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Biological Effects of Sand and Gravel Mining in the Lower Bay of New York Harbor: An Assessment from the Literature

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B.H. Brinkhuis

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Approved for Distribution

J.R. Schubel

J.R. Schubel, Director

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Finally, I would like to thank three special people who were really put to the task in typing and drafting figures for this lengthy report: Marjorie Sumner, Mary Jane Hamilton, and Marie Eisel.

SCOPE

This overview is designed to provide an assessment of potential biological effects of sand and gravel mining in the Lower Bay Complex of New York Harbor. This assessment is made from the currently available literature concerning distribution and abundance of organisms in the Lower Bay Complex in relation to what is known about effects associated with sand and gravel mining/dredging operations. In particular, the effects of suspended sediments on various organisms will be examined. Most of the literature regarding potential suspended sediment effects on Lower Bay organisms is derived from studies conducted elsewhere. The assessment encompasses suspended sediment effects on benthic infauna (e.g., shellfishes, worms, and other burrowing animals) and epibenthic fauna, including amphipods, crustacea, and demersal fishes. Other effects associated with mining/dredging operations, e.g., release of contaminants and nutrients from sediments, also are examined.

In order to properly evaluate mining/dredging effects, not limited only to suspended sediment loads, nutrient and contaminant release, a survey of the literature on other biological, chemical, and physical properties of Lower Bay waters and sediments is included.

A variety of mining strategies which could minimize suspended sediment loads to within reported tolerance ranges of "critical" species is discussed. These strategies are evaluated with the aid of computer simulations of the dispersion of suspended sediment plumes resulting from point sources (mining/processing barges) under a variety of sediment input loads and current regimes in different locations within the Lower Bay Complex. The predicted plume dispersion patterns of suspended sediment concentrations are integrated into assessments of probable effects on organisms (from the aforementioned literature survey) in various areas of the Lower Bay Complex.

BACKGROUND

Sand deposits in the Lower Bay Complex of New York Harbor (Fig. 1) are becoming the largest single source of commercial sand for fill and aggregate in construction projects within the New York metropolitan area since 1963 (Schlee, 1975; Kastens et al., 1978; Carlisle and Wallace, 1978). According to the New York State Office of General Services (Marotta, personal communication) and calculations from bathymetric changes (Brinkhuis and Sanko, unpublished data), more than 89 million cubic yards (mcy) [68 million cubic meters (mcm)] have been mined for commercial and public works projects between 1950 and 1975. From 1950 to 1971, most of the sand was obtained from the West Bank region of the Lower Bay, while after 1971 mining was conducted principally on the East Bank (see Fig. 1). A review of these mining projects and yearly volumes of sediment removed is presented in Kastens et al. (1978) and is summarized in Table 1.

The demand for sand obtained from the Lower Bay Complex will likely increase in the near future (Carlisle and Wallace, 1978; Courtney et al., 1979). Based on current and pending construction proposals, the demand for sand and aggregate in the New York metropolitan area will probably exceed 8.5 mcy (6.5 mcm) per year

Fig. 1: Location Map.

