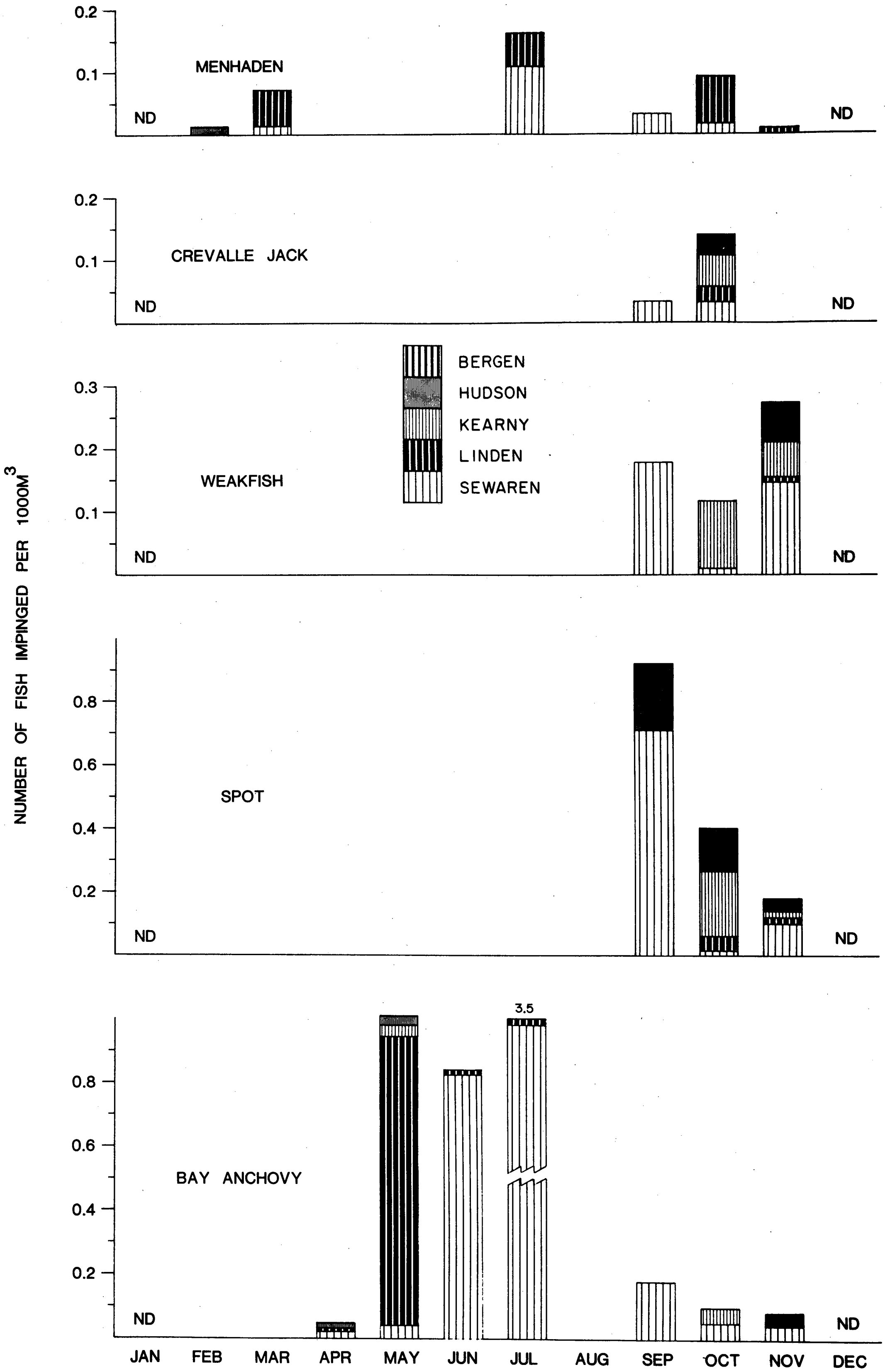


Figure 24. D) Seasonal and spatial distribution of migratory finfish impinged on the cooling water intake screens of Arthur Kill-Hackensack River-Passaic River power-generating stations in 1973. (From the data of Ichthyological Associates, Inc., 1974a,b,c,d,e,f)

(Osmerus mordax, Microgadus tomcod and Morone saxatilis) were most numerous near Kearny. Those whose maximum numbers occurred in spring and fall (Alosa aestivalis, A. pseudoharengus, A. sapidissima and Anguilla rostrata-catadromous) were found primarily near Linden.

Some marine species use the estuary as a nursery area. Anchoa mitchilli and Brevoortia tyrannus were most numerous in the late spring-early summer and fall and found in greatest densities near Sewaren and Linden. Those with fall peaks in abundance (Caranx hippos, Leiostomus xanthurus and Cynoscion regalis) were most common near Sewaren and Kearny.

6.2.3. The Hudson River Estuary

The tidally influenced or estuarine portion of the Hudson River extends from the southern tip of Manhattan (Battery Park, km 0) to the Federal Dam near Albany (km 246). The Hudson River is generally divided into three regions based on river width and depth. This report deals only with the Lower Hudson (Tappan Zee Bridge, km 39 to the Battery). Below the Tappan Zee Bridge (km 39), water depth increases gradually as the width decreases, and the salinity is greater and less variable. In much of the lower Hudson, marine and freshwater species coexist. River morphometry, the existence of backwater coves, and the addition of

Table 9. Fish species caught during surveys of Hudson River Estuary, 1936 and 1965-75. (From Texas Instruments, Inc., 1977)

Family	Scientific Name	Common Name	Residency*	Salinity Preference**	Spawning†	Abundance‡
Petromyzontidae	*Petromyzon marinus*	Sea lamprey	Oc	E	?	R
Rajidae	*Raja laevis*	Barndoor skate	Oc	M	0	R
Acipenseridae	*Acipenser brevirostrum*	Shortnose sturgeon	Y	E	Sp	R
	Acipenser oxyrhynchus	Atlantic sturgeon	A	E	Sp	U
Anguillidae	*Anguilla rostrata*	American eel	C	E	0	A
Clupeidae	*Alosa aestivalis*	Blueback herring	A	E	Sp	A
	Alosa pseudoharengus	Alewife	A	E	Sp	A
	Alosa mediocris	Hickory shad	Oc	E	?	R
	Alosa sapidissima	American shad	A	E	Sp	A
	Brevoortia tyrannus	Atlantic menhaden	S	M	0	C
	Clupea harengus	Atlantic herring	Oc	M	0	R
	Dorosoma cepedianum	Gizzard shad	Oc	E	?	U
	Etrumeus teres	Round herring	Oc	E	?	R
Engraulidae	*Anchoa mitchilli*	Bay anchovy	Y	E	Sp-S	A
	Anchoa hepsetus	Striped anchovy	Oc	M	0	R
Salmonidae	*Salmo trutta*	Brown trout	Oc	F	0	R
	Salvelinus fontinalis	Brook trout	Oc	F	G	R
Osmeridae	*Osmerus mordax*	Rainbow smelt	A	E	Sp	A
Umbridae	*Umbra limi*	Central Mudminnow	Oc	F	0	R
	Umbra pygmaea	Eastern mudminnow	Oc	F	0	R
Esocidae	*Esox americanus*	Redfin pickerel	Y	F	W-Sp	U
	Esox lucius	Northern pike	Oc	F	?	R
	Esox niger	Chain pickerel	Y	F	W-Sp	U
Synodontidae	*Synodus foetens*	Inshore lizardfish	Oc	M	0	R

Table 9. (page 2 of 5)

Family	Scientific Name	Common Name	Residency*	Salinity Preference**	Spawning†	Abundance‡
Cyprinidae	*Carassius auratus*	Goldfish	Y	F	Sp	A
	Cyprinus carpio	Carp	Y	F	Sp-s	C
	Exoglossum maxillingua	Cutlips minnow	Oc	F	?	R
	Hybognathus nuchalis	Silvery minnow	Y	F	Sp	C
	Notemigonus crysoleucas	Golden Shiner	Y	F	Sp-s	A
	Notropis amoenus	Comely shiner	Oc	F	?	R
	Notropis analostanus	Satinfin shiner	Y	F	Sp-s	R
	Notropis atherinoides	Emerald shiner	Y	F	Sp-s	A
	Notropis bifrenatus	Bridle shiner	Oc	F	?	R
	Notropis cornutus	Common shiner	Y	F	Sp-S	R
	Notropis hudsonius	Spottail shiner	Y	F	Sp-s	A
	Notropis rubellus	Rosyface shiner	Oc	F	?	R
	Notropis spilopterus	Spotfin shiner	Oc	F	?	R
	Notropis volucellus‡	Mimic shiner	Oc	F	?	R
	Pimephales promelas	Fathead minnow	Oc	F	?	R
	Pimpehales notatus	Bluntnose minnow	Oc	F	?	R
	Rhinichthys atratulus	Blacknose dace	Oc	F	?	R
	Rhinichthys cataractae	Longnose dace	Oc	F	?	R
	Semotilus atromaculatus	Creek chub	Oc	F	?	R
	Semotilus corporalis	Fallfish	Oc	F	?	R
Catostomidae	*Catostomus commersoni*	White sucker	Y	F	Sp	C
	Erimyzon oblongus‡	Creek chubsucker	Oc	F	?	R
	Hypentelium nigricans	Northern hogsucker	Oc	F	?	R
Ictaluridae	*Ictalurus catus*	White catfish	Y	E	Sp	A
	Ictalurus natalis	Yellow bullhead	Oc	F	?	R
	Ictalurus nebulosus	Brown bullhead	Y	F	Sp-s	C
Percopsidae	*Percopsis omiscomaycus*	Trout-perch	Oc	F	?	R
Gadidae	*Enchelyopus cimbrius*	Fourbeard rockling	Oc	M	O	R
	Merluccius bilinearis	Silver hake	Oc	M	O	R
	Microgadus tomcod	Atlantic tomcod	Y-A	M-E	W	A
	Pollachius virens	Pollock	Oc	M	O	R
	Urophycis chuss	Red hake	Oc	M	O	R
	Urophycis regius	Spotted hake	Oc	M	O	R

Table 9. (page 3 of 5)

Family	Scientific Name	Common Name	Residency*	Salinity Preference**	Spawning†	Abundance‡
Belonidae	*Stongylura marina*	Atlantic needlefish	Y	M	O	U
Cyprinodontidae	*Fundulus diaphanus*	Banded killifish	Y	E	Sp-s	A
	Fundulus heteroclitus	Mummichog	Y	E	Sp-s	A
	Fundulus luciae	Spotfin killifish	Oc	M	?	R
	Fundulus majalis	Striped killifish	Oc	M	?	R
Atherinidae	*Membras martinica*	Rough silverside	Oc	M	?	R
	Menidia beryllina	Tidewater silverside	Y	E	Sp-s	C
	Menidia menidia	Atlantic silverside	Y	M	Sp-s	C
Gasterosteidae	*Apeltes quadracus*	Fourspine stickleback	Y	E	Sp-s	C
	Culaea inconstans	Brook stickleback	Oc	F	?	R
	Gasterosteus aculeatus	Threespine stickleback	Oc	E	?	R
Syngnathidae	*Hippocampus erectus*	Lined seahorse	Oc	M	?	R
	Syngnathus fuscus	Northern pipefish	Y	M	?	U
Percichthyidae	*Morone americana*	White perch	Y-A	E	S	A
	Morone chrysops	White bass	Oc	F	?	R
	Morone saxatilis	Striped bass	A	E	S	A
Centrarchidae	*Ambloplites rupestris* ‡	Rock bass	Y	F	S	U
	Enneacanthus gloriosus ‡	Blue-spotted sunfish	Oc	F	?	R
	Lepomis auritus	Redbreast sunfish	Y	F	S	A
	Lepomis cyanellus ‡	Green sunfish	Oc	F	?	R
	Lepomis gibbosus	Pumpkinseed	Y	F	S	A
	Lepomis macrochirus	Bluegill	Y	F	S	A
	Micropterus dolomieui	Smallmouth bass	Y	F	S	U
	Micropterus salmoides	Largemouth bass	Y	F	S	C
	Pomoxis annularis	White crappie	Oc	F	?	R
	Pomoxis nigromaculatus	Black crappie	Y	F	S	U
Percidae	*Etheostoma olmstedi*	Tessellated darter	Y	F	Sp	A
	Perca flavescens	Yellow perch	Y	F	Sp	C
	Percina caprodes	Logperch	Oc	F	O	R
	Percina peltata ‡	Shield darter	Oc	F	?	R

Table 9. (page 4 of 5)

Family	Scientific Name	Common Name	Residency*	Salinity Preference**	Spawning†	Abundance‡
Pomatomidae	*Pomatomus saltatrix*	Bluefish	S	M	0	A
Carangidae	*Caranx hippos*	Crevalle jack	S	M	0	U
	Selene vomer	Lookdown	Oc	M	0	R
	Vomer setapinnis	Atlantic moonfish	Oc	M	0	R
Sparidae	*Stenotomus chrysops*	Scup	Oc	M	0	R
Sciaenidae	*Bairdiella chrysura*	Silver perch	Oc	M	0	R
	Cynoscion regalis	Weakfish	S	M	0	C
	Leiostomus xanthurus	Spot	S	M	0	R
	Menticirrhus saxatilis	Northern kingfish	Oc	M	0	R
	Micropogon undulatus	Atlantic croaker	Oc	M	0	R
Labridae	*Tautoga onitis*	Tautog	Oc	M	0	R
Mugilidae	*Mugil cephalus*	Striped mullet	Oc	M	0	R
	Mugil curema	White mullet	Oc	M	0	R
Uranoscopidae	*Astroscopus guttatus*	Northern stargazer	Oc	M	0	R
Ammodytidae	*Ammodytes americanus*	American sandlance	Oc	M	0	R
Eleotridae	*Dormitator maculatus*	Fat sleeper	Oc	M	0	R
Gobiidae	*Gobiosoma ginsburgi*	Seaboard Goby	Oc	M	0	R
Stromateidae	*Peprilus triacanthus*	Butterfish	Oc	M	0	R
Triglidae	*Prionotus carolinus*	Northern searobin	Oc	M	0	R
	Prionotus evolans	Striped searobin	Oc	M	0	R
Cottidae	*Myoxocephalus aeneus*	Grubby	Oc	M	0	R

Table 9. (page 5 of 5)

Family	Scientific Name	Common Name	Residency*	Salinity Preference**	Spawning†	Abundance‡
Bothidae	*Paralichthys dentatus*	Summer flounder	Oc	M	0	R
	Paralichthys oblongus	Fourspot flounder	Oc	M	0	R
	Scophthalmus aquosus	Windowpane	Oc	M	0	R
Pleuronectidae	*Pseudopleuronectes americanus*	Winter flounder	Oc	M	0	R
Soleidae	*Trinectes maculatus*	Hogchoker	Y	E	S	A
Tetraodontidae	*Sphaeroides maculatus*	Northern puffer	Oc	M	0	R

* Y, year-round or life resident; A, anadromous; C, catadromous; S, seasonal use for nursery; Oc, occasional or infrequent occurrence

** F, freshwater; E, euryhaline or salt-change tolerant; M, marine

† Sp, Spring; S, Summer; F, Fall; W, Winter; O, outside estuarine portion of Hudson River; ?, uncertain spawning location

‡ A, abundant; C, common but less abundant; U, uncommon; R, rare

‡ Specimens not available for positive identification

freshwater from tributaries prevent rapid salinity changes in many parts of the shore zone.

In 1976, Bath et al. listed 111 fish species collected from the Hudson. In another report (Texas Instruments, Inc. et al., 1977), 113 species caught in the Hudson River estuary were tabulated along with their relative abundance, spawning period, salinity preference and the extent of their residency in the estuary (Table 9). Of these species, 22 are listed as abundant, 11 as common, but less abundant, 10 as uncommon and 70 as rare. Of the 33 abundant and common species, 14 are euryhaline, and five are marine (Table 9). Seven commercially important species occur in the Hudson. Another seven are significant to both commercial and sport fisheries. Of the remaining dominant species, six are of concern primarily to sport fishermen and eight are important as forage species.

The most recent (April 1979-April 1980) sampling program in the Lower Hudson was conducted for the New York State Department of Transportation, Westway Project (Lawler, Matusky and Skelly, 1980). Fish and ichthyoplankton data were collected from km 2.9 to km 14.5 in the river channel and interpier zones. Water quality and dissolved oxygen levels were found to be adequate to support aquatic life for most of the year. However, oxygen did drop to stressful levels in the summer. The most abundant species, Atlantic tomcod (70%

of the total trawl catch), were ubiquitous but preferred the main river channel to the pier area. Hogchokers (13% of the total) and weakfish (1.5% of the total) were found almost exclusively in the main river channel. Bay anchovy (1.6% of the total) exhibited no preference and were found throughout the area. Winter flounder, striped bass and white perch (5.9%, 3.6%, and 2.4%, respectively, of the total) were more abundant in the interpier areas over the main channel despite the heavy pollution loads entering the zone.

The only species found in the above study to use this region of the Hudson River extensively for reproduction was the bay anchovy. Other larval forms found in the area included the American sand lance, Atlantic tomcod and winter flounder (in order of relative abundance). The authors concluded, however, that the primary spawning and hatching grounds for these species are outside the study area.

Based on seine collections, the estimated number of species present in the Hudson increases through the spring to a peak in July, then decreases through December (Texas Instruments, Inc. et al., 1977). The spring peak probably reflects the movement of some species into the shore zone from deeper waters and movement into the estuary by seasonal and occasional species. Some marine and freshwater species appear only in summer and early fall. Occasional or seasonal marine species invade the

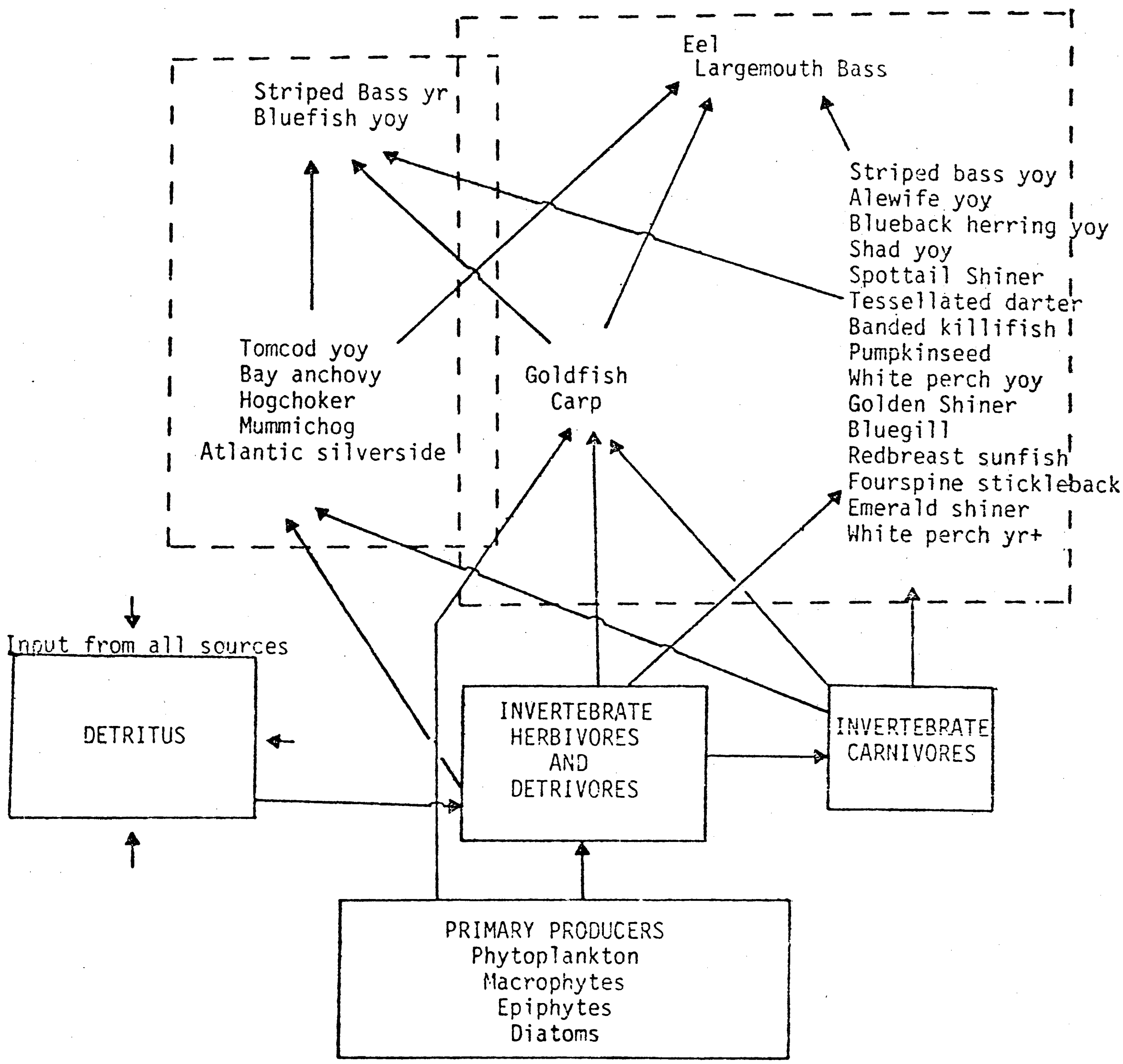


Figure 25. Simplified trophic structure for two fish communities in the shore zone of the Hudson River Estuary (YOY = young of the year; YR = yearling)(From Texas Instruments, Inc., 1977)

lower estuary often to the position of the salt front and provide much of the increase in species number for the lower third of the river (Texas Instruments, Inc. et al., 1977).

Models of trophic structure are complicated by age, seasonal and other changes in the role of a particular species in the community. A simplified trophic structure for two fish communities on the shore zone of the Hudson River estuary was constructed from cluster analysis of daytime seining data during July-September (Texas Instruments, Inc. et al., 1977). The model distinguishes between the lower estuary community in which striped bass and bluefish are the top carnivores and the upper-middle estuary where the American eel and largemouth bass occupy that position (Fig. 25).

Historical trends in the Hudson River fish populations can be viewed only from the perspective of the number of species present, as comparable estimates of abundance are not available. Reasonably comprehensive surveys were conducted in 1936 (Greeley, 1937) and 1965-1975 (Texas Instruments, Inc., 1975). There was no apparent decline in the number of species in the river. The range and intensity of sampling affected the number of species caught. The 1936 and 1973-75 surveys were the most far-ranging geographically and involved the greatest number of samples. Species composition appeared not to have changed dramatically between 1936 and 1975, despite sampling differences. Where changes are apparent, they involve primarily uncommon species. The 1975 survey yielded 87 species, compared with 59 species during 1936. The differences probably originated from the greater sampling effort in 1975, especially in the lower portion of the river.

6.3. A comparison of species composition and abundance in the Lower Bay complex with other estuarine areas

Comparison of fish populations among estuaries is complicated by natural fluctuations in species abundance, physical and chemical differences between estuaries and sampling methods. Three areas were selected for comparison: the Delaware Bay (Daiber and Smith, 1971), the Great Bay-Mullica River estuary of New Jersey (Ichthyological Associates, Inc., 1974g) and Narragansett Bay (Oviatt and Nixon, 1973). To compare densities between estuaries, an approximation of the area sampled was computed by multiplying the length of the tow (either stated by the authors or boat speed times duration of trawl) times the width of the footrope (Table 10). Comparisons of the number of fish per square meter between areas must then include consideration of mesh size differences.

Given these limitations, there do appear to be differences in fish density among the four estuaries

(Table 10). The Lower Bay had a density (29 fish/1000 meter^2) lower than that of the Great Bay-Mullica River estuary (38 fish/1000 meter^2) for collections where mesh sizes were equivalent (0.5 in.). Where mesh sizes were larger, the densities were lower: 23/1000 meter^2 in Narragansett Bay (1 in. mesh) and 14/1000 meter^2 in the Delaware Bay (2 in. mesh).

Samples taken in the Lower Bay yielded far fewer species (10 species/1000 meter^2) than did those taken in Little Egg Inlet (26 species/1000 meter^2) where collections from both areas were made with the same mesh size otter trawls (Table 10). Shannon Weiner diversity indices, H_1, and measures of evenness were similar for both areas: $H_1 = 2.7$, $E = 0.7$ (Lower Bay); $H_1 = 2.5$, $E = 0.6$ (Great Bay-Mullica River). Bay anchovy data were not included for these calculations as schools of these fish were captured in densities close to an order of magnitude greater than any other species. The abundance of particular species also differed among estuaries (Table 10). The herrings (Blueback herring, alewife, menhaden and shad) were about ten times more abundant in the Lower Bay than in each of the other areas. Bluefish were also about ten times more numerous in the Lower Bay. Several species were absent from Lower Bay Trawls but ranked among the 15 most abundant in one of the three other estuaries. These fish included the hogchoker, tomcod, northern puffer, oyster toadfish, clearnose skate

Table 10. A comparison of fish populations of the Lower Bay with three other local estuaries.
A) The 15 most abundant species of the Lower Bay and their occurrence in the other estuaries.

	Lower Bay[1]					Narragansett Bay[2]					Great Bay-Mullica River[3]					Delaware Bay[4]				
SPECIES	RANK	#/T	#/1000m²	% TOT	% OCC	RANK	#/T	#/1000m²	% TOT	% OCC	RANK	#/T	#/1000m²	% TOT	% OCC	RANK	#/T	#/1000m²	% TOT	% OCC
Bay anchovy	1	76	17	58	27						1	76	31	79	44	37	0.1	0.004	0.03	11
Silver anchovy	2	11	2.4	8.4	8.7						59	<0.1	0.001	<0.1	0.2					
Blueback herring	3	9.7	2.2	7.4	30	13	0.9	0.23	1.0		19	0.2	0.08	0.2	2.7	31	0.3	0.01	0.07	8.6
Winter flounder	4	5.4	1.2	4.1	53	1	33	8.3	36		6	1.1	0.44	1.1	31	21	1.7	0.06	0.4	23
Alewife	5	5.0	1.1	3.8	32	18	0.4	0.10	0.4		13	0.2	0.08	0.2	7.1	27	0.5	0.02	0.1	23
Red hake	6	3.1	0.69	2.3	20	7	2.7	0.68	2.9		18	0.2	0.08	0.2	7.1	22	1.7	0.06	0.4	23
Menhaden	7	2.6	0.58	2.0	26	24	0.2	0.05	0.2		12	0.2	0.08	0.3	3.7	35	0.2	0.007	0.05	11
Shad	8	2.4	0.53	2.0	24						40	0.02	0.008	0.03	1.2					
Weakfish	9	2.3	0.51	1.8	28	5	7.1	1.8	7.7		4	1.4	0.56	1.4	13	1	128	4.8	34.0	71
Windowpane	10	2.0	0.44	1.5	35	2	13	3.2	14		10	0.4	0.16	0.4	18	4	20	0.72	5.2	91
Butterfish	11	1.7	0.38	1.3	21	4	8.6	2.2	9.4		28	0.09	0.04	0.09	9.0	17	2.3	0.09	0.6	46
Atlantic silverside	12	1.5	0.33	1.1	22	27	0.07	0.02	0.08		5	1.2	0.48	1.3	13					
Summer flounder	13	1.2	0.26	0.9	21	31	0.03	0.008	0.03		16	0.2	0.08	0.2	10	25	1.1	0.04	0.3	37
Silver hake	14	1.1	0.24	0.8	21	12	1.0	0.25	1.1		43	0.02	0.08	0.2	1.2	26	0.8	0.03	0.2	20
Bluefish	15	1.1	0.24	0.8	16	30	0.03	0.008	0.03		31	0.06	0.02	0.07	4.4	38	0.1	0.004	0.03	11

Table 10. A comparison of fish populations of the Lower Bay with three other local estuaries.
B) Species which rank among the top 15 in at least one of the other estuaries, but not in the Lower Bay.

SPECIES	Lower Bay					Narragansett Bay					Great Bay-Mullica River					Delaware Bay				
	RANK	#/T	#/1000m²	% TOT	% OCC	RANK	#/T	#/1000m²	% TOT	% OCC	RANK	#/T	#/1000m²	% TOT	% OCC	RANK	#/T	#/1000m²	% TOT	% OCC
Scup	16	0.9	0.2	0.7	11	3	9.1	2.3	9.8		32	0.06	0.02	0.06	3.4	3	37	1.3	9.8	40
Little skate	18	0.7	0.16	0.5	0.6	10	1.2	0.3	1.4		59	<0.01	<0.01	<0.01	0.2	24	1.5	0.06	0.4	34
Spotted hake	19	0.6	0.13	0.5	11						29	0.07	0.03	0.08	3.2	8	7.6	0.28	2.0	51
Atlantic herring	20	0.6	0.13	0.5	17	11	1.1	0.28	1.2		11	0.3	0.12	0.3	7.3	13	2.5	0.09	0.7	34
White hake	21	0.4	0.09	0.3	2.5						17	0.2	0.08	0.2	3.7					
Striped searobin	22	0.3	0.07	0.2	5.6	8	1.8	0.45	2.0		24	0.1	0.04	0.1	3.9	7	7.9	0.29	2.1	60
Tautog	25	0.2	0.04	0.1	8.1	14	0.9	0.23	0.9		27	0.09	0.04	0.1	7.1	43	0.06	<0.01	0.02	5.7
Cunner	26	0.1	0.02	0.1	1.2	9	1.8	0.45	1.9		45	0.01	<0.01	0.02	1.5					
Northern searobin	29	0.07	0.02	0.05	2.5	6	5.6	1.4	6.0		49	0.02	<0.01	0.01	1.0	5	9.8	0.36	2.6	60
Silver perch	30	0.06	0.01	0.05	2.5						8	0.7	0.28	0.7	9.8	20	1.9	0.07	0.5	34
Spot	31	0.04	<0.01	0.03	2.5						2	7.8	3.1	8.1	22	40	0.1	<0.01	0.04	2.8
Longhorn sculpin	38	0.02	<0.01	0.01	1.2	22	0.3	0.08	0.3		47	0.01	<0.01	0.02	1.2	9	7.2	0.27	1.9	31
White perch	46	<0.01	<0.01	<0.01	0.6	34	0.02	<0.01	0.02		3	2.2	0.88	2.3	13	28	0.5	0.02	0.1	8.6

Table 10. A comparison of fish populations of the Lower Bay with three other local estuaries.
C) Species present in at least one of the other estuaries, but absent in the Lower Bay.

SPECIES	Lower Bay					Narragansett Bay					Great Bay-Mullica River					Delaware Bay				
	RANK	#/T	#/1000m²	% TOT	% OCC	RANK	#/T	#/1000m²	% TOT	% OCC	RANK	#/T	#/1000m²	% TOT	% OCC	RANK	#/T	#/1000m²	% TOT	% OCC
Hogchoker						35	0.02	<0.01	0.02		7	0.8	0.32	0.8		2	112	4.2	30	57
Tomcod						15	0.7	0.18	0.8											
Northern puffer						17	0.4	0.1	0.5		41	0.02	<0.01	0.02	1.0	12	2.9	0.11	0.8	49
Oyster toadfish						19	0.3	0.08	0.4		20	0.2	0.08	0.2	9.0	14	2.5	0.09	0.7	34
Clearnose skate											59	<0.01	<0.01	<0.01	0.2	15	2.4	0.09	0.6	46
Black drum																10	3.2	0.12	0.8	29
Four spot flounder						21	0.3		0.3											
Sea raven						37	0.01		0.01											
Orange filefish						44	0.01	<0.01	0.01		59	<0.01	<0.01	<0.01	0.2	32	.2	<0.01	0.06	11
Ocean pout						20	0.3	0.08	0.4							36	.2	<0.01	0.05	8.6
Bullnose ray											46	0.01	<0.01	0.02	1.2	19	2.0	<0.07	0.5	14
Striped burrfish											39	0.02	<0.01	0.03	1.7	44	.03	<0.01	<0.01	2.8
Striped cusk eel											59	<0.01	<0.01	<0.01	0.2					
Conger eel											59	<0.01	< .01	<0.01	0.2	44	.03	<0.01	<0.01	2.8
Striped mullet											59	<0.01	< .01	< .01	0.2	44	.03	<0.01	<0.01	2.8

Table 10. A comparison of fish populations of the Lower Bay with three other local estuaries.
D) Species present in the Lower Bay, but absent in the other estuaries.

	Lower Bay					Narragansett Bay					Great Bay-Mullica River					Delaware Bay				
SPECIES	RANK	#/T	#/1000m²	% TOT	% OCC	RANK	#/T	#/1000m²	% TOT	% OCC	RANK	#/T	#/1000m²	% TOT	% OCC	RANK	#/T	#/1000m²	% TOT	% OCC
Spotfin butterflyfish	40	<0.01	<0.01	<0.01	0.6															
Gulf stream flounder	41	<0.01	<0.01	<0.01	0.6															
Shorthorn sculpin	48	<0.01	<0.01	<0.01	0.6															
TOTAL # SPECIES			49					44					64					51		
TOTAL # INDIVIDUALS			21150					9301					39432					13221		
TOTAL # TRAWLS			161					101					410					35		
TOTAL #/TRAWL			131					92					96					378		
GEAR																				
FOOTROPE (FT)			30	(9.1m)				30	(9.1m)				19	(5.8m)				40	(12.2m)	
COD END MESH (IN)			.5	(1.3cm)				1	(2.5cm)				.5	(1.3cm)				2	(5cm)	
TOW LENGTH (FT)			~5300	(500m)				~1500					~2500					~7300	(2200m)	
(MIN)			15					10					10					30		
*AREA SAMPLED (FT^2)/T			~48400	(~4500m²)				43000	(4000m²)				26900	(2500m²)				(291,700)	(27,000m)	
TOT #/AREA			0.029					0.023					0.038					0.014		
TOT # SP/AREA SAMPLED			11					11					26					1.9		

*(Footrope length) x (Tow length)

1. From the data of Wilk et al. (1977)
2. From the data of Oviatt and Nixon (1973)
3. From the data of Ichthyological Associates, Inc. (1974g)
4. From the data of Daiber and Smith (1971)

and black drum. Others not found in the Lower Bay but present in relatively low numbers in the other regions were orange filefish, ocean pout, bullnose ray, striped burrfish, striped cusk eel, conger eel, and striped mullet. Interestingly, more than half of the species absent from the Lower Bay trawls are bottom-feeders. Furthermore, relative to the number of non-bottom-feeding fish, the Lower Bay contains fewer bottom-feeders than either the Delaware Bay or Narragansett Bay. (This relationship was found to be highly significant at the 0.01 level by a 2-x-2 contingency test.) This apparent paucity of bottom-feeders may be a reflection of the physico-chemical environment or the depauperate nature of the bottom community. The densities of other species in the Lower Bay are similar to those of one or more of the other estuaries.

The mean density of fish in the Arthur Kill-Hackensack River ($2.7/1000m^2$) was over ten times less than that of Lower Bay (Table 6) and ranged from 0.6 fish/1000^2 near Kearny to 6.1 in the Upper Hackensack. Diversity was also extremely low in this area. The number of species captured in trawl collections averaged only 6.7 vs. 49 in the Lower Bay and ranged from a low of one species to 13.

6.4. Major species

6.4.1. Bay anchovy

The bay anchovy (*Anchoa mitchilli*) was the most abundant species reported by Wilk et al. (1977) in the Lower Bay complex (inclusive of Sandy Hook Bay and Raritan Bay), representing 76% of the mean yearly catch/trawl (Table 4). Bay anchovy were found in the Lower Hudson River, representing only 2% of the total trawl catch (Lawler, Matusky and Skelly, 1980). No adult bay anchovies were found in Newark Bay, the Passaic or Hackensack Rivers. The seasonal distribution of the bay anchovy appears to be governed both by its migratory reproductive behavior and the availability of food. Spawning generally occurs in late May through early August (Texas Instruments, Inc., 1976). *Anchoa mitchilli* eggs were observed in May and June in the Arthur Kill and Hackensack River (Ichthyological Associates, Inc., 1974a,b,e, 1976), in the Liberty State Park area (Texas Instruments, Inc., 1976), in the lower Hudson River (Lawler, Matusky and Skelly, 1980), and in the Sandy Hook estuary (Croker, 1965). Bay anchovy eggs dominated the egg catch in the Lower Hudson (90% of the total eggs collected) and the larvae ranked second (27% of the total). They are the only species that use the Lower Hudson extensively for spawning, embryonic development and hatching (Lawler, Matusky and Skelly, 1980). Larvae and juveniles taken by seine and trawl occurred in the Arthur Kill almost exclusively in June, July and early August (Table 7, Fig. 23)(Ichthyological Associates, Inc., 1974a,b, 1976). As adults were virtually absent from the Lower Bay in the spring (Mar. 21-June 21), it seems likely that they migrate to the more inland and littoral areas for spawning in the spring. Larvae and juveniles spend the early summer in these areas and return to the Lower Bay in the late summer and early fall. In fact, bay anchovy are most prevalent in the Lower Hudson from June through early September (Lawler, Matusky and Skelly, 1980), but peak in the Lower Bay in September and October (Fig. 26). In the winter months through March, _A. mitchilli_ densities were very low throughout the area, suggesting that they may migrate offshore.

The distribution of _A. mitchilli_ within the Lower Bay may be related to its preference for "deeper water stations" (Derickson and Price, 1973, pg. 560) and its role as a planktonic filter feeder. During the fall peak in abundance, seven of the twenty sampling grids contained 97% of the total abundance of bay anchovies (Fig. 26). Five of these seven areas were within the deeper regions of the bay (the Raritan Bay shipping channel and the West Bank dredge hole).

The three areas (Fig. 26) of peak abundance in September 1974, coincided with the areas of maximum total

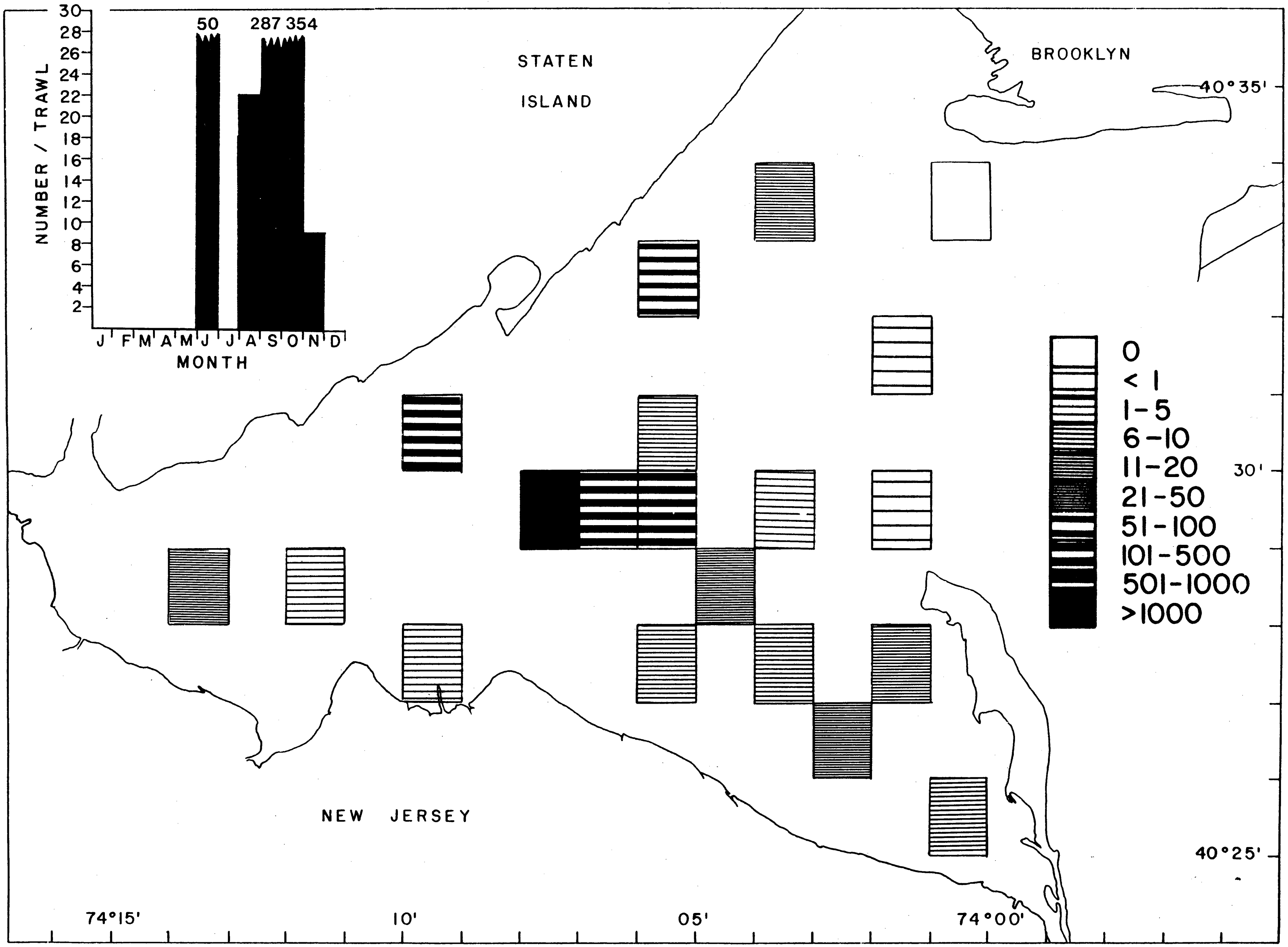


Figure 26. Seasonal and spatial distribution of bay anchovy (*Anchoa mitchilli*) in the Lower Bay complex. (From the data of Wilk et al., 1977)

photosynthetic capacity (O'Reilly et al., 1976). Similarly, the peak density of bay anchovies in October 1974, also fell within the area of greatest photosynthetic capacity (Fig. 27). As zooplankton have been reported to cluster in areas of high primary productivity, planktivorous fish may be thus attracted to the same regions.

6.4.2. The Herrings

Blueback herring (Alosa aestivalis), alewife (A. pseudoharengus) and shad (A. sapidissima) collectively represented 13% of the mean annual catch in the Lower Bay complex in the survey of Wilk et al. (1977). In the Arthur Kill, Newark Bay and lower Hackensack River, blueback herring were among the four most abundant species ranging from 3% to 25% of the total number of impinged fish collected. Alewife ranked among the six most abundant fish or 2% to 10% of total. Shad were less common, representing between 0.1% and 1% of the total number of impinged individuals. In both areas, the three species were in most cases and irrespective of sampling method, found in the following proportions: 65 (A. aestivalis): 29 (A. pseudoharengus): 6 (A. sapidissima).

The herrings are most common in the Lower Bay in the late fall and winter months and occur in smaller numbers in April and May. They are virtually absent from the

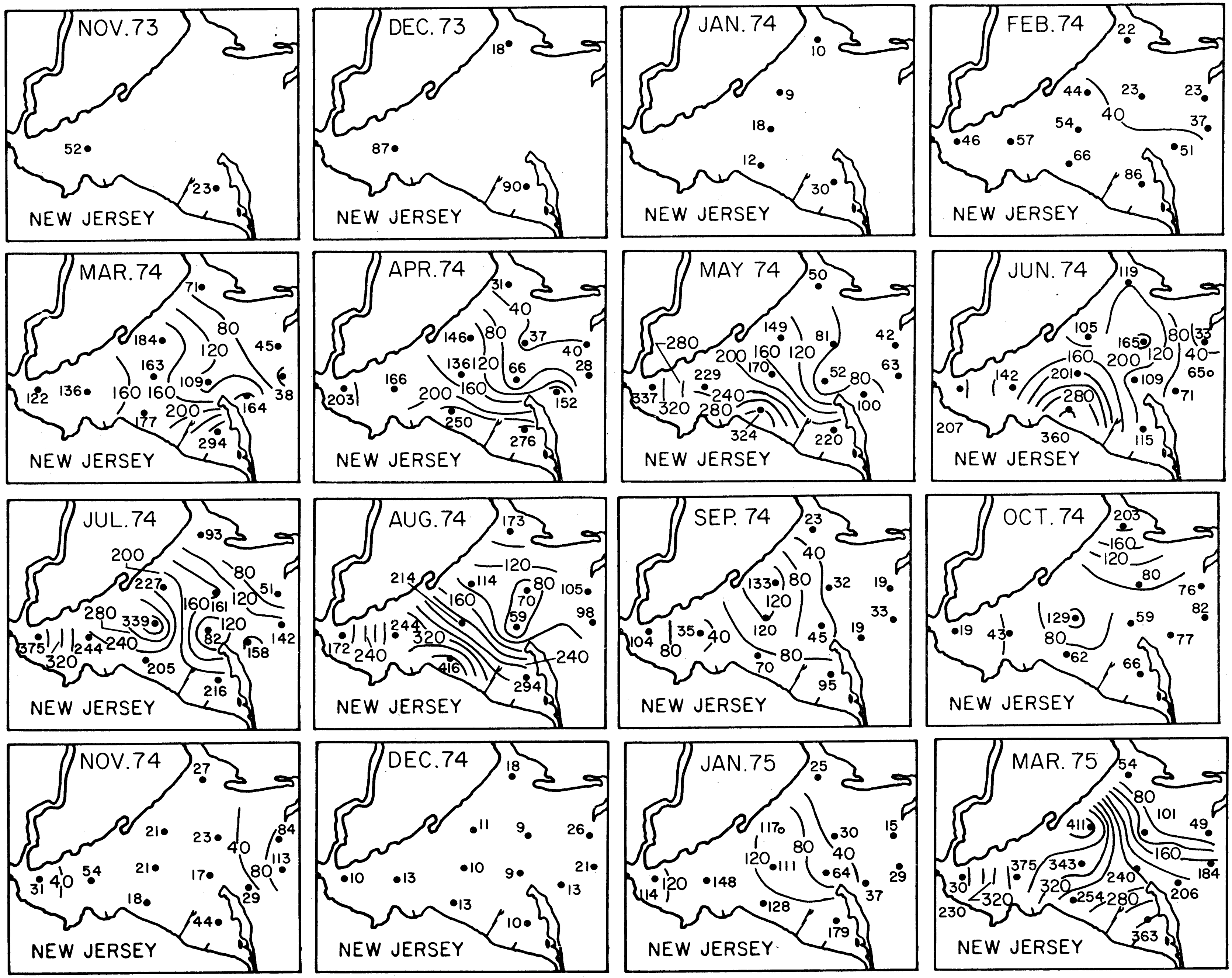


Figure 27. Total photosynthetic capacity ($mgCm^{-3}hr^{-1}$) of surface water in the Lower Bay complex. (From O'Reilly et al., 1976)

area from late June through late September (Figs. 28, 29, 30). The seasonal distribution is similar in the Arthur Kill-Hackensack River estuary (Fig. 24). This pattern is probably a reflection of the movement of herrings in April and May through these areas to upper less saline spawning grounds. American shad (Alosa sapidissima) are abundant in the Hudson River. Adults enter the estuary in late March or early April, depending on water temperature, and spawn though June (Texas Instruments, Inc. et al., 1977). The primary spawning areas are between Hyde Park (km 123) and Catskill (km 171)(Texas Instruments, Inc. et al., 1977). After spawning, the adults return to the ocean. The fall appearance of shad and other herrings in the Lower Bay complex is due to the seaward migration of juveniles. Most have left the estuary by mid-November. The herrings apparently do not spawn in and around the Lower Bay complex or Arthur Kill-Hackensack estuary. Ichthyoplankton collections by Croker (1965) in the Sandy Hook estuary, Ichthyological Associates, Inc. (1974) in the Arthur Kill and Hackensack River and Texas Instruments, Inc. et al., (1977) in the Upper Bay, indicated few or no eggs and larvae of Alosa. The absence of herrings from the upper Hackensack, a potential spawning and nursery area, may be a result of the high summer temperature and low dissolved oxygen.