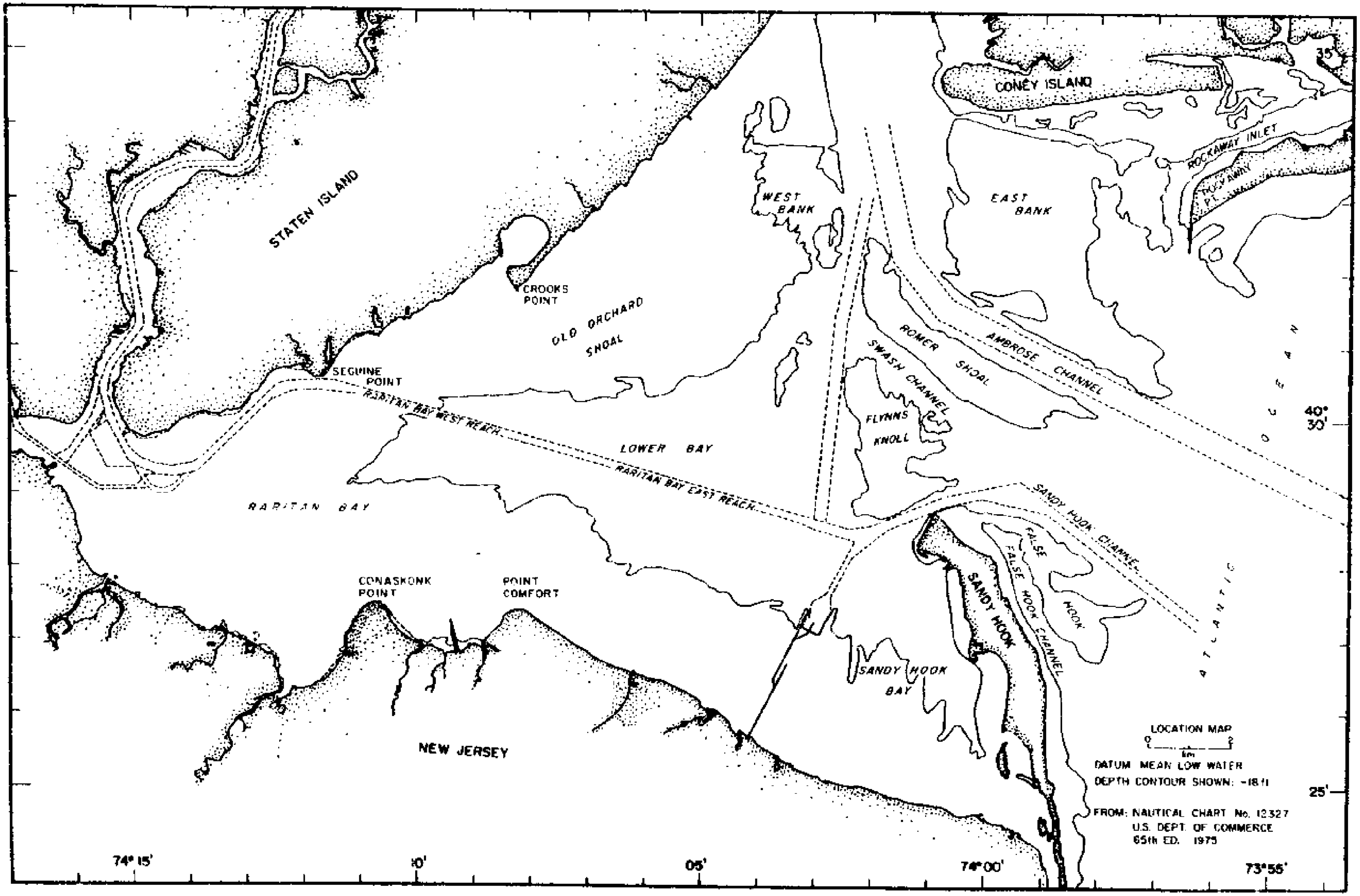


Table 1. Estimates of Volume of Sediment Dredged from New York Harbor[1]

Year	Commercial Mining*, ** (Royalties Paid) Volume, m^3	(yds³)	Public Works Mining*,** (No Royalties) Volume, m^3	(yds³)	Project	Location of Mining†	Maintenance Dredging†† Ambrose and Chapel Hill Volume, m^3	(yds³)			Year
1950	764,600	(1,000,000)	2,610,310	(3,414,157)	Newark Airport						1950
1951	764,600	(1,000,000)									1951
1952	764,600	(1,000,000)									1952
1953	229,400	(300,000)									1953
1954	229,400	(300,000)									1954
1955	229,400	(300,000)									1955
1956	229,400	(300,000)									1956
1957	229,400	(300,000)	206,300	(269,800)	Brooklyn Piers						1957
1958	841,000	(1,100,000)	837,900	(1,095,900)	LaGuardia/Brooklyn Piers						1958
1959	841,000	(1,100,000	143,000	(187,000)	Port Newark						1959
1960	841,000	(1,100,000)									1960
1961	841,000	(1,100,000)	6,115,100	(7,998,200)	Elizabeth Piers		454,600	(594,600)			1961
1962	841,000	(1,100,000)					115,400	(151,000)			1962
1963	3,440,500	(4,500,000)	11,125,600	(14,551,800)	Newark Airport		240,800	(315,000)			1963
1964	3,440,500	(4,500,000)									1964
1965	261,100	(341,500)			Rte. 78, N.J.						1965
1966	1,778,000	(2,325,500)			Rte. 78, N.J.		675,900	(884,050)	636,400	(832,400)	1966
1967	3,757,400	(4,914,400			N.J. Turnpike						1967
1968	2,592,700	(3,391,100)			Elizabeth Piers		167,100	(218,500)			1968
1969	3,402,300	(4,450,000)			Amer. Export Ind. N.J. Turnpike						1969
1970	727,400	(951,400)	1,662,900	(2,175,000)	Port Elizabeth N.J. Turnpike Amer. Export Ind.						1970
1971	3,284,100	(4,295,400	764,600	(1,000,000)	Newark, N.J., P.O.						1971
1972	(1,540,600)	(2,015,000)	4,086,200	(5,344,400)	Port Elizabeth Newark, N.J. Airport Battery Park City Hartz Mt. Ind. Pk	90% East Bank 10% Chapel Hill North	1,167,300	(1,526,779)	463,170	(605,810)	1972
1973	(3,321,900)	(4,344,800)	1,895,200	(2,478,800	Port of N.J. Port of Newark Battery Park City Bowery Bay Poll Plt.	92% East Bank 6% West Bank 2% Unknown					1973