During peak abundance (January, February) in the Lower Bay complex, the herrings are concentrated in Sandy

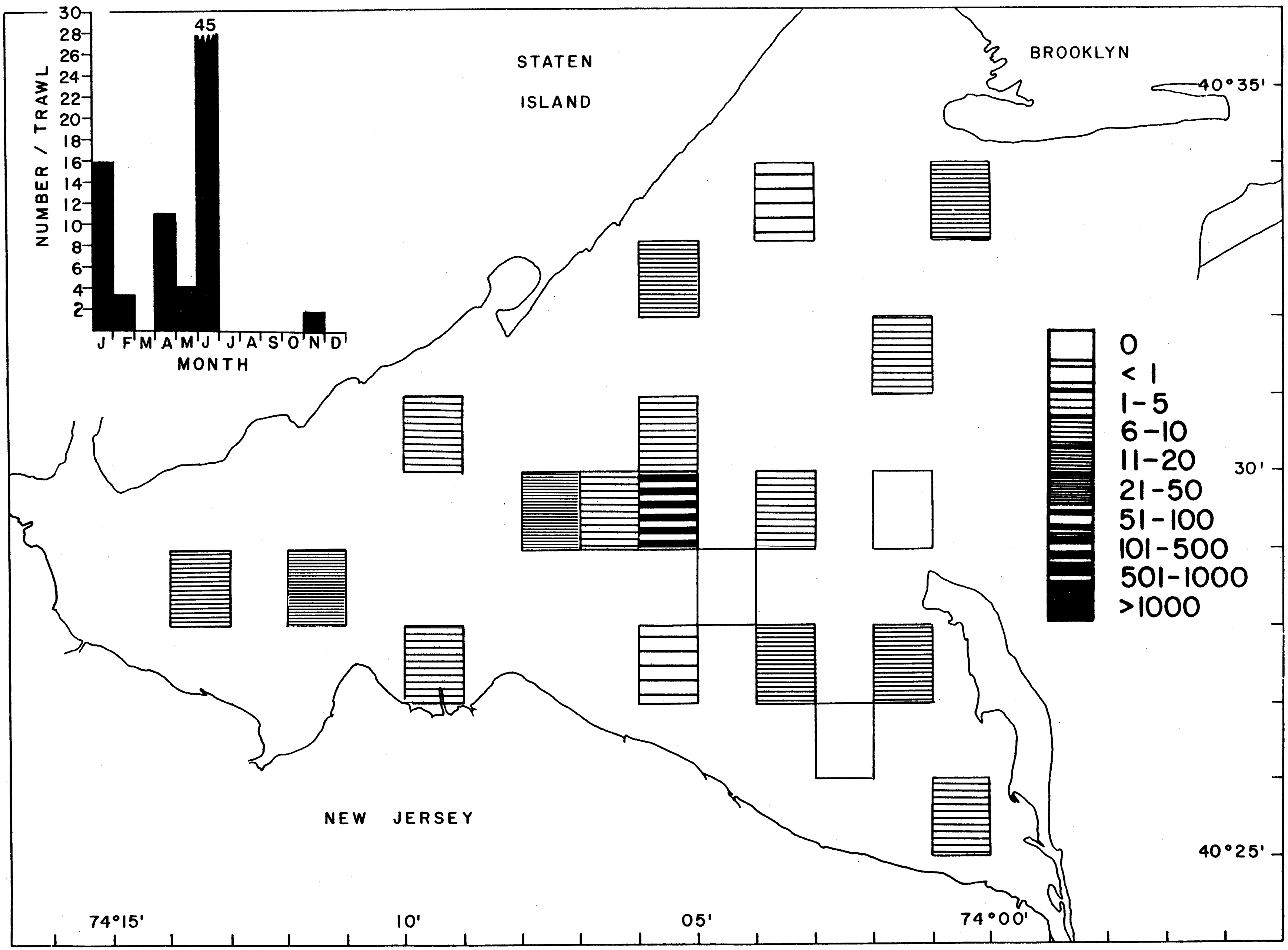


Figure 28. Seasonal and spatial distribution of blueback herrings (*Alosa aestivalis*) in the Lower Bay complex. (From the data of Wilk et al., 1977)

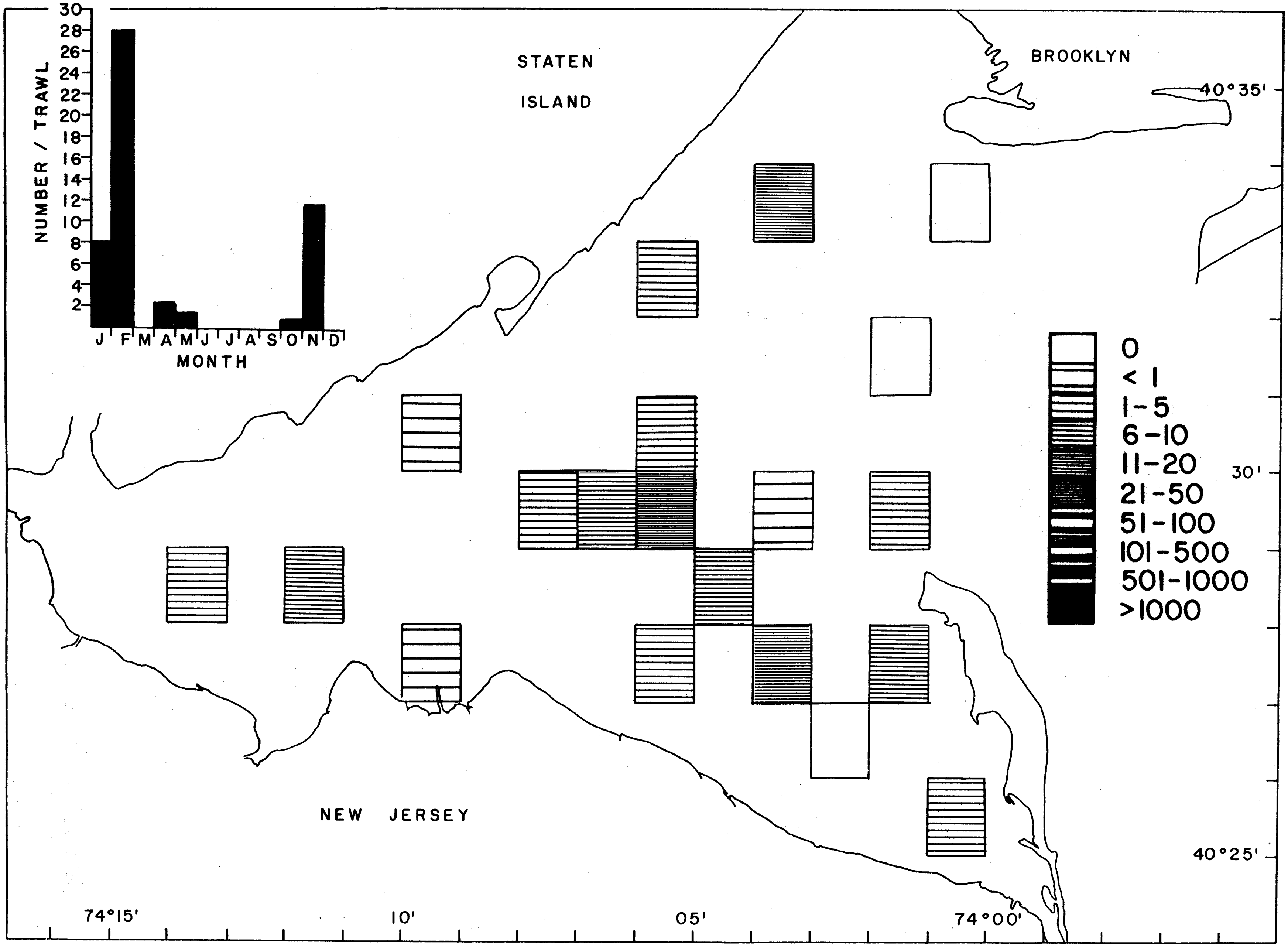


Figure 29. Seasonal and spatial distribution of alewife (*Alosa pseudoharengus*) in the Lower Bay complex. (From the data of Wilk et al., 1977)

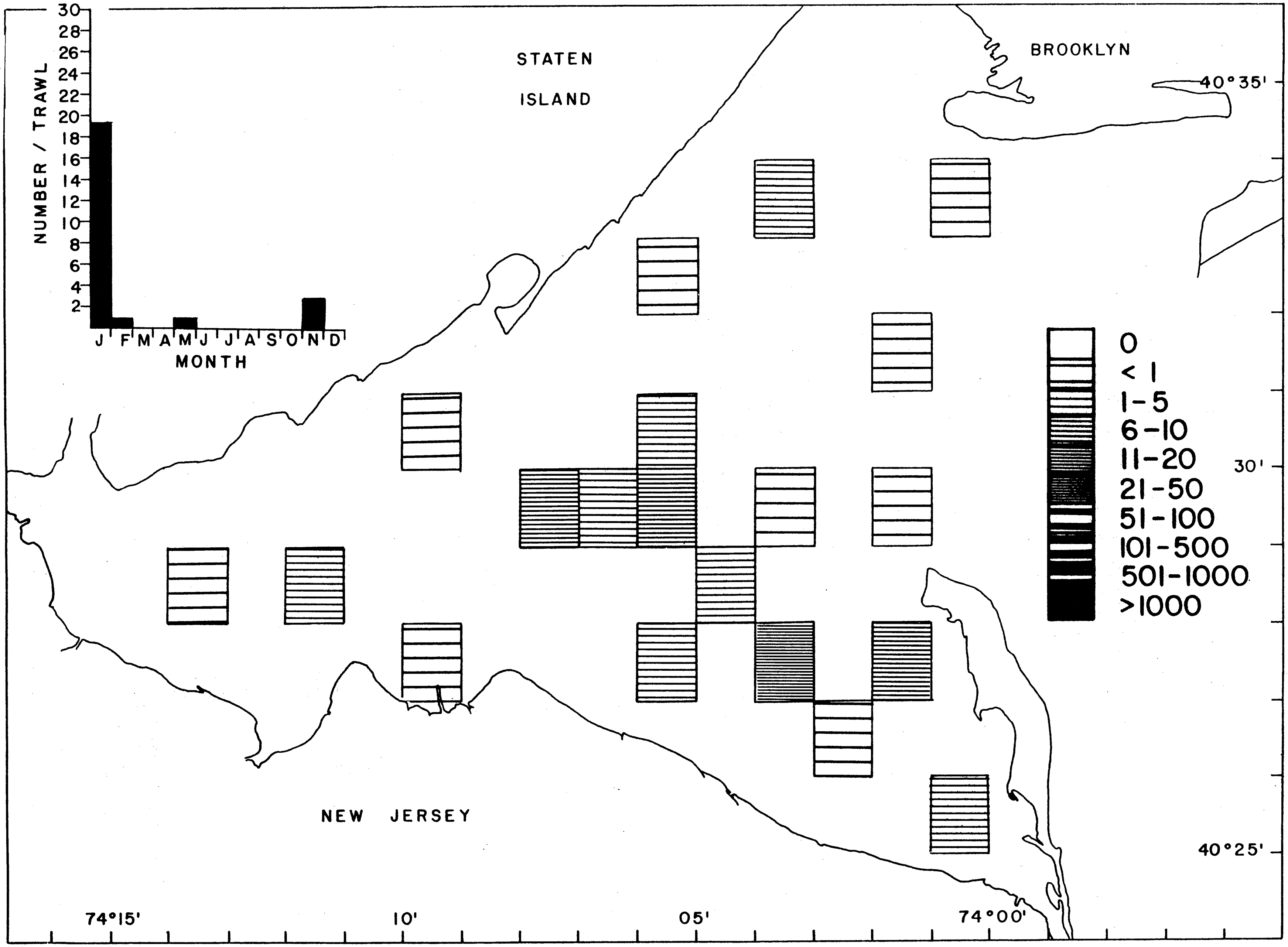


Figure 30. Seasonal and spatial distribution of shad (*Alosa sapidissima*) in the Lower Bay complex. (From the data of Wilk et al., 1977)

Hook Bay and central Lower Bay (Figs. 28, 29, 30). The apparent preference for Sandy Hook Bay in the winter season may be correlated to food availability. Primary productivity is higher in this sector relative to the entire Bay complex (O'Reilly et al., 1976) (Fig. 27) and consequently secondary productivity may also be elevated. The concentration of herrings in the central Lower Bay may be related to the major flux of N.Y. Bight water into the Lower Bay complex through the central Lower Bay (Fig. 2). In January and February when zooplankton abundance inside the Bay is low, water from the N.Y. Bight may be a source of nutrition for these herrings. Though all the herrings are or have been of commercial value, the American shad in particular is a highly desirable food fish and contributes heavily to the Atlantic coast commercial fishery. Annual landings have, however, fluctuated greatly and have been far below the 45,000,000 pounds landed near the turn of the century (Saila and Pratt, 1971). In 1975, the shad catch along the Atlantic coast was 2,567,000 pounds valued at 853,000 dollars (Table 11). During 1965-74, the middle Atlantic district (NY, NJ and DE) produced less than 10% of the total Atlantic Coast catch.

The Passaic and Hackensack Rivers and Newark Bay supported an extensive shad fishery in the early and mid-1800s (Esser, 1982). After a second period of high production (3,809,000 lb), production dropped to about

Table 11. Commercial landings (thousands of pounds) and value to fishermen (thousands of dollars) of American shad reported along Atlantic coast since 1965.

Region	1965	1966	1967	1968	1969	1970	1971	1972	1973*	1974**	1975**
Hudson River †											
Pounds	238	116	176	254	243	232	171	289	252	232	233
Dollars	36	15	29	46	32	33	33	58	83	63	93
New York ‡											
Pounds	133	81	113	126	136	106	73	103	157	164	197
Dollars	22	11	18	22	20	13	16	19	51	42	79
Mid-Atlantic ‡											
Pounds	635	379	387	379	342	314	222	375	308	293	338
Dollars	78	42	54	59	44	41	43	54	79	69	111
New England ‡											
Pounds	380	279	754	218	201	186	283	264	261	258	206
Dollars	76	54	52	62	59	55	68	76	73	78	62
Chesapeake ‡											
Pounds	4,298	3,564	3,005	3,508	3,540	5,134	2,473	3,014	3,033	1,790	1,318
Dollars	457	351	311	267	291	421	259	343	471	276	352
So. Atlantic ‡											
Pounds	2,379	1,736	1,562	2,052	1,904	1,851	1,452	1,091	685	817	705
Dollars	484	371	283	384	439	415	340	296	215	267	328
TOTAL											
Pounds	7,692	5,958	5,708	6,157	5,987	7,485	4,430	4,744	4,287	3,158	2,567
Dollars	1,095	818	700	772	833	932	710	769	838	690	853

* From USNOAA, 1975; Current Fisheries Statistics, District Summaries
** From USNOAA, 1976; Current Fisheries Statistics
† Provided by Fred Blossum (NMFS)
‡ From USNOAA, 1967-74; Fisheries Statistics of the United States

200,000 lb per year during the early 1970s (Esser, 1982). The Hudson River was also among the most important contributors to the shad fishery. In the late 1800s and early 1900s, catches averaged several million pounds (Table 12). The catch subsequently declined to an average of several hundred thousand pounds. By 1944, the catch had increased to almost 4,000,000 pounds. During World War II and immediately after, overfishing contributed to the decline in the late 1940s (Texas Instruments, Inc. et al., 1977). The shad catch of the Hudson River has not exceeded 300,000 pounds since 1965 (Texas Instruments, Inc. et al., 1977). Many factors have been cited as contributing to the decline of shad populations including various physical barriers and pollution, yet most studies agree that shad abundance has been most influenced by fishing effort (Talbot, 1954; Burdick, 1954; Klauda et al., 1977).

Blueback herring and alewives are generally cited together in commercial fishery statistics. They are used primarily for industrial purposes due to their boniness and small size. Most are landed south of New Jersey and only 11,000 pounds ($500) were caught in the Middle Atlantic district (Texas Instruments, Inc. et al., 1977)(Table 13). Landings have not exceeded 300,000 pounds in the middle Atlantic district since 1966 when purse seiners took 4,200,000 pounds seeking substitutes for declining menhaden stocks. Processing plants could

Table 12. The Hudson River shad fishery, 1896-1974 (from Texas Instruments, Inc., 1975)

Year	NEW YORK Pounds	NEW YORK Value	NEW JERSEY Pounds	NEW JERSEY Value	TOTAL Pounds	TOTAL Value
1896	1,681,371	$ 58,921	675,595	$ 24,316	2,356,966	$ 83,237
1897	1,506,142	49,353	529,920	17,934	2,036,062	67,287
1898	1,534,877	50,875	606,423	18,510	2,141,300	69,385
1901	3,202,302	100,762	577,260	21,647	3,779,562	122,409
1904	402,496	28,896	201,800	17,758	604,296	46,654
1910	506,136	51,715	406,880	49,109	913,016	100,824
1915	48,654	5,969	20,104	2,674	63,768	8,643
1916	32,923	4,540	7,250	925	40,173	5,465
1917	38,344	5,810	5,040	720	43,384	6,530
1918	220,602	44,784	14,000	3,400	234,602	48,184
1919	301,306	60,690	73,668	23,034	374,974	83,724
1920	157,715	43,882	42,129	12,427	199,844	56,309
1921	104,883	24,329	25,920	6,294	130,803	30,623
1922	128,324	27,451	46,862	12,255	175,186	39,706
1923	97,863	22,644	23,865	6,000	121,728	28,644
1924	72,519	17,619	21,850	5,485	94,369	23,104
1925	110,359	24,030	13,975	2,400	124,334	26,430
1926	219,183	47,175	46,237	6,300	265,420	53,475
1927	299,693	56,950	58,362	6,700	358,055	63,650
1928	194,181	32,689	52,050	10,460	246,231	43,149
1929	157,895	25,801	38,850	4,882	196,745	30,633
1930	165,004	27,688	41,500	5,684	206,504	33,372
1931	342,611	40,840	72,000	8,941	414,611	49,781
1932	397,754	40,087	132,000	10,762	529,754	50,849
1933	347,656	28,156	171,024	12,573	518,680	40,729
1934	314,200	24,764	123,800	11,310	438,000	36,074
1935	453,300	38,151	394,100	32,485	847,400	70,636
1936	834,400	52,808	1,633,500	117,379	2,467,900	170,187
1937	967,000	73,191	1,756,200	139,595	2,723,200	212,786
1938	972,500	53,989	1,494,500	118,486	2,467,000	172,475
1939	1,516,400	66,319	1,754,300	98,943	3,270,700	165,262
1940	1,297,700	66,703	1,816,700	116,074	3,114,400	182,777
1941	1,341,000	91,041	1,792,500	107,589	3,133,500	198,630
1942	1,294,800	76,025	1,891,100	128,963	3,185,900	204,988
1943	1,640,000	155,800	1,585,350	201,556	3,225,350	357,356
1944	1,651,200	90,445	2,158,200	134,535	3,809,400	224,980
1945	2,091,300	275,962	1,385,900	228,161	3,477,200	304,123
1946	1,446,900	218,546	1,525,243	240,638	2,972,143	459,184
1947	957,400	95,527	1,024,392	161,447	1,981,792	256,974
1948	1,121,600	146,679	1,232,800	185,867	2,354,400	332,546
1949	748,800	113,305	978,570	173,120	1,727,370	286,425
1950	413,600	62,012	595,300	118,137	1,008,900	180,149
1951	413,675	62,675	350,700	85,690	764,375	148,365
1952	487,600	59,150	589,500	87,552	1,077,100	146,702
1953	465,000	62,744	473,722	92,744	938,722	155,488
1954	584,580	67,882	664,706	96,936	1,249,286	164,818
1955	503,696	60,562	1,006,644	137,962	1,510,340	198,524
1956	579,734	48,776	1,101,432	109,446	1,681,166	158,222
1957	468,205	42,805	1,029,475	89,574	1,497,680	132,379
1958	433,463	41,218	612,302	75,034	1,045,765	116,252
1959	492,468	47,447	678,744	77,532	1,171,212	124,979
1960	273,936	38,407	449,636	69,693	732,572	108,100
1961	236,445	33,111	352,544	65,220	588,989	98,331
1962	218,149	28,348	309,531	49,525	527,680	77,873
1963	132,564	25,807	215,454	54,018	348,018	79,825
1964	78,084	16,993	103,781	20,720	181,865	37,713
1965	119,958	20,300	117,563	15,629	237,521	35,929
1966	67,908	9,346	48,424	5,811	116,332	15,157
1967	76,491	11,550	99,867	19,976	176,358	31,526
1968	113,100	19,896	141,272	26,079	254,372	45,975
1969	122,676	17,789	120,428	14,451	243,104	32,240
1970	95,900	12,176	135,671	19,620	231,571	31,796
1971	70,038	15,361	100,760	18,137	170,798	33,498
1972	93,660	16,859	195,100	39,020	268,760	55,879
1973	153,357	50,600	98,248	32,845	251,605	83,454
1974	163,690	44,197	67,941	19,610	231,631	63,807

not even be supported by that catch. As a result, the commercial fishery in New York is virtually nonexistent (McHugh, 1972).

Menhaden (*Brevoortia tyrannus*) ranked seventh in the total catch of the Lower Bay complex (Wilk et al., 1977), averaging 2.6/10-min tow or 2.0% of the total catch. In the Arthur Kill, *B. tyrannus* ranked seventh and eighth at two stations averaging 0.015 and 0.016/1000m^3 or 2.0% and 0.8% of the total catch (Table 5).

Menhaden spawn chiefly at sea (Scotton et al., 1973). However, their eggs and larvae have been observed in the Sandy Hook estuary in May-June and November-December respectively (Croker, 1965). Larvae were reported from the Arthur Kill and Hackensack River in late September and October (Table 7) and in the Upper Bay in November and December (Texas Instruments, Inc. et al., 1977).

Trawl collections of menhaden in the Lower Bay complex (Wilk et al., 1977) revealed a peak abundance in January, and relatively low concentrations in May-June and October-November. Menhaden were absent from the Arthur Kill-Hackensack River trawl collections of 1973 (Ichthyological Associates, 1974a,b,c,d,e,f), but did appear in impingement collections (Table 5) in the Arthur Kill. There, peak numbers occurred in July and smaller densities in February-March and September to November. The May, June and July appearance of *B. tyrannus* coincides with their reported spawning period

Table 13. Commercial landings (thousands of pounds) and value to fishermen (thousands of dollars) of blueback herring and alewife reported along Atlantic Coast since 1965.

Region	1965	1966	1967	1968	1969	1970	1971	1972	1973*	1974**	1975**
Hudson River†											
Pounds											
Dollars	--	--	--	--	--	--	--	--	--	--	--
New York ‡											
Pounds	24	4,188	4	7	9	11	--	1.0	22	1.0	0.3
Dollars	<0.5	63	<0.5	<0.5	1	<0.5	--	<0.5	<0.5	<0.1	<0.1
Mid-Atlantic ‡											
Pounds	46	4,200	13	15	14	19	10	15	30	12	11
Dollars	2	63	<0.5	<0.5	1	1	<0.5	<0.5	<0.5	<0.5	<0.5
New England ‡											
Pounds	10,400	8,693	7,323	2,643	2,132	3,076	2,279	4,204	3,437	3,478	5,432
Dollars	129	119	114	51	50	63	54	83	106	121	156
Chesapeake ‡											
Pounds	38,292	29,968	30,444	36,282	33,904	21,110	13,096	12,141	11,300	14,730	12,055
Dollars	551	514	611	597	677	44	294	316	346	460	424
So. Atlantic ‡											
Pounds	15,607	15,336	21,288	18,345	21,737	11,621	13,440	11,534	8,359	6,331	6,024
Dollars	189	190	374	283	334	196	215	202	226	254	226
TOTAL											
Pounds	64,345	58,197	59,968	57,285	57,285	35,826	28,825	27,894	23,126	24,551	23,522
Dollars	871	886	1,099	931	1,062	304	563	601	678	836	807

* From USNOAA, 1975; Current Fisheries Statistics, District Summaries.
**From USNOAA, 1976; Current Fisheries Statistics.
† Not available
‡ From USNOAA, 1967-74; Fisheries Statistics of the United States.

(Perlmutter, 1939) and the appearance of eggs in the Sandy Hook estuary (Croker, 1965). The fall population of menhaden are most likely juveniles leaving the estuary to begin the migration south.

The fall and winter distribution of the menhaden is concentrated in the central Lower Bay and entrance to Sandy Hook Bay (Fig. 31). Similar to the other herrings, this distribution also coincides with areas of major water movement from the N.Y. Bight Apex into the Bay. During this season, Malone (1977b) has stated that maximum chlorophyll a concentration occurs in the bottom layer of the Lower Bay having been transported from the Apex into the estuary by the undercurrent. Thus, herrings may congregate in these deeper areas where plankton abundance is expected to be highest.

6.4.3. The Flounders

The winter flounder (*Pseudopleuronectes americanus*) was the fourth most abundant species in the Wilk et al. (1977) survey. It occurred most frequently (53%) of all species in trawls in the Arthur Kill-Hackensack River estuary. In the Lower Hudson, it ranked third in trawl catches (5.9% of the total)(Lawler, Matusky and Skelly, 1980). In the same survey, they were found during all months except August, but were most abundant during winter and early spring. In the Lower Bay complex, the seasonal distribution of *P. americanus* was bimodal with a

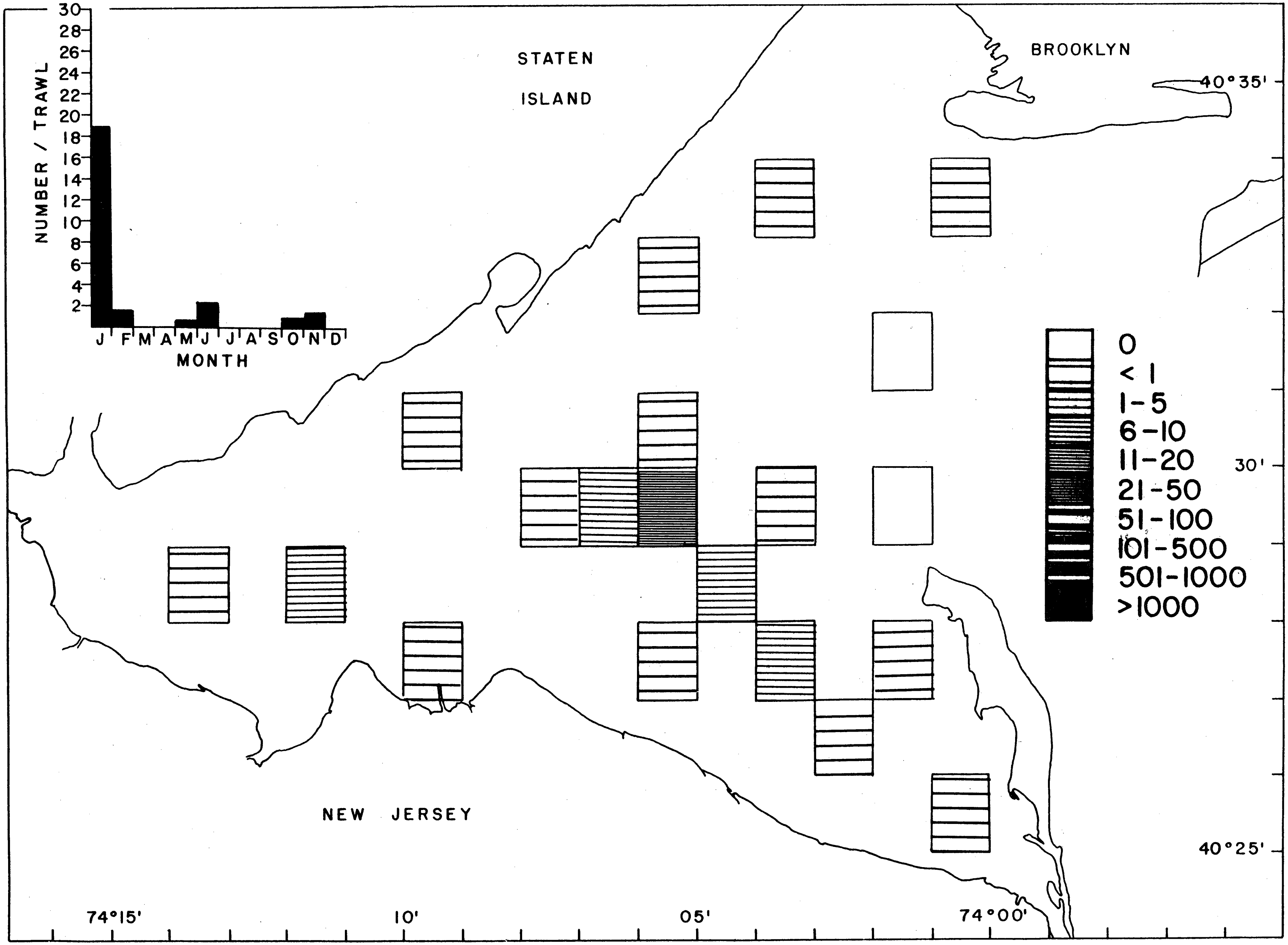


Figure 31. Seasonal and spatial distribution of menhaden (*Brevoortia tyrannus*) in the Lower Bay complex. (From the data of Wilk et al., 1977)

major peak in late fall and a secondary peak in late spring (Fig. 32). Few were observed in January and none in February and March (Fig. 32). The winter decline in the Lower Bay may be due to the availability of inshore shallows where winter flounder are known to lay dormant in the winter, half buried in the mud (Wise, 1975). These areas do not exist in the Lower Hudson pier zones sampled by Lawler, Matusky and Skelly (1980). The late spring increase in numbers is probably the result of late winter-early spring spawnings. Croker (1965) reported the appearance of P. americanus larvae in the Sandy Hook estuary from April through June. In the Liberty State Park area of the Upper Bay, eggs were observed from February through May, and larvae primarily in April and May (Texas Instruments, Inc., 1976). Larvae and juveniles were found in the Arthur Kill from late February through early June, though greatest numbers occurred in March and April (Ichthyological Associates, Inc., 1974a,b,e, 1976)(Table 7).

Winter flounders were notably absent from the Lower Hudson in August and the Lower Bay complex in summer. As this species is known to prefer cooler summer waters (Wise, 1975), it would avoid the Raritan Bay which is the warmest part of the region in this season (Jeffries, 1962). In the Hudson River, dissolved oxygen levels are lowest and temperatures highest in August, particularly in the interpier areas (Lawler, Matusky and Skelly, 1980).

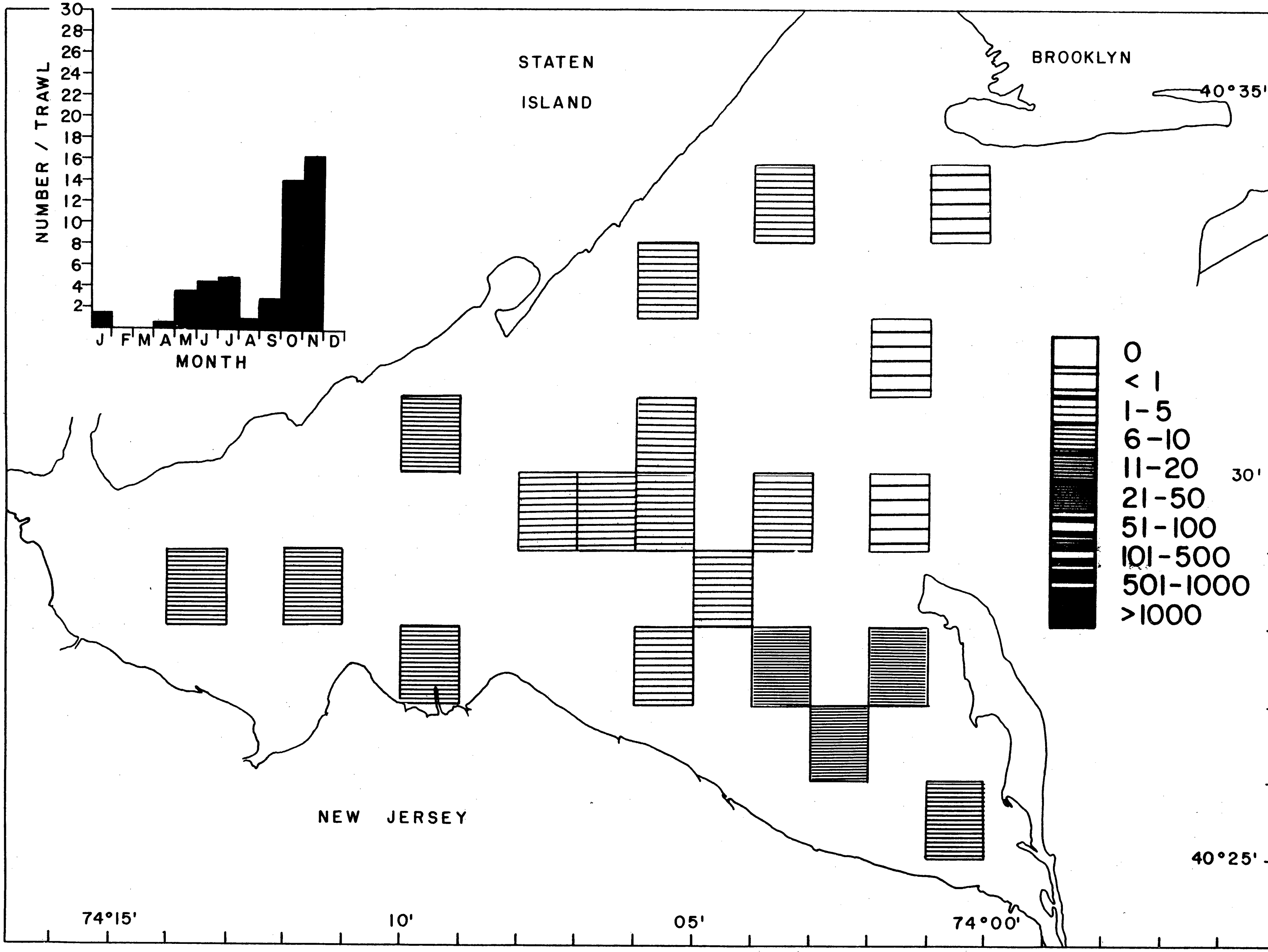


Figure 32. Seasonal and spatial distribution of winter flounder (*Pseudopleuronectes americanus*) in the Lower Bay complex. (From the data of Wilk et al., 1977)

Dissolved oxygen concentrations are also lowest in the western end of the Lower Bay complex. By fall, this part of the bay along with Sandy Hook Bay, are the most populated regions of the area. All but one of the most densely populated areas are located over muddy bottoms (Fig. 33). Similarly, they were found to prefer the muddy interpier areas over the main river channel of the Lower Hudson River (Lawler, Matusky and Skelly, 1980). As winter flounders are bottom feeders, preferring polychaetes (Texas Instruments, Inc., 1976), this distribution may be related to food availability. This species was observed in only four areas in winter. Higher densities were generally found over sandy spawning areas (Scotten et al., 1973).

The summer flounder (Paralichthys dentatus) was the 13th most abundant species in the Wilk et al. (1977) survey and it occurred in 21% of all trawls and had a mean annual density in the Lower Bay complex of 1.2/15-min tow. This species was not reported in any trawls in the Arthur Kill-Hackensack River estuary, nor was it impinged on the intake screens of generating stations in the same region. Unlike the winter flounder, P. dentatus spawns offshore (Esser, 1982) from mid-October to mid-April and the larvae return to the estuary in late spring and early summer (Gaertner, 1976). This pattern is reflected in its seasonal distribution in the Lower Bay complex (Fig. 34). Summer flounder were not observed from November

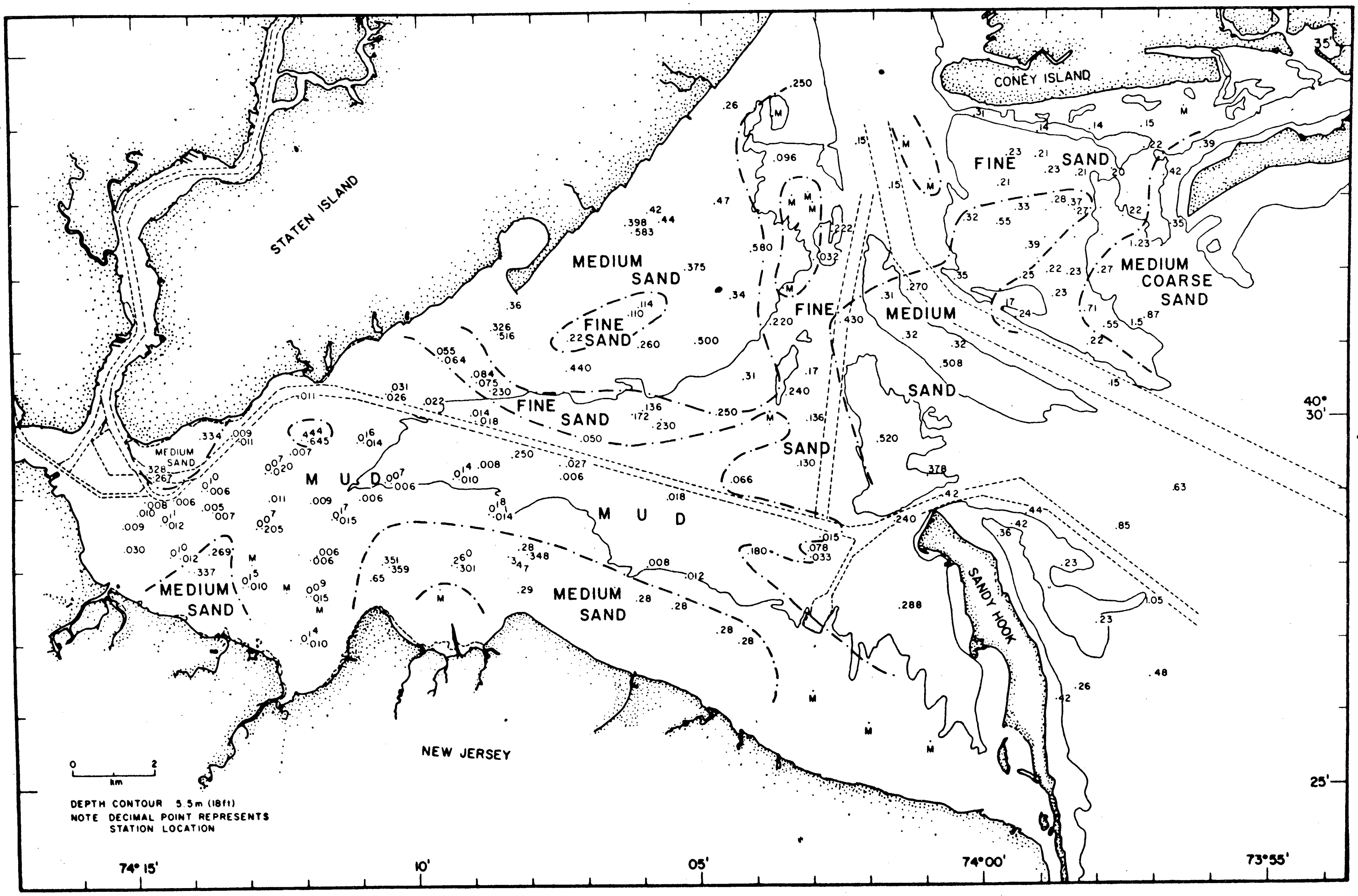


Figure 33. Median diameter of surface sediment samples of the Lower Bay complex. (From Kastens et al., 1978)

through May. Few summer flounder were seen in late spring (Fig. 35) and those occurred only in the eastern end of the Lower Bay complex. Peak abundance was reported in August. During the summer, the adults feed on small fish such as Fundulus spp., Menidia spp. and juvenile Pseudopleuronectes americanus (Pearcy and Richard, 1962). As the latter species is most abundant in the region, it is not surprising that the summer distribution of P. dentatus is virtually identical in relative number and area to that of P. americanus (Fig. 32). In early fall, the numbers of summer flounder drop off as they migrate offshore. There was no apparent pattern to their distribution during this season.