Table 1. (continued)

Year	Commercial Mining*, ** (Royalties (Paid) Volume, m^3	(yds³)	Public Works Mining*, ** (No Royalties) Volume, m^3 (yds³)	Project	Location of Mining†	Maintenance Dredging†† Ambrose and Chapel Hill Volume, m^3	(yds³)	Year
1974	2,305,200	(3,015,100)		N.J. Turnpike Battery Pk. City Port of N.J. Bowery Bay Poll.Plant	90% East Bank 8% Chapel Hill North 2% Great Kill 90% East Bank 10% Chapel Hill North	470,670	(615,619)	1974
1975	3,821,800	(4,998,600)		N.J. Sports Complex Port of N.J. Bayonne Military Transport N.J. Turnpike Battery Park City				1975
TOTALS:	41,319,300[∞]	(54,042,800)	26,836,800[∞] (35,100,900)		3,292,207[∞] (4,306,048)	1,092,508[∞]	(1,429,210)	

† Reported values for volumes of sand dredged before 1965 may be too highly a factor of 2x, or more.

* From Peter Sanko for period 1950-1966

** From James Marotta for period 1966-1975

† From James Marotta

†† From John Zammit

∞ Metric equivalents were calculated from the basic data which were reported in yds³. The discrepancies result from rounding off.

(Schlee, 1975; Courtney et al., 1979). Sand resources located on land in, or near New York City have dwindled in recent years and are expected to be depleted within three to five years (Sanko, personal communication) due to competition for land with urban and suburban spreading and rising overland transportation costs. Overland transport from sources greater than 50 to 60 miles (80-95 kilometers) is becoming prohibitively expensive (Carlisle and Wallace, 1978). It has become more economical to mine, process, and barge sand from the Lower Bay Complex.

Since 1973, the mining of sand from the Lower Bay Complex has been restricted due to environmental concerns raised by a variety of agencies and citizen groups. The New York State Office of General Services and the New York Sea Grant Institute have, accordingly, sponsored a number of research projects designed to determine resource availability and environmental effects associated with sand mining in the Lower Bay Complex. These studies include:

1) effects on shore erosion due to altered bathymetry (Kinsman et al., 1979)

2) effects on circulation patterns and tidal currents and elevations due to altered bathymetry (Wong and Wilson, 1979)

3) environmental descriptions (Kastens et al., 1978)

4) effects of deep holes on circulation, water quality, and sediments (Swartz and Brinkhuis, 1978)

5) surficial sediment distribution and resource availability (Kastens et al., 1978; Jones et al., 1979; Carlisle and Wallace, 1978)

6) distribution and depth of surficial sediment deposits (Bokuniewicz and Fray, 1979)

7) site-specific faunal surveys in proposed mining sites (Brinkhuis, in progress)

8) assessments of biological effects of sand mining on fauna as determined from the literature (this report)

Until reports from all items, and especially 7 and 8, are available, it is unlikely that agencies and citizen groups will alter the current restriction on sand mining.

This report concerns an assessment of biological effects associated with sand mining as interpreted from existing literature on biota distribution in the Lower Bay Complex and literature on biological effects of sediment mining/dredging conducted elsewhere. Included are additional observations by the author on organism distribution in and around existing mined holes in the Lower Bay East and West Banks.

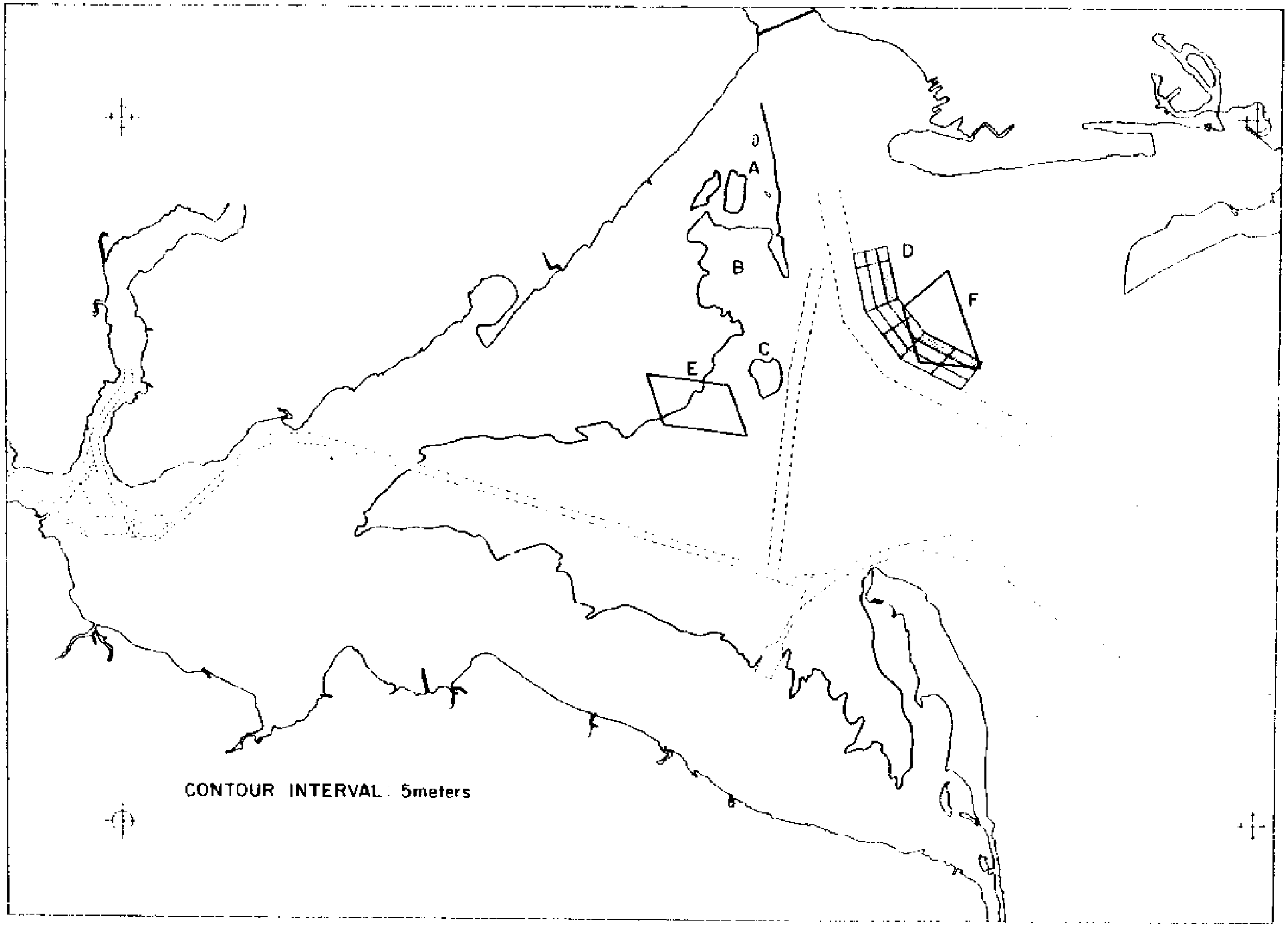
INTRODUCTION

General Features

The Lower Bay Complex of New York Harbor is an estuarine area, consisting of the Lower, Raritan, and Sandy Hook bays at the mouths of the Hudson and Raritan rivers (see Fig. 1). Waters of the Lower Bay Complex exchange and mix with 1) the waters of the Upper Bay of New York Harbor to the north through a narrow constriction between Brooklyn and Staten Island, called *The Narrows* and 2) the sea to the southeast through a relatively wide (~8 km) transverse opening between Sandy Hook and Rockaway Point, often referred to as the *Sandy Hook-Rockaway Pt. Transect*.