Windowpane (Scopthalmus aquosus) were the second most frequently occurring species (35%) in trawls of the Lower Bay complex and ranked tenth in total abundance for the area. Windowpane occurred very rarely in the Arthur Kill and only in the spring months (Table 5). S. aquosus eggs were observed May through June in the Sandy Hook estuary (Croker, 1965). Larvae were reported by the same author in June. They were caught in the Arthur Kill in late May and early June in the vicinity of the Exxon Bayway Refinery (Ichthyological Associates, Inc., 1976). In the Upper Bay, larvae occurred in June and late July (Texas Instruments, Inc., 1976). These observations are in good agreement with Perlmutter's (1939) finding of maximal egg

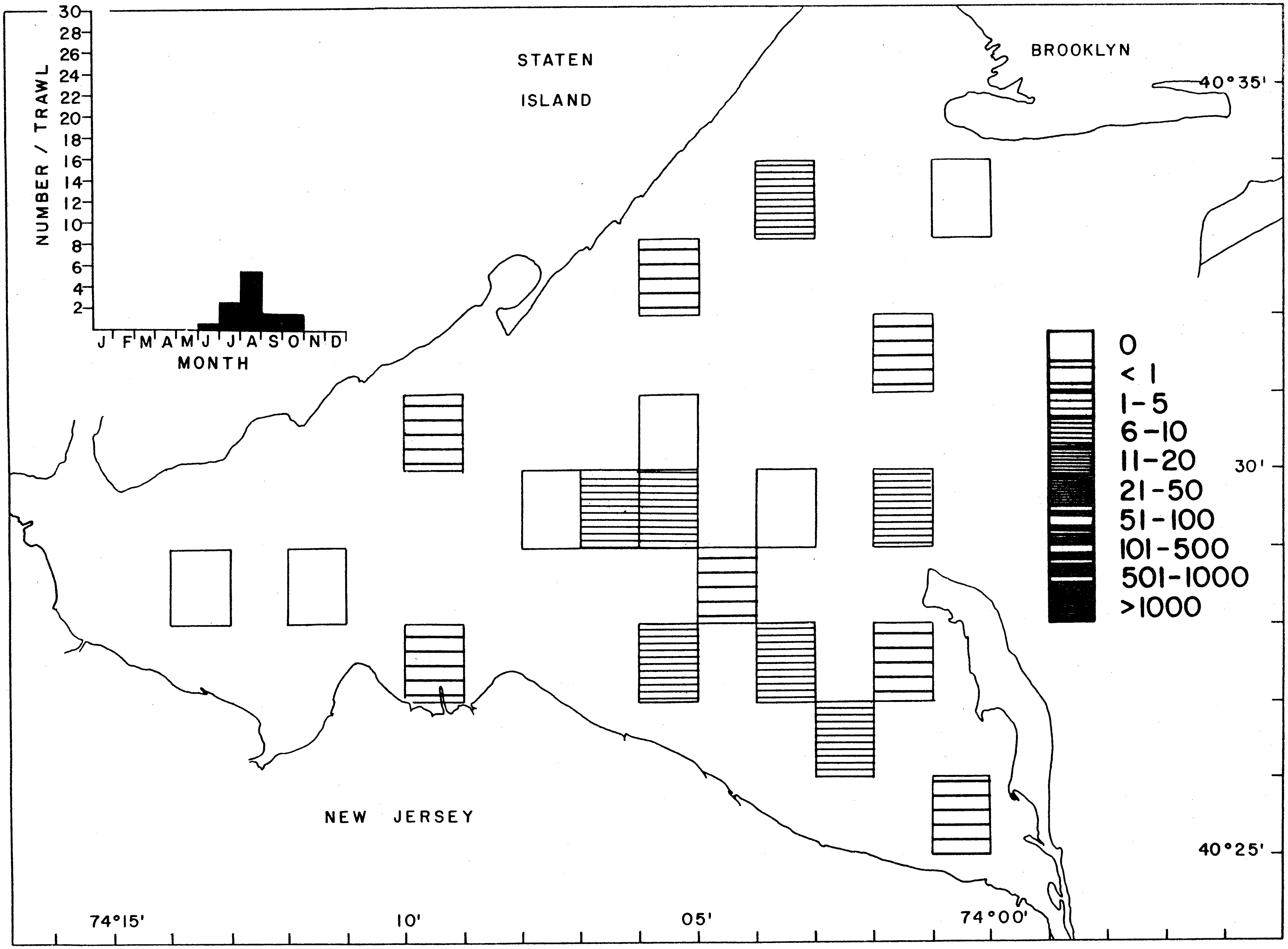


Figure 34. Seasonal and spatial distribution of summer flounder (*Paralichthys dentatus*) in the Lower Bay complex. (From the data of Wilk et al., 1977)

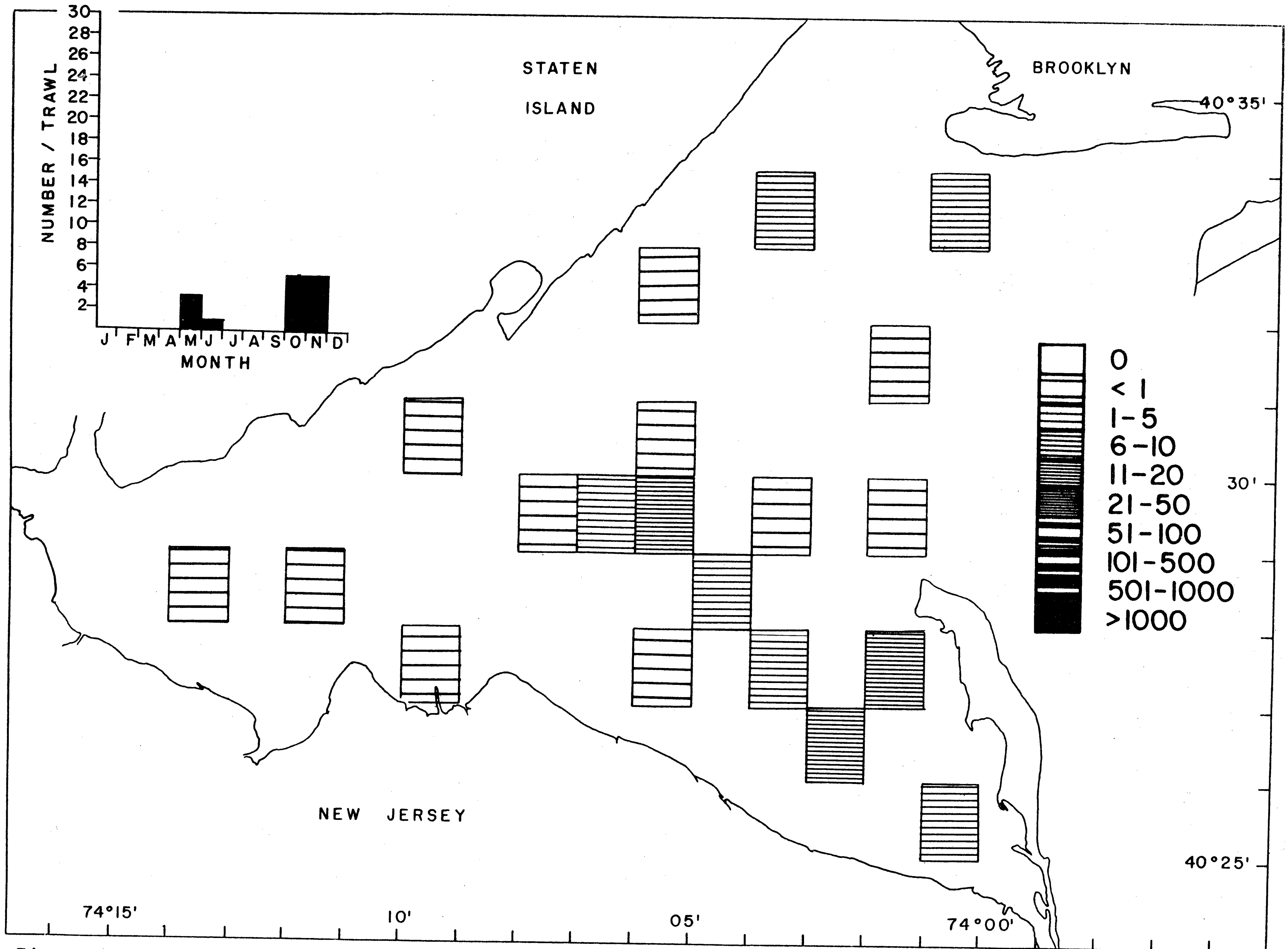


Figure 35. Seasonal and spatial distribution of windowpane (*Scopthalmus aquosus*) in the Lower Bay complex. (From the data of Wilk et al., 1977)

production in late May through early June, with spawning continuing through August.

Trawl collections in the Lower Bay complex included windowpane primarily in May-June and October-November (Wilk et al., 1977). Few occurred in the summer and winter months. As the windowpane has been called a brackish water resident species (Esser, 1982), its low abundance in the summer months may be a reflection of movement to more upper estuarine areas where salinities are lower. The Lower Bay complex reaches its salinity maximum in summer when freshwater flows are minimal. The virtual disappearance of the species in winter may reflect a dormant, semiburied habit during this season, similar to _Pseudopleuronectes americanus_. During spring (Fig. 35), windowpane is most abundant in the Sandy Hook Bay and in the northern end of the Lower Bay complex. It was collected in lower numbers in central and western regions. Its spring distribution parallels closely the areas of lower salinity inputs to the area. In the fall, _S. aquosus_ is more widely distributed throughout the region, though major concentrations exist in central and Sandy Hook Bay areas (Fig. 35). During fall, it is found in greater densities in deeper areas, a finding consistent with its reported preference for cooler and deeper waters in late summer and early fall (Wilk and Silverman, 1976). Hogchokers (_Trinectes maculatus_), though not reported in the Lower Bay complex and Arthur

Kill-Hackensack River, were the second most abundant species in the Lower Hudson River (13% of the total trawl catch) (Lawler, Matusky and Skelly, 1980). They were present from May through November, but were most abundant during June and July. Hogchokers are reported to be summer spawners, to prefer estuarine over marine waters and to be abundant in Hudson River waters (generally above the Tappan Zee area)(Texas Instruments, Inc. et al., 1977).

6.4.4. Weakfish

Weakfish (*Cynoscion regalis*) occurred in 28% of the trawls of the Lower Bay complex and were the ninth most abundant species in the survey of Wilk et al. (1977). Weakfish were impinged on the intake screens of four Arthur Kill-Hackensack River generating stations (Table 5). They were more numerous in the lower Arthur Kill (near Sewaren) and the mouth of the Hackensack River (near Kearny) than in the upper reaches of either body of water. Weakfish ranked as the seventh most abundant species in trawls of the Lower Hudson River (1.5% of the total catch) (Lawler, Matusky and Skelly, 1980).

The seasonal distribution of *C. regalis* is governed by its migratory behavior. It reportedly appears in the area from mid-May through June and spawns from June to late August (Wise, 1975). Juveniles spend their first summer close to shore in the more protected bays and river estuaries. In fall, weakfish migrate offshore and south to wintering grounds off Virginia and North Carolina. In the spring of the second year, they return to more northerly waters to spawn (Wise, 1975). Accordingly, Wilk et al. (1977) observed weakfish in the Lower Bay complex only from June through November (Fig. 36). They are most abundant in the Lower Hudson from August through October (Lawler, Matusky and Skelly, 1980). In the Arthur Kill, larvae were netted in late July only near the Sewaren generating station and the Exxon Bayway Refinery (Ichthyological Associates, Inc., 1974a, 1976). Weakfish were impinged on generating station intake screens from September through November, probably as they were migrating out of the estuary.

During summer, weakfish are fairly evenly distributed throughout most of the Lower Bay complex, though densities in the northern areas are somewhat lower. In fall, C. regalis was present in three areas in densities an order of magnitude greater than the rest of the Lower Bay complex. These aggregations may be a preliminary step before offshore migration or a grouping near food species. Juveniles feed on small crustaceans and anchovy fry (Richards, 1963). Adults are mainly piscivorous, feeding on menhaden, butterfish, silversides, mummichogs and bay anchovies (Wise, 1975). Of these forage species,

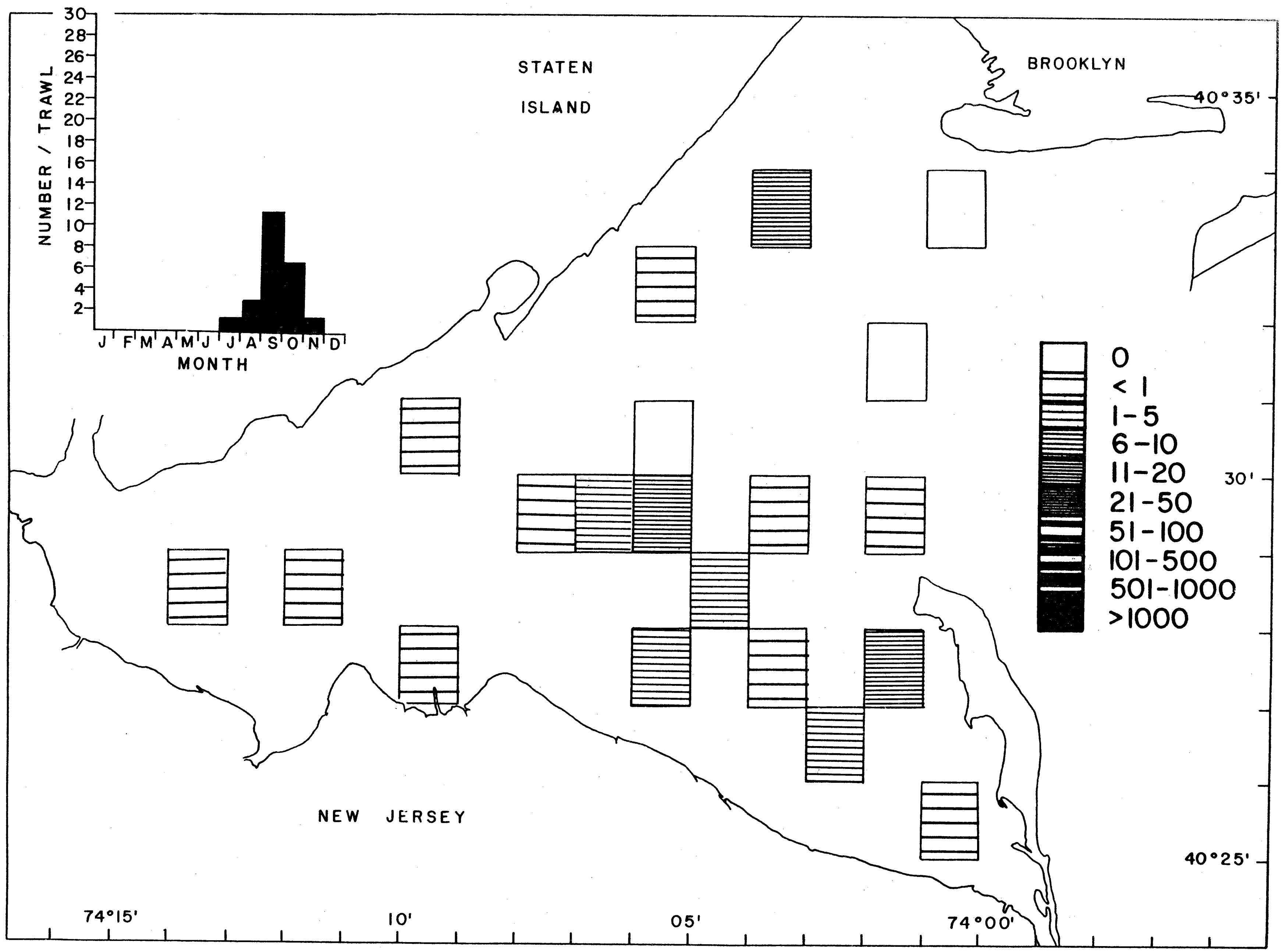


Figure 36. Seasonal and spatial distribution of weakfish (*Cynoscion regalis*) in the Lower Bay complex. (From the data of Wilk et al., 1977)

only the fall distribution of the bay anchovy is similar to that of the weakfish (Fig. 26).

6.4.5. Bluefish

Bluefish (Pomatomus saltatrix) occurred in 16% of all trawls of the Lower Bay complex, and were found in mean annual densities of 1.1/15-min trawl (Wilk et al., 1977). They ranked 15th in overall abundance, or 0.8% of the total yearly catch of the same survey. It was found in impingement collections through most of the Arthur Kill-Hackensack River area in relatively low numbers (Table 5).

P. saltatrix eggs and larvae were not observed in any of the areas as spawning occurs offshore. The first appearance of the species was in June. Densities increased ten times in July which corresponds to the inshore migration of bluefish about one month after offshore spawning (Gaertner, 1976). By November, the number of bluefish decreased to June levels, with none reported thereafter till the following late spring. This is consistent with the reported disappearance of the species from the northeast coast by late November, when the southerly migration begins (Gaertner, 1976).

In summer, P. saltatrix was found only in the central Lower Bay complex (Fig. 37), Sandy Hook Bay, and lower Arthur Kill (near Sewaren). During the fall, it was

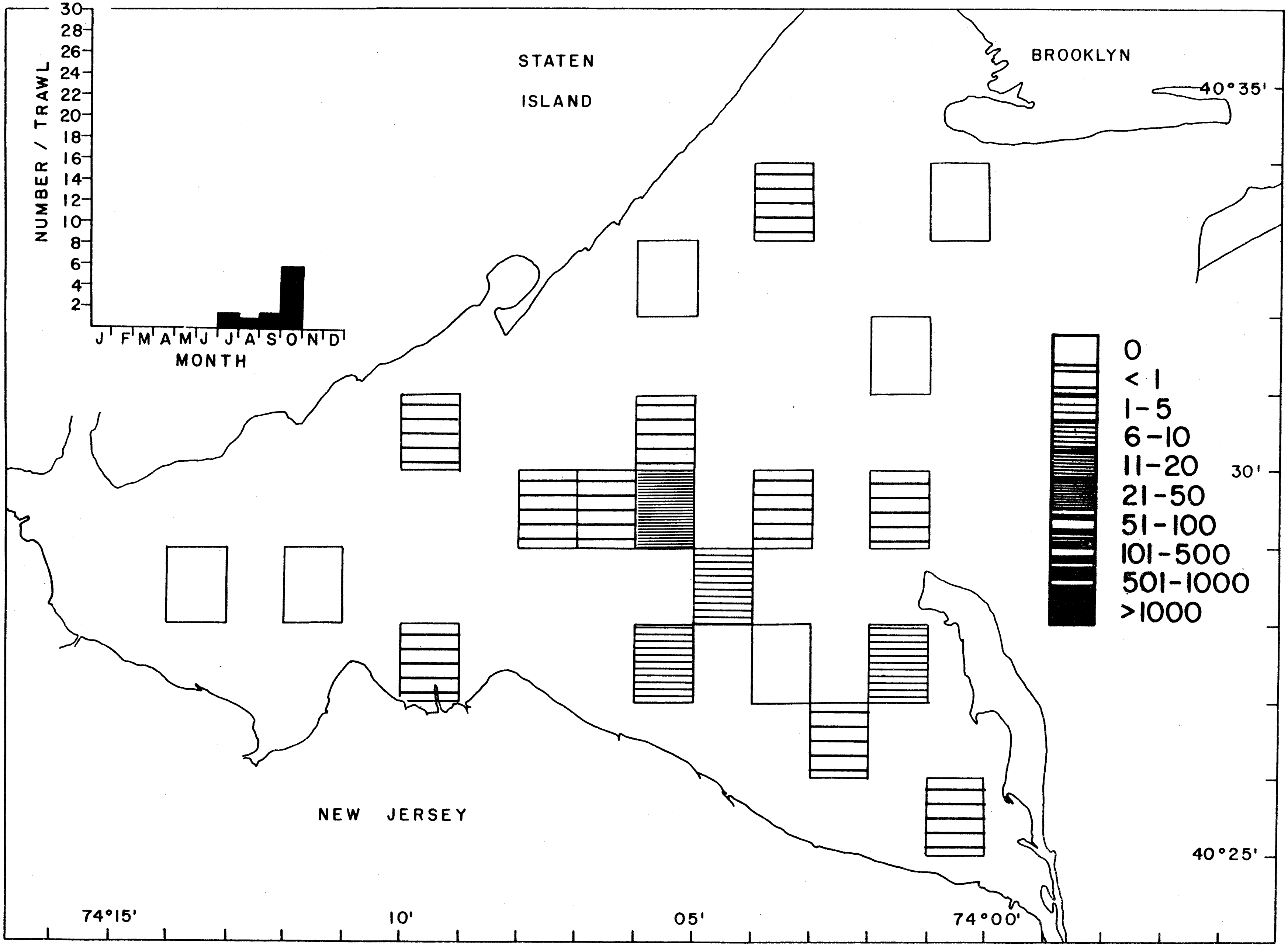


Figure 37. Seasonal and spatial distribution of bluefish (*Pomatomus saltatrix*) in the Lower Bay complex. (From the data of Wilk et al., 1977)

observed primarily in the central Lower Bay complex with scattered occurrences throughout other areas including the Arthur Kill-Hackensack estuary. The fall distribution of several prey species (Menidia menidia, Cynoscion regalis, Alosa sapidissima) is also maximal in the central Lower Bay complex (Figs. 42, 36, 30).

6.4.6. The Hakes

Four species of hakes were observed in the Lower Bay complex. They were, in decreasing order of abundance, Urophysis chuss (3.1/15-min trawl), Merluccius bilinearis (1.1/15-min trawl), U. regius (0.6/15-min trawl) and U. tenuis (0.4/15-min trawl). Red hake (U. chuss) ranked sixth in total abundance and occurred in 20% of all trawls (Wilk et al., 1977). Silver hake (M. bilinearis) was 14th and was found in 21% of tows in the same survey. The spotted hake (U. regius) and white hake (U. tenuis) were less abundant, occurring in 11% and 2.5% of trawls, respectively. In the Arthur Kill-Hackensack River, only M. bilinearis and U. chuss were reported (Ichthyological Associates, Inc., 1974a,b,c,d). Both species were observed in trawl and impingement collections in all locations except in the Hackensack River near Bergen and upriver.

M. bilinearis occurred in all areas in only the early spring and late fall-early winter (Fig. 38, Table 4). In

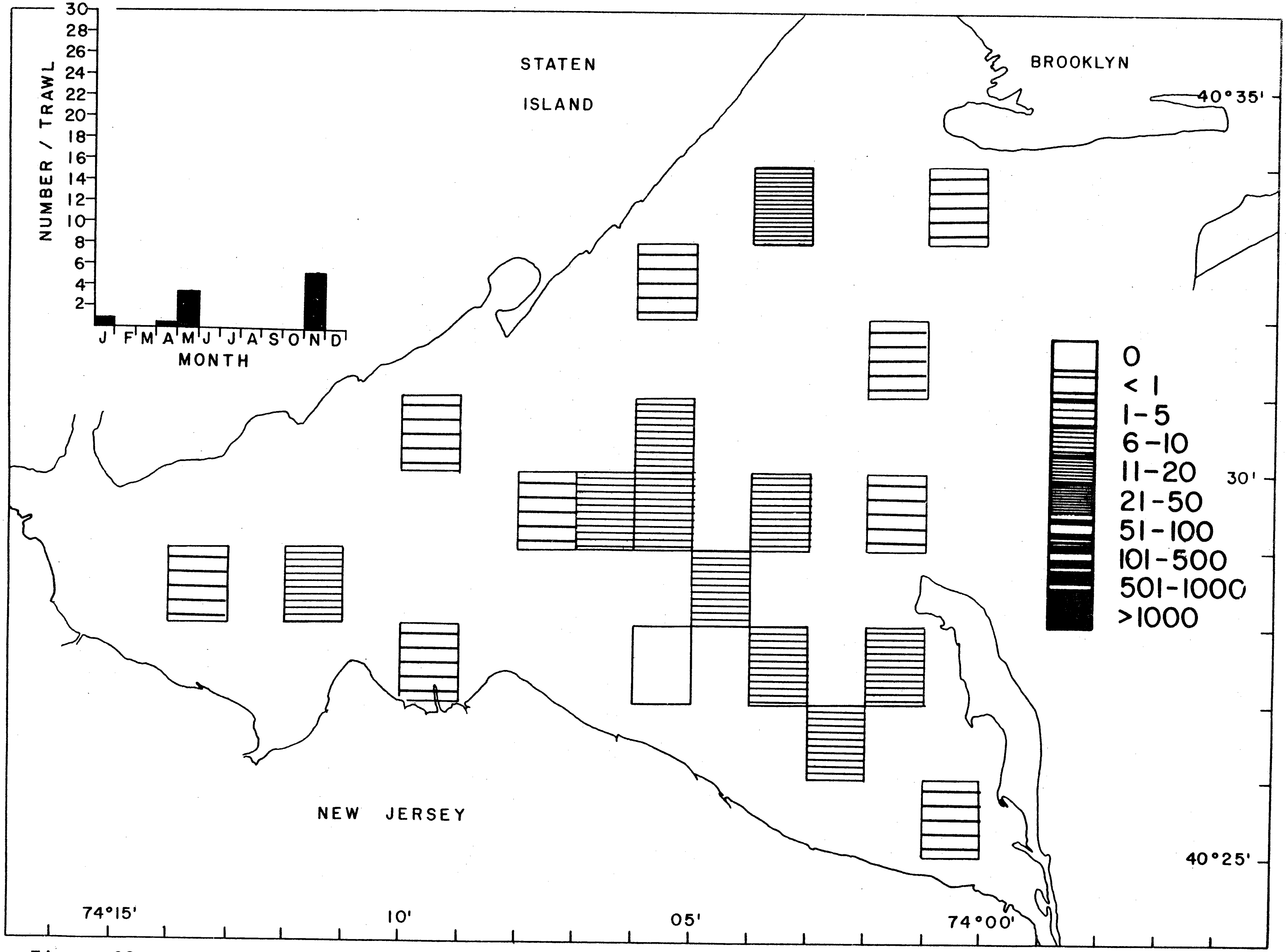


Figure 38. Seasonal and spatial distribution of silver hake (*Merluccius bilinearis*) in the Lower Bay complex. (From the data of Wilk et al., 1977)

spring, the species migrates inshore (Gaertner, 1976) and occupies the Sandy Hook Bay, the western end of the Lower Bay complex and the lower Arthur Kill (Fig. 38, Table 6). By June, the silver hake has disappeared from the area. As it tolerates temperatures from 4 ^{o}C to 18 ^{o}C (Gaertner, 1976), it most likely seeks cooler waters during the summer. The Lower Bay complex summer water temperature ranges from 20 ^{o}C to 25 ^{o}C (Jeffries, 1962; National Marine Fisheries Service, 1971). Furthermore, as M. bilinearis spawns in the summer (Perlmutter, 1939) and its eggs and larvae were not observed in the area, it most likely migrates elsewhere to reproduce. Its reappearance throughout the area coincides with the lower water temperature of November. The greatest number of silver hake in the Arthur Kill-Hackensack River were reported in November and December. This fact along with their winter distribution in the Lower Bay complex suggests that the species uses the estuary only as a migratory route to offshore areas where it reportedly overwinters (Gaertner, 1976).

The red hake (U. chuss) had a temporal distribution similar to that of the silver hake. Its peak density occurred in May. It was virtually absent from the Lower Bay complex and Arthur Kill-Hackensack River areas in summer and was only reported in several stations of the Lower Bay complex in fall and winter (Fig. 39). In spring, it is more numerous in the lower Arthur Kill than

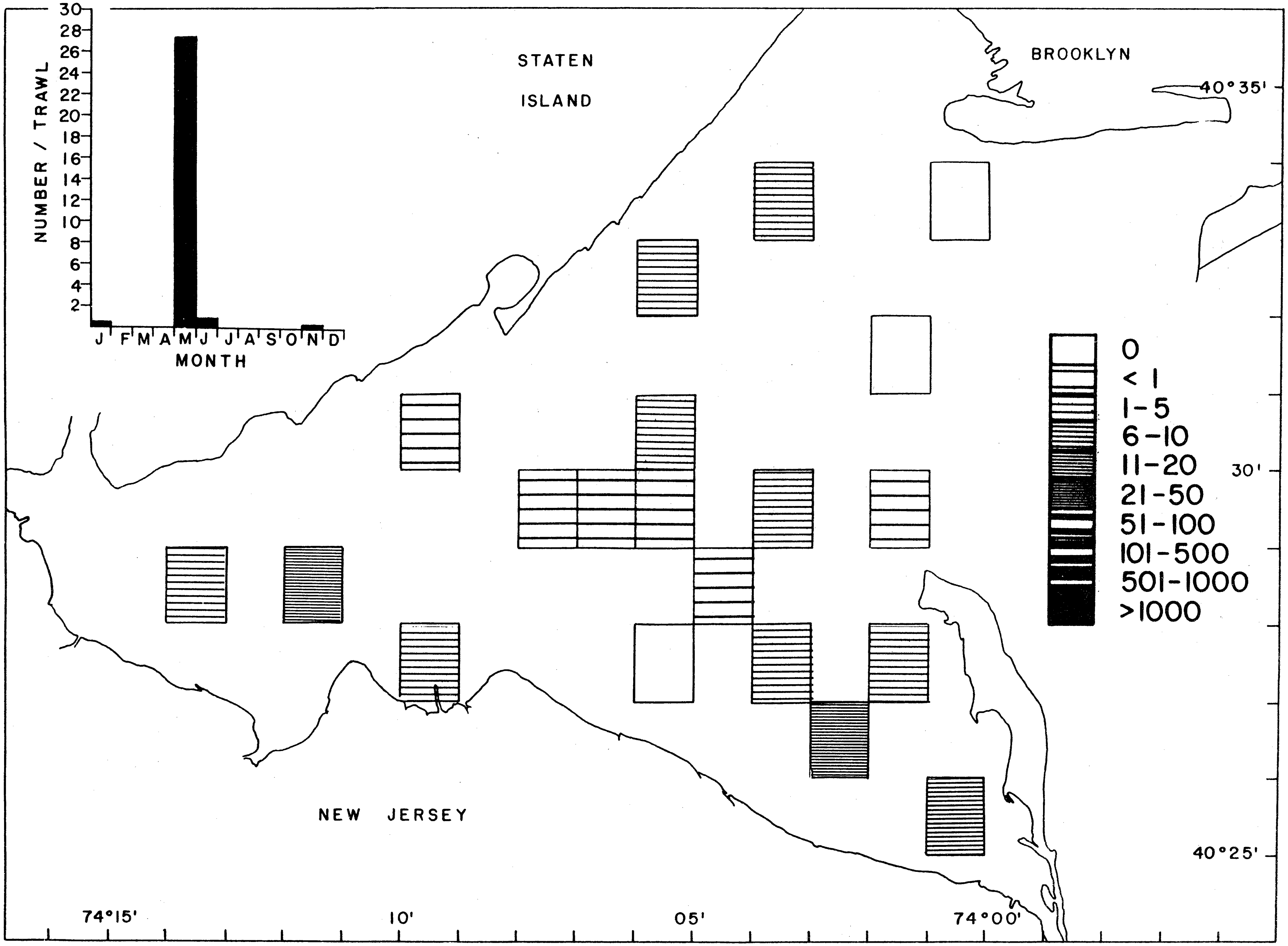


Figure 39. Seasonal and spatial distribution of red hake (*Urophysis chuss*) in the Lower Bay complex. (From the data of Wilk et al., 1977)

in the upper reaches of the Hackensack River area. Maximum concentrations occurred in Sandy Hook Bay and to a lesser extent in the western end of the Lower Bay complex.

6.4.7. Silversides and Mummichogs

The Atlantic silverside (*Menidia menidia*), tidewater silverside (*M. beryllina*), and mummichog (*Fundulus hetroclitus*) are the most common inshore resident species of the estuary. They are also important forage species in the diet of several commercially significant larger fish (striped bass, summer flounder, bluefish).

Though the survey of Wilk et al. (1977) did not sample inshore areas, *M. Menidia* was still the 12th most abundant species. In a survey of the shoreline of Conaskonk Point, Raritan Bay, *M. menidia* was the most abundant spies and *F. heteroclitus* the second most numerous (New Jersey Department of Environmental Protection, 1973). Haul seine samples from the intertidal and nearshore area off Atlantic Highlands, Sandy Hook Bay, were dominated by *M. menidia* (New Jersey Department of Environmental Protection, 1975b). Atlantic silverside was the most numerous of species, representing 44% of the mean annual catch in beach seine collection from Liberty State Park, Upper Bay (Texas Instruments, Inc., 1976). *Menidia menidia* was the most abundant

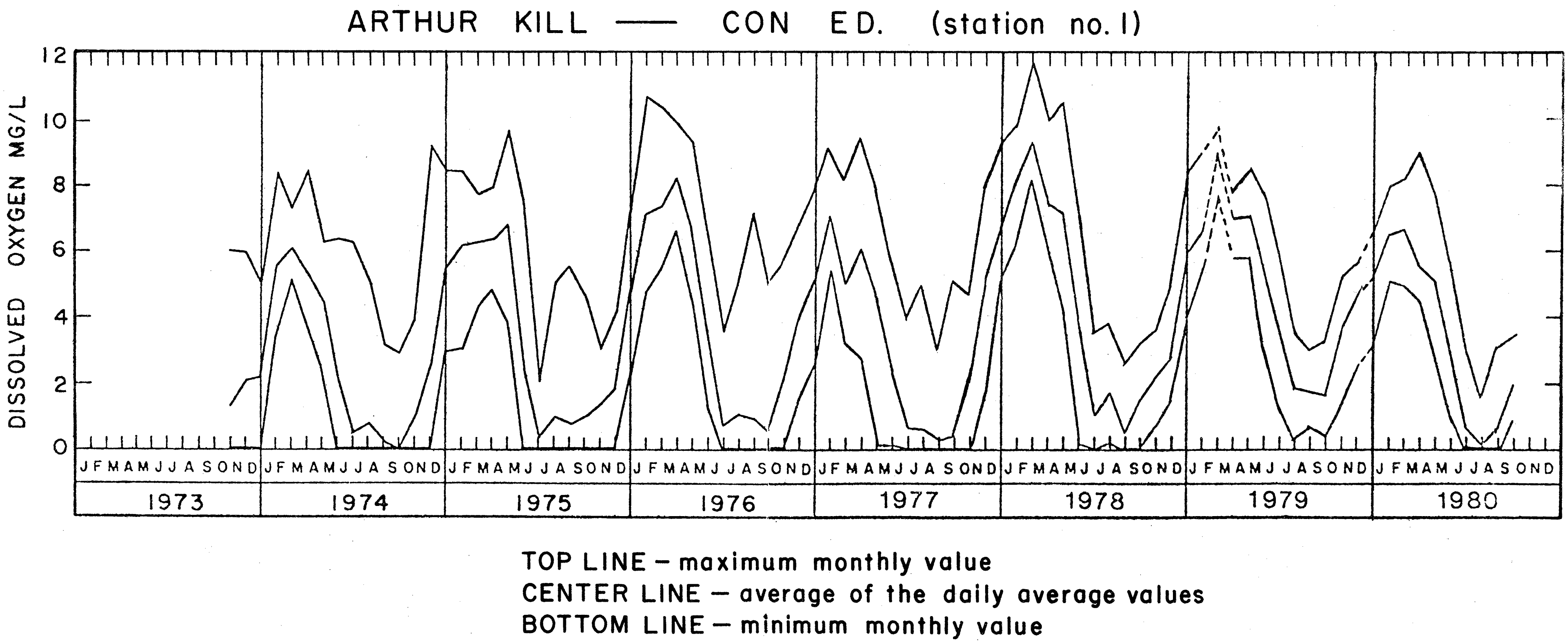


Figure 40. Seasonal distribution of dissolved oxygen levels in the Arthur Kill from 1973 to 1980. (From Interstate Sanitation Commission, 1981)

species collected by seine in the East River off Astoria, Queens (Oceanographic Analysts, 1970).

Although *M. menidia* was consistently more abundant than *F. heteroclitus* in the Lower Bay complex, Upper Bay and East River, the inverse was true in the Arthur Kill-Hackensack River area. *Fundulus heteroclitus* was not reported in trawl collections of the Lower Bay complex (Wilk et al., 1977), whereas it was often the most numerous species in trawls of the Arthur Kill-Hackensack River. *M. menidia* was not observed in the Arthur Kill-Hackensack River trawls, though it ranked twelfth in the Lower Bay complex trawls. The mean annual density of *M. menidia* in the Arthur Kill-Hackensack River (from impingement studies, Ichthyological Associates, Inc., 1974a,b,c,d,e,f) was $0.008/1000m^3$ whereas *F. heteroclitus* averaged $5.4/1000m^3$.

The different distributions of these species is probably a consequence of their dissolved oxygen tolerance. *Fundulus heteroclitus* is known to be tolerant of low oxygen levels. Dissolved oxygen falls below 3.0 mg/l throughout most of the Arthur Kill-Hackensack (Fig. 40) in the summer months, yet during those months, *F. heteroclitus* often reached its annual peak abundance (Fig. 41). *Menidia menidia*, however, was not reported in any area during July, August and September in trawl and impingement collections (Fig. 42).

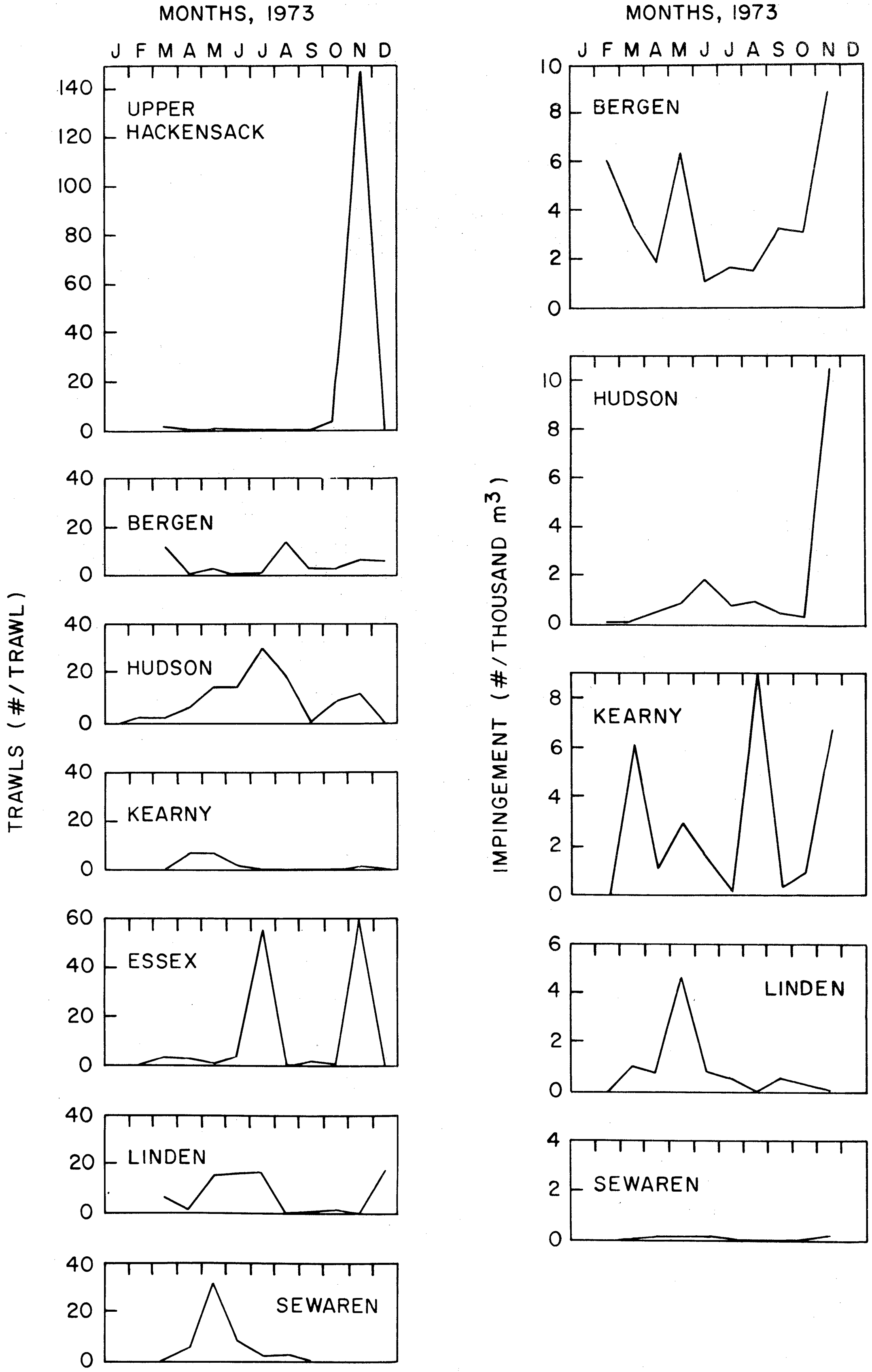


Figure 41. Seasonal and spatial distribution of mummichog (*Fundulus heteroclitus*) in the Arthur Kill-Passaic River-Hackensack River Estuary from trawl and impingement collections. (From the data of Ichthyological Associates, Inc., 1974a,b,c,d,e,f, 1976)

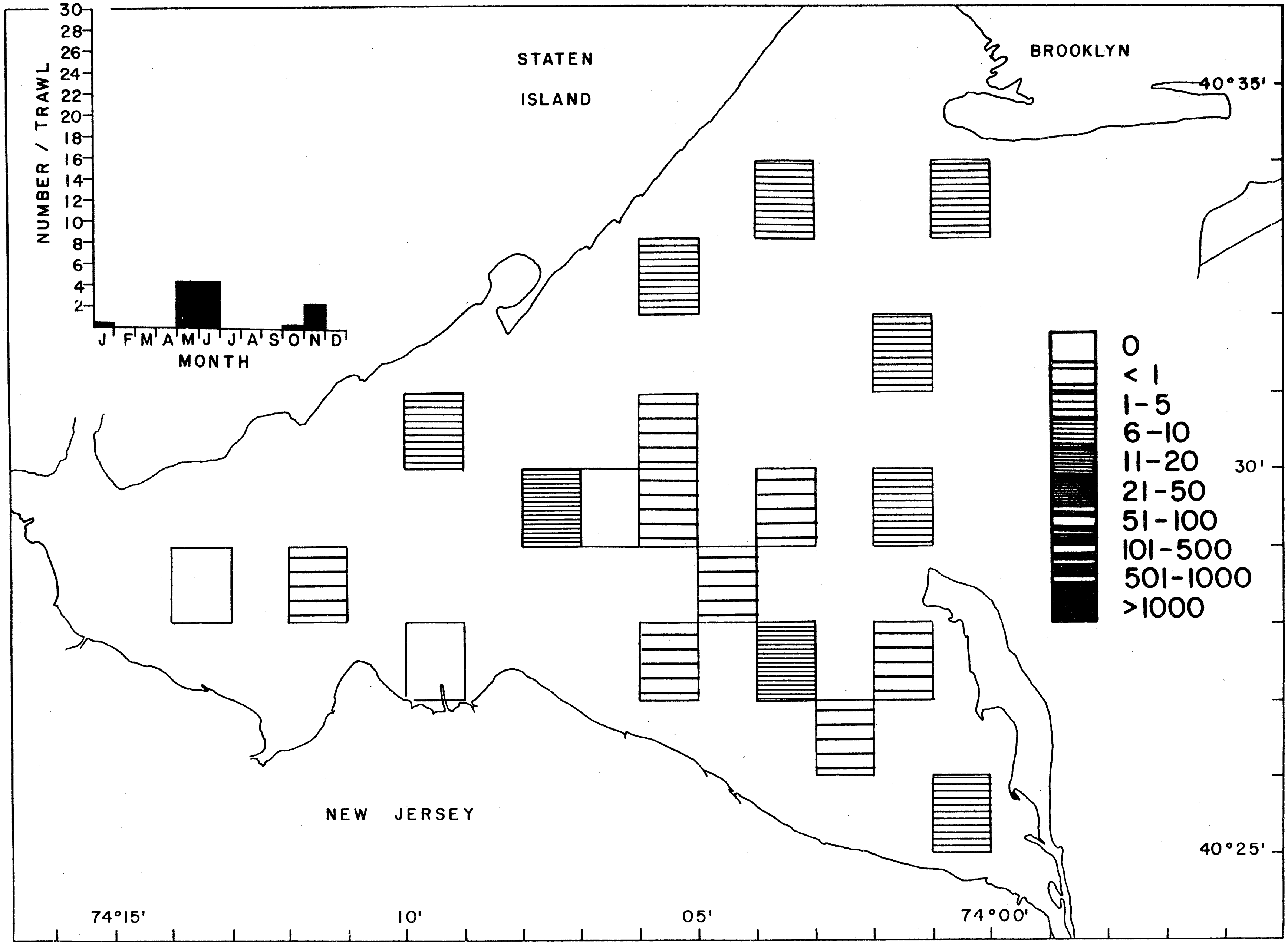


Figure 42. Seasonal and spatial distribution of Atlantic silversides (*Menidia menidia*) in the Lower Bay complex. (From the data of Wilk et al., 1977)

Menidia menidia larvae, on the other hand, were reported in the Arthur Kill (Table 7) in May and June, the greater density in June in the lower Arthur Kill. Thus, either spawning does occur in the Arthur Kill or larvae migrate there from Raritan Bay. No larvae apparently remain there past June. In the Sandy Hook estuary, larvae were observed from May through June (Croker, 1965). This is consistent with earlier reports of the spawning period of silversides on the southern New England coast (Bigelow and Welsh, 1925). *Fundulus heteroclitus* larvae occurred throughout the Arthur Kill-Hackensack River area primarily in the months of June, July and August. They were most numerous in the upper regions of the Arthur Kill-Hackensack River. Near Hudson in the Hackensack River, mummichog were 67% of the larvae collected (Ichthyological Associates, Inc., 1973). It was far less abundant in the Upper Bay (Texas Instruments, Inc., 1976) and Sandy Hook estuary (Croker, 1965).

6.4.8. Butterfish

Butterfish occurred in 21% of all trawls of the Lower Bay complex (Wilk et al., 1977) and ranked eleventh in total abundance (Table 4). It was not reported in trawls of the Arthur Kill-Hackensack River or Upper Bay. *Peprilus triacanthus* was impinged on the intake screens

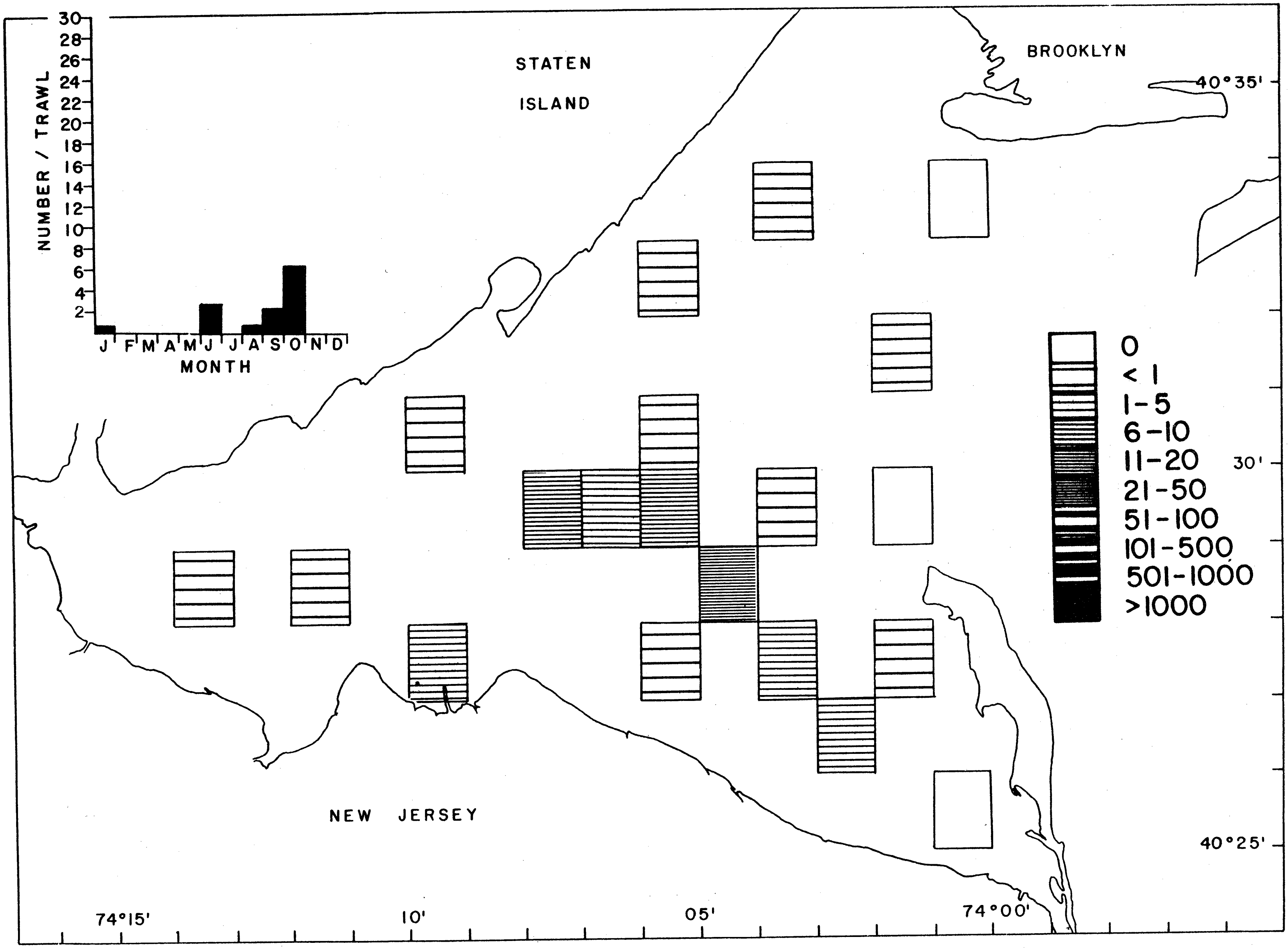


Figure 43. Seasonal and spatial distribution of butterfish (*Peprilus triacanthus*) in the Lower Bay complex. (From the data of Wilk et al., 1977)

of Arthur Kill-Hackensack River generating stations from September through November (Table 5) though most occurred in October. Densities were low, however, and P. triacanthus is probably only an accidental visitor to this area.

Butterfish spawn from June through August from Cape Sable to Block Island (Scotten et al., 1973). Larvae were captured in low numbers only in the Sandy Hook estuary in July (Croker, 1965). Butterfish were most common in early fall and late spring in the central Lower Bay complex (Fig.43).

6.4.9. Scup

Scup, or porgy, (Stenotomus chrysops) have been called the most important sport fish of the Long Island Sound (Wise, 1975). Scup landings in the Sound sharply decreased from their historical peak in 1956 (Wise, 1975). Only very minor quantities have been caught there in recent years though the resource has been increasing in abundance (Wise, 1975). In the survey of the Lower Bay complex (Wilk et al., 1977), scup were 16th in total abundance and occurred in 11% of all trawls (Table 4). S. chrysops was not reported in the winter and early spring months, but appeared first in June. This is consistent with its seasonal migratory habits. Scup overwinter in the offshore waters over the continental shelf between New Jersey and North Carolina (Wise, 1975). They return to northern inshore areas to spawn in late spring. In June, they enter the Lower Bay complex but do not spawn until July (Anon., 1962). The drop in abundance in August probably reflects the tendency of older fish to stay in the ocean or near the mouths of large bays in the summer months after spawning (Anon., 1962). The young spend the summer in the shallower waters of bays. The majority of the scup caught in summer months in the Sandy Hook Bay were yearlings (Wilk and Silverman, 1976). Scup start to move out of the bay shallows and offshore during September. This accounts for the peak abundance reported in that month (Wilk and Silverman, 1976; Wilk et al., 1977). By the end of November, all scup have migrated offshore and south.

6.4.10. Atlantic Tomcod

Tomcod (Microgadus tomcod) were not observed in any trawls of the Lower Bay complex by Wilk et al. (1977). They were, however, reported in trawls, net tows and impingement collections from the Arthur Kill north to the mouth of the Hackensack River. Tomcod were the most abundant species in trawls of the Lower Hudson River, representing 70% of the total catch (Lawler, Matusky and Skelly, 1980). They were present year-round but most abundant during May and June (Lawler, Matusky and Skelly, 1980).

1980). Tomcod enter the estuary in the fall and spawn in the winter (Esser, 1982). Most spawn in the Hudson River (December-February) around Poughkeepsie (Texas Instruments, Inc., 1976). After spawning, the adults return to more saline waters (Esser, 1982). As the survey of Wilk et al. did not include the months of December and March, it is possible that the survey missed the spawning runs of tomcod. Tomcod does apparently spawn in the lower estuary as well as in the Hudson River. Tomcod was the third most abundant member of the ichthyoplankton in the Lower Hudson River primarily from October through December (Lawler, Matusky, and Skelly, 1980). Eggs were reported from the Liberty State Park area of the Upper Bay in February and March and larvae in March and early April (Texas Instruments, Inc., 1976). Larvae were also seen in the Arthur Kill north to the Hackensack River in late March and early April (Ichthyological Associates, Inc., 1974a,b). Juveniles were observed in these areas from late April through early July. Tomcod juveniles may migrate to other areas of the estuary when summer temperatures and oxygen levels make the Arthur Kill-Hackensack River region unsuitable as a nursery area. Juvenile tomcod do inhabit the lower Hudson River down to the George Washington Bridge or possibly farther from late May through early August (Texas Instruments, Inc. et al., 1977).

There is little information on the extent of the tomcod fishery. They are not classified separately in commercial landings records, but are included with other species as "unclassified" food fish. The last year for which Hudson River catch information is available was 1965, when 2000 pounds were marketed (Texas Instruments, Inc., 1977). Data on sport fishery landings of tomcod do not exist.

6.4.11. White Perch

The white perch (*Morone americana*) was virtually absent from the Lower Bay complex (Wilk et al., 1977). This is not surprising in light of its preference for brackish or fresh water (Bigelow and Schroeder, 1953). It was generally about 10 times more abundant in the Hackensack River than in the Arthur Kill (Ichthyological Associates, Inc., 1974a,b,c,e,f), also a reflection of its salinity tolerance. It appeared in the Arthur Kill only during the spring and late fall when freshwater flows are maximal. In the Hackensack River, white perch occurred year-round. The white perch apparently spawns successfully in the Hackensack River. Larvae appear in late May-early June and juveniles through July. *Morone americana* was the most numerous species found in the Upper Hackensack (mean annual density of $98/1000m^3$) comprising 94% of the larval and juvenile fish netted in that area (Ichthyological Associates, Inc., 1974f).

Table 14. Landings (thousands of pounds) and value (thousands of dollars) of top 20 commercial fishes (in order of decreasing value) in middle Atlantic region during 1973.*

	Species	Landings	Value
1	Menhaden	156,250	3,992
2	Flounder	12,379	3,048
3	Porgy	5,873	1,808
4	Whiting	8,303	1,079
5	Striped Bass	3,093	1,020
6	Weakfish	4,165	646
7	Butterfish	1,698	390
8	Black Sea Bass	878	337
9	Bluefish	2,303	294
10	Tuna	1,272	271
11	Tilefish	718	235
12	Atlantic Mackerel	1,478	144
13	Common Eel	406	124
14	Red Hake	1,454	116
15	Cod	417	106
16	American Shad	308	79
17	White Perch	268	66
18	Silversides	91	22
19	White Hake	64	12
20	Carp	141	11
	Sturgeon	22	4
	Alewife	30	>1
	TOTAL**	202,386	13,863

* From USNOAA, 1975; Current Fisheries Statistics No. 6816
**Includes species in addition to those listed.

Table 15. Commercial landings (thousands of pounds) and value to fishermen (thousands of dollars) of white perch reported along Atlantic Coast since 1965.

Region	1965	1966	1967	1968	1969	1970	1971	1972	1973*	1974**	1975**
Hudson River †											
Pounds	3.6	1.1	1.5	1.7	2.6	1.4	0.2	0.0	0.8	0.8	0.7
Dollars	0.5	0.1	0.2	0.3	0.6	0.4	0.1	0.0	0.1	0.2	0.1
New York ‡											
Pounds	37	61	82	88	67	166	107	55	103	136	83
Dollars	6	9	14	18	14	31	16	14	27	31	20
Mid-Atlantic ‡											
Pounds	156	256	223	262	166	259	212	179	268	256	207
Dollars	23	40	38	50	30	48	38	40	66	58	50
New England ‡											
Pounds	46	28	12	13	35	50	64	81	91	88	38
Dollars	7	3	2	2	6	10	13	22	27	27	11
Chesapeake ‡											
Pounds	1,759	2,389	1,692	2,196	2,704	1,925	1,969	1,420	1,014	673	789
Dollars	220	246	225	292	427	303	303	248	214	128	151
So. Atlantic ‡											
Pounds	261	402	384	299	207	211	367	202	145	309	239
Dollars	27	24	46	31	24	30	45	27	22	57	52
TOTAL											
Pounds	2,222	3,075	2,311	2,770	3,112	2,445	2,612	1,882	1,518	1,326	1,283
Dollars	277	313	311	375	487	391	399	337	329	270	264

* From USNOAA, 1975; Current Fisheries Statistics, District Summaries
**From USNOAA, 1976; Current Fisheries Statistics
† Provided by Fred Blossum (NMFS)
‡ From USNOAA, 1967-74; Fisheries Statistics of the United States

White perch are one of the 22 species listed as "abundant" in the Hudson River (Texas Instruments, Inc., 1977). It is found throughout the river and spawns primarily north of the Croton-Haverstraw area in shallow water. Juveniles move downstream gradually during the first summer and overwinter in the lower portions of the estuary (Texas Instruments, Inc., 1977). They have been reported in the Lower Hudson River primarily from October through December (Lawler, Matusky and Skelly, 1980).

In the Middle Atlantic district, the white perch ranked 17th in value ($66,000) and pounds landed (268,000 lb) in 1973 (Table 14). Of the 1975 catch of 207,000 lb ($50,000), New York contributed 83,000 lb; and only 700 lb ($100) came from the Hudson River (Table 15). Hudson River landings since 1965 have ranged from zero reported landings (1972) to 3,600 lb (1965) (Table 15).

6.4.12. Striped bass

The Hudson River has been documented as a major East Coast spawning ground for striped bass *Morone saxatilis* (Raney et al., 1954; Texas Instruments, Inc., 1975. Striped bass spawn 80 to 113 km north of the Battery near Poughkeepsie in May and June (Texas Instruments, Inc., 1976). The juvenile population moves downriver and reaches the George Washington Bridge by mid-fall (Texas Instruments, Inc., 1977). Young of the year probably move through the East River during late fall and early winter. They were impinged on the intake screens of the Astoria generating station in Queens during November and January (1971-1972)(Quirk, Lawler and Matusky, 1973) and continued to be impinged through March, 1972 at Astoria; they did not appear again until December, 1972. As juveniles leave the Hudson River, they appear to disperse in all directions: to the east through Long Island Sound, to the south along Staten Island and the south shore of Long Island, and to the west through the Kill Van Kull and Newark Bay into the Hackensack River (Texas Instruments, Inc., 1977). Juveniles remain in the estuary until their second year when they begin the annual offshore migration (Gaertner, 1976) The shallow nearshore areas are therefore important nursery grounds for the young fish until they reach a sufficient size to move offshore.

Trawls in the Lower Bay complex netted few striped bass, (Wilk et al., 1977). *M. saxatilis* ranked 35th in abundance and occurred in only 2.5% of trawls (Table 4). Catches were reported in May, July and October only. Seine collections at Atlantic highlands in Sandy Hook Bay, and near Conaskonk Point in Raritan Bay yielded no striped bass (New Jersey Department of Environmental Conservation, 1973). Seine collections made off southeast Staten Island also yielded no striped bass. Only in Great Kills Harbor, Staten Island, was this species captured in haul seines (Texas Instruments, Inc., 1977), in densities of 1.2 per seine collection in early September only. It appears, therefore, that very few striped bass use the Lower Bay complex as a nursery area or even as a passageway for offshore migrations.

Other areas of the lower estuary may be more important to M. saxatilis. The Hudson River interpier areas of Manhattan provide one such habitat for striped bass (Lawler, Matusky, and Skelly, 1980). They were found to be one of the seven most abundant species in trawls of the Lower Hudson, occurring primarily from October through April (Lawler, Matusky, and Skelly, 1980). Results of a survey of Caven Point Cove on the western shore of the Upper Bay, found yearling M. saxatilis to be the most numerous fish species (New Jersey Department of Environmental Protection, 1975). Their findings indicated extensive use of the cove by this species. In another study of the Upper Bay (Texas Instruments, Inc., 1976) near Liberty State Park, striped bass were fifth in abundance among shore-zone fishes. They were found in beach areas throughout most of the year but apparently moved offshore as water temperatures dropped during the winter. Young of the year appeared in the nearshore areas in September. Catches were highest in the spring when yearlings from the previous year's spawn appeared in the beach seines. The authors concluded that the Liberty State Park area served as a nursery for young fish until they reached a sufficient size to move into the surrounding bays and ocean. Striped bass were found in Newark Bay from May through September; the peak abundance occurred in September (McCormick and Koepp, 1978). *Morone saxatilis* was reported in samples from the intake screens of several Arthur Kill-Hackensack River generating stations (Ichthyological Associates, Inc., 1974a,b,c,e,). The species ranked 4th, 6th and 6th in abundance of all species impinged at the Linden, Kearny and Hudson-Marion generating stations, respectively. Striped bass were present in the upper Arthur Kill and mouth of the Hackensack River in these collections from March through July and again in November and December. It seems, therefore, that *M. saxatilis* does utilize the northern Arthur Kill and Newark Bay as a nursery area in the spring and early summer and probably passes out of the area in the late fall.

The Hudson River, however, supports a commercially important spawning stock of the striped bass. This population contributes to the fishery of Long Island and to a lesser degree, the fishery from the coast of Massachusetts to New Jersey. Many other Atlantic coastal rivers are no longer suitable for striped bass spawning due to dam construction and water pollution (Saila and Pratt, 1971).

Striped bass is one of the most valuable commercial species of the Middle Atlantic region (New York, New

Table 16. Commercial landings (thousands of pounds) and value to fishermen (thousands of dollars) of striped bass reported along the Atlantic Coast since 1965.

Region	1965	1966	1967	1968	1969	1970	1971	1972	1973*	1974**	1975**
Hudson River†											
Pounds	36.7	44.3	54.6	60.8	77.2	45.9	24.7	17.9	67.0	30.3	46.2
Dollars	4.0	5.3	4.4	11.6	12.3	7.8	4.5	5.0	24.0	12.1	24.9
New York‡											
Pounds	740	1,050	1,630	1,551	1,535	1,338	1,184	836	1,741	1,409	1,183
Dollars	140	193	306	350	369	363	329	269	654	535	639
Mid-Atlantic ‡											
Pounds	1,533	1,429	2,023	2,059	1,888	1,615	1,513	1,457	3,093	2,262	1,715
Dollars	308	282	392	488	453	423	424	447	1,020	748	890
New England ‡											
Pounds	531	843	802	987	1,182	1,442	895	1,499	2,024	434	381
Dollars	97	137	145	191	282	378	242	476	736	181	192
Chesapeake ‡											
Pounds	5,162	6,150	5,827	6,146	7,759	4,702	3,964	5,888	7,864	6,131	4,051
Dollars	975	1,130	935	1,215	1,427	1,029	1,150	1,498	2,324	1,561	1,805
So. Atlantic‡											
Pounds	486	654	1,817	1,913	1,569	2,320	1,451	1,266	1,758	1,016	1,303
Dollars	77	100	253	385	325	479	314	359	594	393	630
TOTAL											
Pounds	7,712	9,076	10,469	11,105	12,398	10,079	7,823	10,110	14,739	9,893	7,450
Dollars	1,457	1,649	1,725	2,279	2,487	2,309	2,130	2,780	4,674	2,883	3,517

* From USNOAA, 1975; Current Fisheries Statistics, District Summaries
**From USNOAA, 1976; Current Fisheries Statistics (preliminary)
† Provided by Fred Blossum (NMFS)
‡ From USNOAA, 1967-74; Fisheries Statistics of the United States

Table 17. Ranking of fish landed (thousands of pounds) by sport fishermen in North Atlantic sport fishery region (1970 Salt-Water Angling Survey; Deuel, 1973).

Rank	Species	Landings
1	Bluefish	50,161
2	Striped bass	45,844
3	Atlantic mackerel	41,482
4	Flounder	36,295
5	Cod	35,688
6	Tautog	15,629
7	Puffer	7,899
8	Pollack	5,584
9	Shark	4,795
10	Tuna	3,711
11	Kingfish	3,457
12	Searobin	2,343
13	Porgy	2,296
14	Cunner	1,914
15	Weakfish	1,645

Jersey and Delaware). In 1973, striped bass ranked fifth in value ($1,020,000) and sixth in pounds landed (3,093,000 lb) in the Middle Atlantic district (Table 16). In 1975, this region contributed 23% of the total commercial poundage from the Atlantic Coast. In New York State, 1,183,000 lb ($639,000) of striped bass were landed. This was about 16% of the Atlantic Coast poundage. The Hudson River contribution was 46,200 lb valued at $24,900, approximately 4% of the New York State total and < 1% of the total Atlantic Coast catch. Hudson River landings since 1965 have ranged from 17,900 lb (1972) to 77,200 lb (1969)(Table 16).

The striped bass sport catch is even more extensive than commercial landings. In 1970, the catch ranked second behind that of bluefish (Table 17). Although sport catch statistics have been considered overestimations (Deuel, 1973), sport landings may have exceeded commercial landings by a factor of 8.3 along the New England and New York coast (Texas Instruments, Inc., 1977) in 1975. If this is so, the sport catch of striped bass for the North Atlantic can be estimated to be 12,981,000 lb (Texas Instruments, Inc., 1977).

7. CONCLUSIONS

We divide our concluding remarks between some general conclusions concerning the biology of the estuary and points concerning work that may be needed to understand the biology of the estuary more fully.

The plankton-nutrient cycle of the estuary is rather well understood and decidedly unusual. Nutrient concentrations are remarkably high and do not limit primary production. A substantial amount of the total nutrient supply moves into the New York Bight apex and fuels primary production there. Within the estuary, primary production is more strongly related to increasing light and temperature in the spring and summer. Nutrient supply is governed mainly by sewage input into the estuary.

Species composition of the phytoplankton follows a pattern expected in an estuarine system. Diatoms are more abundant in winter months and are probably from offshore via the salt intrusion. In the summer, nannoplankton dominate. Zooplankton are dominated by typical estuarine species such as calanoid copepods, but strong fluctuations occur between locations and years. Some of these fluctuations can be related to hydrography (e.g., Jeffries, 1962). No strong evidence exists to relate zooplankton abundance to phytoplankton abundance patterns, save for a general common abundance peak in the summer.

The benthos are known mainly from periodic sampling over wide areas of Raritan Bay. Because of the complex spatial pattern of variation, one can only be confident of a general association between sediment-type and macrobenthic species occurrence. Two major surveys in 1957-1960 (Dean, 1975) and 1973-1974 (McGrath, 1974) can be used to assess temporal changes. Several molluscan species declined significantly between the two sampling periods. In addition, species richness and overall macrobenthic abundance declined significantly. Species indicative of overall disturbance were more abundant in the later sampling survey period. This may be construed as a pattern of decline of the benthos. No causal relationship, however, has been established between the decline and any particular natural or anthropogenic factor.

Fish species composition is generally what might be expected for a typical middle-Atlantic estuary. Patterns of abundance, both seasonal and spatial, are not surprising, given our knowledge of the habitat preferences and spawning migration cycles of the major species. The Lower Bay seems to have lower fish densities and fewer species than the Great Bay-Mullica River estuary. Of interest is the paucity of benthic-feeding species, relative to other estuaries of the region.

Aside from studies on phytoplankton productivity and nutrient movement within the estuary, there is a conspicuous lack of emphasis on processes within the estuary. Thus, little is known about the following matters of crucial concern to the ecological well-being of benthic and fish populations:

1. Cycling of particulate matter between the water column and the benthos.
2. Microbial cycling of organic matter within the sediment. Effects of toxic substances on microbial activity. Availability of various classes of particulate organic matter to microbes and the benthos.
3. Secondary production of the macrobenthos. Seasonal variation of benthic distributions.
4. Extent of predation on the benthos by benthic invertebrate feeders and demersal fishes.
5. Secondary production of the finfishes and commerially important invertebrates. Demographic studies useful to relate abundance to food supply, substratum, spawning cycles, etc.
6. Mechanisms and routes of transfer of toxic substances through the food web.

In lieu of the above, most studies, as we have reported, tend to consist of static, one-time-only samplings. Where successive sampling has occurred, differences in sampling gear, sample station array, or taxonomic analysis, usually weaken some, or even most, conclusions that may be drawn. Even when differences can be inferred with confidence, explanations are usually elusive. Any of a number of factors may usually be invoked in a system with natural variation, large anthropogenic inputs, and even occasional catastrophes (e.g., summer anoxia). The system is, therefore, an ideal but virtually untapped environment for the study of nutrient enrichment, toxic effects, and waste effects in general.

Standardized sampling has been adopted in recent years and will permit more consistent comparisons among years within the same estuary and among estuaries. However, aside from some studies on phytoplankton and nutrients, a continued reliance upon static sampling studies will add little to our understanding of pollution, as it affects estuarine biological dynamics. The understanding of processes requires an experimental approach in conjunction with field sampling.

Several recommendations stem from our summary of current knowledge. First, far too little synthesis has been attempted by most of the active researchers in the region. Numerous data sets have been collected and left unanalyzed. This practice accumulates data, but fails to present a useful picture of the overall state of the estuary. It is essential that a clearinghouse for data accumulation and analysis be established. This will help to eliminate redundant work, standardize sample collecting, and give statisticians easy access to previous work.

Second, large-scale sampling programs should be avoided unless some specific hypothesis is to be tested, or the accumulation of some essential information (e.g., census of a commercial stock) is deemed necessary. The scattered surveys now available have, in retrospect, taught us little.

Third, biologically important aspects of the environment should be assessed--particularly sedimentary and hydrodynamic parameters. How can surveys of benthic invertebrates and fish be useful without a thorough investigation of the biologically meaningful properties of sediments? Bottom erosion, sediment-water column interactions, biogenically related properties of sediment, etc., have been unstudied.

Finally, we recommend that an experimental approach be adapted to problem-solving. It is often possible to manipulate field conditions or establish laboratory microcosms to experimentally intercede with complex processes.

Laboratory investigation of toxicants, for example, might establish whether field populations have evolved tolerance, or whether increased toxicant loads will inevitably drive the species in question to extinction. An experimental introduction (e.g., oysters in racks) might define the ecological and physiological reasons why populations disappear. Experiments may preclude complete realism, but they at least circumvent the problems of interpreting the complex correlations to be found in static surveys.

It is easy to see why so much previous effort has yielded so little. Most studies have not asked any questions beyond simply "what is there." This lack of a problem-solving approach has diffused our efforts and has led to the fuzzy picture we now have of the Hudson-Raritan estuary.

8. REFERENCES

Anon. 1962. The porgy in Raritan Bay. N.J. Div. Fish Game. Fish R & D Sec. Admin. Rept. 2 (Mimeo).

Ayers, J.C., B.H. Ketchum, and A.C. Redfield. 1949. Hydrographic considerations relative to the location of sewer outfalls in Raritan Bay. Woods Hole Oceanographic Institute Ref. No. 49-13, 41 pp.

Bath, D., C.A. Beebe, C.B. Dew, R.H. Reider, and J.H. Hecht. 1976. A list of common and scientific names of fishes collected from the Hudson River. Paper #33. In: Proc. 4th Symp. Hudson R. Ecol. W.H. McKeon and G.J. Lauer (eds.). Hudson River Environmental Society, Inc., New York. 6 pp.

Bigelow, H.B., and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish Wildlife Service Bull. 74:1-577.

Bigelow, H.B., and W.W. Welsh. 1925. Fishes of the Gulf of Maine. U.S. Bureau of Fisheries. 40:1-567.

Brinkhuis, B.H. 1980. Biological effects of sand and gravel mining in the Lower Bay of New York Harbor: An assessment from the literature. Marine Sciences Research Center, State Univ. of N.Y. Special Rept. 34. 193 pp.

Burdick, G.E. 1954. An analysis of the factors including pollution having possible influence on the abundance of shad in the Hudson River. N.Y. Fish Game J. 1:188-205.

Calabrese, A. 1971. The pH tolerance of embryos and larvae of the coot clam *Mulinia lateralis* (Say). Veliger 13:122-126.

Croker, R.A. 1965. Planktonic fish eggs and larvae of Sandy Hook Estuary. Chesapeake Sci., 6:92-95.

Daiber, F.C., and R.W. Smith. 1971. An analysis of fish populations in the Delaware Bay area. 1970-71 Annual Dingell-Johnson Report to Delaware Board of Game and Fish Commissioners. Project No. F-13-R-13, Job No. I-1, 116 pp.

Dean, D. 1975. Raritan Bay macrobenthos survey. 1957-1960. NOAA Nat'l. Mar. Fish Serv. Data Rept. 99, 51 pp.

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

de Falco, P. 1967. Report for the conference on pollution of Raritan Bay and adjacent interstate waters, 3rd session. Fed. Wat. Pollut. Contr. Admin., N.Y. pp. 815-865.

Derickson, W.K., and K.S. Price, Jr. 1973. The fish of the shore zone of Rehoboth and Indian River Bays, Delaware. Trans. Am. Fish. Soc. pp. 552-562.

Deuel, D.G. 1973. 1970 saltwater angling survey. U.S. Dept. Comm. NOAA, Nat'l. Mar. Fish. Ser., Current Fish Statistics 6200, 54 pp.

Diaz, R.J., and D.F. Boesch. In press. The macrobenthos of the Hudson-Raritan estuary. In: The Ecology of Macrobenthos of the New York Bight Region., D.F. Boesch (ed.). Ch. VI NOAA Tech. Rept.

Dougenik, J.A., and D.E. Sheehan. 1976. SYMAP User's Reference Manual. Bedford, Massachusetts, Camera Stat.

Doyle, B.E., and R.E. Wilson. 1978. Lateral dynamic balance in the Sandy Hook to Rockaway Point transect. Est. Coast. Mar. Sci. 6:165-174.

Duedall, I.W., H.B. O'Connors, R.E. Wilson, and J.H. Parker. 1979. The Lower Bay Complex. MESA (Marine Ecosystems Analysis), NY Bight Atlas Monograph 29, NY Sea Grant Inst., Albany, N.Y. 47 pp.

Esser, S.C. 1982. Long-term changes in some finfishes of the Hudson-Raritan Estuary. pp. 299-314. In: Ecological stress and the New York Bight: science and management (G.F. Mayer, ed.). Estuarine Research Federation, Columbia, South Carolina.

Franz, D.R. 1982. An historical perspective on molluscs in Lower N.Y. Harbor, with emphasis on oysters. In: Ecological stress and the New York Bight: science and management (G.F. Mayer, ed.). Estuarine Research Federation, Columbia, South Carolina.

Frederick, W.W., R.L. Heffner, A.T. Packard, P.M. Eldridge, J.C. Eldridge, G.J. Schumacher, K.L. Eichorn, J.H. Currie, J.N. Richards, and O.C. Boody, IV. 1976. Notes on phytoplankton distribution in the Hudson River estuary. Paper #34.

In: W.H. McKeon and G.J. Lauer (eds.), Proc. 4th Symp. Hudson R. Ecol. Hudson River Environmental Society, Inc., New York. 19 pp.

Gaertner, M.P. 1976. Seasonal migration of fishes of importance to New York State. M.S. Thesis, State Univ. of N.Y. at Stony Brook, 58 pp.

Garside, C., T.C. Malone, O.A. Roels, and B.A. Sharfstein. 1976. An evaluation of sewage derived nutrients and their influence on the Hudson Estuary and N.Y. Bight. Est. Coast. Mar. Sci. 4:281-289.

Giese, G.L., and J.W. Barr. 1967. The Hudson River Estuary: A preliminary investigation of flow and water-quality characteristics. State of New York Conservation Dept. Water Resources Commission. Bull. 67. Albany, N.Y. 39 pp.

Greeley, J.R. 1937. II. Fishes of the area with annotatedlist. pp. 45-103. In: A biological survey of the lower Hudson watershed. N.Y.S. Conserv. Dept. Suppl., 26th Ann. Rept. Albany.

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

Gross, M.G. 1970. Analyses of dredged wastes, fly ash, and waste chemicals-New York metropolitan region. Marine Research Center, State Univ. of N.Y. Tech. Rept. 7, 33 pp.

Hazen and Sawyer Engineers. 1980. Newtown Creek water pollution control plant. Final report of monitoring program May-Oct., 1980. For an application for modification of the requirements of secondary treatment under section 301 (h) of PL95-217. Prepared for City of New York, Dept. of Environmental Protection. 75 pp.

Hendrickson, S. 1970. Shellfish population survey of Raritan Bay. N.Y. State Dept. of Envir. Conserv., in house report.

Ichthyological Associates, Inc. 1974a. An ecological study of the Arthur Kill in the vicinity of the Sewaren Generating Station, Sewaren, N.J. Prepared for Public Service Electric and Gas Co. 132 pp.

Ichthyological Associates, Inc. 1974b. An ecological study of the Arthur Kill in the vicinity of the Linden Generating Station, Linden, N.J. Prepared for Public Service Electric and Gas Co. 180 pp.

Ichthyological Associates, Inc. 1974c. An ecological study of the Hackensack River in the vicinity of the Kearny generating station, Kearny, N.J. Prepared for Public Service Electric and Gas Co. 133 pp.

Ichthyological Associates, Inc. 1974d. An ecological study of the Passaic River in the vicinity of the Essex generating station, Newark, N.J. Prepared for Public Service Electric and Gas Co. 131 pp.

Ichthyological Associates, Inc. 1974e. An ecological study of the Hackensack River in the vicinity of the Hudson generating station, Jersey City, N.J. Prepared for Public Service Electric and Gas Co. 133 pp.

Ichthyological Associates, Inc. 1974f. An ecological study of the Upper Hackensack River in the vicinity of the Bergen generating station. Prepared for Public Service Electric and Gas Co. 217 pp.

Ichthyological Associates, Inc. 1974g. Ecological studies in the bays and other waterways near Little Egg Inlet and in the ocean in the vicinity of the proposed site for the Atlantic Generating Station, N.J. Vol. 1 Fishes. Prepared for Public Service Electric and Gas Co. 709 pp.

Ichthyological Associates, Inc. 1976. Ecological studies in the Arthur Kill and Morses Creek in the vicinity of the Exxon Bayway Refinery, Linden, N.J. May 1975-1976, Parts I and II. Prepared for Exxon Company, U.S.A. 585 pp.

Interstate Sanitation Commission. 1981. The 1980 Report of the Interstate Sanitation Commission on the water pollution control activities and the interstate air pollution program. ISC, New York, N.Y. 84 pp.

Jacot, A. 1920. Some marine mollusca about N.Y.C. Nautilus 32:90-94.

Jeffries, H.P. 1962. Environmental characteristics of Raritan Bay - a polluted estuary. Limnol. Oceanogr. 7:21-31.

Kao, A.Z.H. 1975. Current structure in Sandy Hook to Rockaway Point transect. M.S. Thesis, State University of New York, Stony Brook. 82 pp.

Kastens, K.A., C.T. Fray, and J.R. Schubel. 1978. Environmental effects of sand mining in the lower bay of N.Y. Harbor - Phase I. Marine Science Research

Center, State Univ. of N.Y. Special Rpt. 15 (Ref. 78-3). 139 pp.

Kawamura, T. 1966. Distribution of phytoplankton populations in Sandy Hook Bay and adjacent areas in relation to hydrographic conditions in June 1962. U.S. Fish and Wildl. Serv. Tech. Pap. 1. 37 pp.

Ketchum, B.H. 1951. The flushing of tidal estuaries. Sewage and Industrial Wastes 23:198-208.

Klauda, R.J., M. Nittel, and K.P. Campbell. 1977. The commercial fishery for American shad in the Hudson River: Fishing effort and stock abundance trends. Proc. Workshop on American shad. Amherst, MA, Dec. 14-16, 1976. U.S. Fish Wildlife Serv. and Nat'l. Mar. Fish. Ser. pp.107-134.

Lawler, Matusky and Skelly Engineers. 1980. Biological and water quality data collected in the Hudson River near the proposed Westway project during 1979-1980. Vol. 1. Prepared for New York State Department of Transportation, System Design Concepts, Inc.

Levinton, J.S. 1970. The paleoecological significance of opportunistic species. Lethaia 3:69-78.

MacLeod, W.D., L.S. Ramos, A.J. Friedman, D.G. Burrows, P.G. Prohaska, D.L. Fisher, and D.W. Brown. 1981. Analysis of residual chlorinated hydrocarbons, and related compounds in selected sources, sinks and biota of the New York Bight. NOAA Technical Memorandum OMPA-6. 128 pp.

Mahoney, J.B., F.H. Midlege, and D.G. Deuel. 1973. A fin rot disease of marine and euryhaline fishes in the N.Y. Bight. Trans. Amer. Fish Soc. 102:596-605.

Mahoney, J.B., and J.J.A. McLaughlin. 1977. The association of phytoflagellate blooms in lower N.Y. Bight with hypertrophication. J. Exp. Mar. Biol. Ecol. 28:53-65.

Malone, T.C. 1977a. Environmental regulation of phytoplankton productivity in the lower Hudson Estuary. Est. Coast. Mar. Sci. 5:157-171.

Malone, T.C. 1977b. Plankton systematics and distribution. MESA (Marine Ecosystems Analysis), N.Y. Bight Atlas Monogr. 13, N.Y. Sea Grant Institute, Albany. 45 pp.

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

McCarthy, A.J. 1965. An ecologicaly study of the phytoplankton of Raritan Bay. Ph.D. Thesis, Fordham Univ. N.Y. 109 pp.

McCormick, J.M., and S.J. Koepp. 1978. Distribution, diversity, and toxicological response of resident species, as correlated with changes in the physicochemical environment of Newark Bay. Sea Grant Biennial Report RP-1, pp. 15-24, N.J. Marine Sciences Consortium.

McCormick, J.M., and P.T. Quinn. 1975. Phytoplankton diversity and chlorophyll-a in a polluted estuary. Mar. Pollut. Biol. 6:105-106.

McGrath, R.A. 1974. Benthic macrofaunal census of Raritan Bay - preliminary results. Paper #24, Proc. 3rd Symp. Hudson R. Ecol. Hudson River Environmental Society, Inc., N.Y. 27 pp.

McHugh, J.L. 1972. Marine fisheries of New York State. Fish. Bull. 70:585-610.

Mueller, J.A., J.S. Jeris, A. Anderson, and C. Hughes. 1976. Contaminant inputs to the New York Bight. NOAA Tech. Mem. ERL MESA-6. 347 pp.

National Marine Fisheries Service (NMFS). 1971. Review of aquatic resources and hydrographic characteristics of Raritan, Lower New York and Sandy Hook Bays. Sandy Hook Sport Fisheries Marine Laboratory. Prepared for the Battelle Memorial Institute. 65 pp.

N.J. Dept. Env. Prot., Div. Fish, Game & Shellfish, Bur. of Fisheries, Nacote Creek Resch. Sta. 1973a. Survey of aquatic organisms in the vicinity of Conaskonk Pt., Raritan Bay. In house rpt. 12 pp.

N.J. Dept. Env. Prot., Div. Fish, Game & Shellfish, Bur. of Fisheries, Nacote Creek Resch. Sta. 1975b. Survey of aquatic organisms, Caven Pt. Cove, Hudson River. In house rpt. 17 pp.

N.J. Dept. Env. Prot., Div. Fish, Game & Shellfish, Bur. of Fisheries, Nacote Creek Resch. Sta. 1975. Survey of intertidal and nearshore benthic fauna at Atlantic Highlands, Sandy Hook Bay. In house rept. 11 pp.

New York State Department of Environmental Conservation. 1970. Raritan Bay shellfish survey. In house rept., NYSDEC.

National Oceanographic and Atmospheric Administration (NOAA). 1971. Tide tables 1972 east coast of North and South America. U.S. Dept. of Commerce, National Ocean Survey. Washington, D.C. 290 pp.

Oceanographic Analysts, Inc. 1970. Ecological studies related to the proposed increase in generating capacity at the Astoria Power Station. Chapter V. In: Effect of Astoria Plant cooling water discharge on East River temperature distribution and ecology, 30 pp. A report prepared by Quirk, Lawler and Matusky Engineers and Oceanographic Analysts, Inc., for Consolidated Edison Co. of N.Y., Inc.

Ogren, L., and J. Chess. 1969. A marine kill on New Jersey wrecks. Underwater Natur. 6:4-13.

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

O'Reilly, J.E., J.P. Thomas, and E. Evans. 1976. Annual primary production (nannoplankton, netplankton, dissolved organic matter) in the Lower New York Bay, Paper #19. In: Proc. 4th Symp. Hudson R. Ecol. (W.H. McKeon and G.J. Lauer, eds.), Hudson River Environmental Society, Inc., New York. 39 pp.

Oviatt, C.A., and S.W. Nixon. 1973. The demersal fish of Narragansett Bay: an analysis of community structure, distribution and abundance. Est. Coast. Mar. Sci. 1:361-378.

Panuzio, F.L. 1966. The Hudson River Model. In: Hudson R. Ecol. Proc. Symp. on Hudson R. Ecol. Oct. 4-5, 1966, Tuxedo, N.Y. Hudson River Valley Commission of New York.

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

Pearce, J.B. 1979. Raritan Bay - a highly polluted estuarine system. Internat'l Council for the Exploration of the Sea. 16 pp.

Pearcy, W.G., and S.W. Richards. 1962. Distribution and ecology of fishes of the Mystic River estuary, Connecticut. Ecology 43:248-259.

Perlmutter, A. 1939. A biological survey of the salt waters of Long Island, 1938. Sect. I. An ecological survey of young fish and eggs identified from tow-net collections. Suppl. 28th Ann. Rep. N.Y. Cons. Dept., Pt. II:11-71.

Pippy, J.H.C., and G.M. Hare. 1969. Relationship of river pollution to bacterial infection in salmon (Salmo salar) and suckers (Catostomus commersoni). Trans Amer. Fish. Soc. 98:685-690.

Pringle, B.H., D.E. Hissang, E.L. Katz, and S.T. Mulawka. 1968. Trace metal accumulation by estuarine molluscs. Amer. Soc. of Civil Engineers Proc. J. San. Engineering Div. 94(SA 3). Paper 5970, pp. 455-475.

Quirk, Lawler and Matusky, Engineers. 1973. A study of impinged organisms at the Astoria Generating Station. Prepared for Consolidated Edison Co. of N.Y. 63 pp.

Raney, E.C., W.S. Wolcott, and A.G. Mehring. 1954. Migratory pattern and racial structure of Atlantic Coast striped bass. Trans. 19th N. Am. Wildl. Conf.:376-396.

Raytheon Company. 1972. An ecological survey of the Arthur Kill. Prepared for United Engineers and Constructors, Philadelphia, PA. 66 pp.

Rhoads, D.C. 1975. Bivalve death assemblages in central Long Island Sound over the past 150. Ms.

Richards, S.W. 1963. The demersal fish population of L.I. Sound. III. Food of the juveniles from a mud locality (Station 3A). Bull. Bingham Oceanogr. Collect., 18:73-101.

Ristich, S.S., J. Fortier, and M. Crandall. 1973. Benthic community. In: Maintenance of a Functional Environment in the Hudson River Estuary, pp. C - C . Boyce Thompson Inst. 2nd Ann. Rpt. to the Rockefeller Foundation, Yonkers, N.Y.

Sage, L.E., and S.S. Herman. 1972. Zooplankton of the Sandy Hook Bay Area, N.J. Chesapeake Sci. 13:29-39.

Saila, S.B., and S.P. Pratt. 1971. Mid-Atlantic bight fisheries, pp. 6.1-6.125. In: Coastal and offshore environmental inventories - Cape Hatteras to Nantucket shoals. Univ. R. Is.

Sanders, H.L. 1956. Oceanography of L.I. Sound, 1952-1954. X. The biology of marine bottom communities. Bull. Bingham Oceanogr. Coll. 15:345-414.

Sanders, H.L. 1958. Benthic studies in Buzzards Bay. I. Animal-sediment relationships. Limnol. Oceanogr. 3:245-258.

Sanders, H.L., P.C. Mangelsdorf, and G.R. Hampson. 1965. Salinity and faunal distribution in the Pocasset River, Massachusetts. Limnol. Oceanogr. 10:R216-R229.

Scotton, L.N., R.E. Smith, N.S. Smith, K.S. Price, and D.P. de Sylva. 1973. Pictorial guide to fish larvae of Delaware Bay, with information and bibliographies useful for the study of fish larvae. Delaware Bay Report Series, Vol. 7, College Marine Studies, Univ. of Delaware. 206 pp. The study of fish larvae. Delaware Bay Report Series, Vol. 7, College Marine Studies, Univ. of Delaware. 206 pp.

Simpson, H.J., D.E. Hammond, B.L. Deck, and S.C. Williams. 1975. Nutrient budgets in the Hudson River estuary. In: Marine Chemistry in the Coastal Environment, pp. 618-635 (T.M. Church, ed.). Amer. Chem. Soc. Symp. Ser. 18, Washington, D.C.

Sirois, D.L., and S.W. Fredrick. 1978. Phytoplankton and primary productivity in the lower Hudson River estuary. Est. Coast. Mar. Sci. 7:413-423.

Stainken, D., and J. Rollwagon. 1979. PCB residues in bivalves and sediments of Raritan Bay. Bull. Envir. Contam. Toxicol. 23:690-697.

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

Stephenson, R.R., and D. Taylor. 1975. The influence of EDTA on the mortality and burrowing activity of the clam Venerupsis decussata exposed to sublethal concentrations of copper. Bull. Envir. Contam. Toxicol. 14:304-308.

Storm, P.C., and R.L. Heffner. 1976. A comparison of phytoplankton abundance, chlorophyll a and water quality factors in the Hudson River and its tributaries. Paper #17, in: W.H. McKeon and G.J. Lauer (eds.), Proc. 4th Symp. Hudson R. Ecol. Hudson River Environmental Society, Inc., New York, 39 pp.

Swartz, S.M., and B.H. Brinkhuis. 1978. The impact of dredged holes on oxygen demand in the Lower Bay, New York Harbor. Reference 78-5, Special Report 17, Marine Science Research Center, S.U.N.Y. at Stony Brook, 80 pp.

Talbot, G.B. 1954. Factors associated with fluctuations in abundance of Hudson River shad. Fish Wildl. Ser. Fish. Bull. 56:373-413.

Texas Instruments, Inc. 1975. First annual report for the multi-plant impact study of the Hudson River estuay. Volume I and II. Prepared for Consolidated Edison Company of New York, Inc.

Texas Instruments, Inc. 1976. Liberty State Park Ecological Study. Prepared for the Port Authority of New York and New Jersey. 171 pp.

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

Thomas, J.P., W.C. Phoel, F.W. Steimle, J.E. O'Reilly, and C.E. Evans. 1976. Seabed oxygen consumption - N.Y. Bight apex. Am. Soc. Limnol. Oceanogr. Spec. Symp. 2:354-369.

Waldhauer, R., A. Matte, and R. Tucker. 1978. Lead and copper in the waters of Raritan Bay and Lower N.Y. Bay. Mar. Pollut. Bull. 9:38-42.

Weis, P., and J.W. Weis. 1977a. Methylmercury teratogenesis in the killifish, Fundulus heteroclitus. Teratology 16:317-326.

Weis, J.S., and P. Weis. 1977b. The effects of heavy metals on embryological development of the killifish, Fundulus heteroclitus. J. Fish. Biol. 11:49-54.

Wilk, S.J., W.W. Morse, D.E. Ralph, and T.R. Azarovitz. 1977. Fishes an associated environmental data collected in N.Y. Bight, June 1974-June 1975. NOAA Tech. Rpt. NMFS SSRF-716, 53 pp.

Wilk, S.J., and M.J. Silverman. 1976. Summer benthic fish fauna of Sandy Hook Bay, N.J. Natl. Mar. Fish. Serv. Tech. Rpt. NMFS-SSRF-698, 20 pp.

Wise, W.M. 1975. The fisheries and fishery resources of Long Island Sound. M.S. Thesis, S.U.N.Y. at Stony Brook, N.Y.

Yamazi, I. 1966. Zooplankton communities of the Navesink and Shrewsbury Rivers and Sandy Hook Bay, N.J. U.S. Fish. Wildl. Serv. Tech. Pap. 2:1-44.

Ziskowski, J., and R. Murchelano. 1975. Fin erosion in winter flounder. Mar. Pollut. Biol. 6:26-29.