The Lower Bay Complex is shallow (5-20 m) and has an irregular submarine topography composed of numerous shoals, banks, and ship channels. These features, shown in Figure 1, have been described in detail by Fray (1969) and Kastens et al. (1978). On the West Bank of Ambrose Channel there are three areas which were mined for sand prior to 1973 (Fig. 2, Areas *A*, *B*, and *C*). The holes in Areas *A* and *B* were mined to depths of 8 to 14 m while in *C* the hole is 20 m deep. Unmined bottom sediment generally lies between 3 and 5 m below the water surface. On the East Bank

Fig. 2: Map showing locations of past mining activities (A-D) and future proposed mining (E, F).



of Ambrose Channel there is a large shoal which rises to within 2 to 4 m of the surface. There are numerous irregularly shaped holes 15 to 22 m deep in Area *D* which resulted from mining for sand between 1973 and 1976. These past mining operations were authorized to a depth of -15 m. Recent surveys by Brinkhuis (unpublished data, 1978) indicate that within Area *D*, only the shaded sectors still contain sand resource above the 15 m depth contour. In May 1978, the New York State Office of General Services proposed to explore the possibility of mining in Area *E* of the West Bank, near Old Orchard Shoal and Area *F* on the East Bank, adjacent to Area *D*. These areas will be *mined experimentally* in computer simulations to determine potential effects on circulation patterns, current velocities, tidal elevations, and shore erosion in the manner of Wong and Wilson (1979) and Kinsman and Schubel (1979). Further, faunal surveys of these proposed areas are in progress by the author.

Physical Oceanography

A number of studies have been conducted on circulation in the Lower Bay Complex and exchanges of these waters across The Narrows and the Sandy Hook-Rockaway Pt. Transect. Circulation in the Lower Bay Complex is controlled by inputs from the Hudson and Raritan rivers, winds, and tidal and nontidal flows. The tides in this region are dominated by the semi-diurnal tide (Parsons, 1913; Schureman, 1934). Tidal ranges for various locations in the Complex are shown in Table 2. Tides in the New York Bight cause tides in the New York Harbor (and Long Island Sound) to have different characters and phases from pure semi-diurnal tides (Marmer, 1923, 1935).

Jeffries (1962) indicated that the net current pattern of the Raritan and Lower bays produces a large counter-clockwise gyre (Fig. 3). A persistent clockwise eddy off Great Kills Harbor (Staten Island) separates the Raritan and Hudson river flows (Ayers, et al., 1949). Tidal current vectors for maximum ebb (Fig. 4) and maximum flood (Fig. 5) for July 1977 have been computed by Wong and Wilson (1979). During flood tide, higher salinity water enters Lower Bay between the Ambrose Channel and Rockaway Pt. (see Fig. 1), and continues in a southwesterly direction along the Staten Island shore. Duedall et al. (1979) and Doyle and Wilson (1978) indicate that tidal and nontidal flows, respectively, to the east of Ambrose Channel enter the Lower Bay at all depths. Over a complete tide cycle, there is a net westward drift of this water mass due principally to nontidal flows (Doyle and Wilson, 1978). During ebb tide, the lower salinity water from Sandy Hook and Raritan bays, diluted by freshwater input from the Raritan River, escapes around Sandy Hook into the New York Bight Apex (Fig. 6). Water from the Lower Bay, diluted primarily by fresh water from the Hudson River, flows out over the Ambrose Channel (Ayers et al., 1949).

Duedall et al. (1979) and Doyle and Wilson (1978) describe a two-layer nontidal circulation pattern in waters to the west of Ambrose Channel. Less saline water leaves the Lower Bay near the surface. A tongue of more saline New York Bight water persists at depth in channels

Table 2. 1976 tidal ranges in the Lower Bay Complex (from Swanson, 1976)

Location	Tidal range (m) Mean	Spring
Sandy Hook	1.40	1.71
The Narrows Hook	1.43	1.74
Great Kill Harbor	1.43	1.74
The Battery	1.37	1.65
Coney Island	1.43	1.74
South Amboy	1.52	1.83
Keyport	1.52	1.83
Atlantic Highlands	1.43	1.74
St. George	1.37	1.65

Fig. 3: Net current flows in the Lower Bay Complex. After Jeffries (1962).

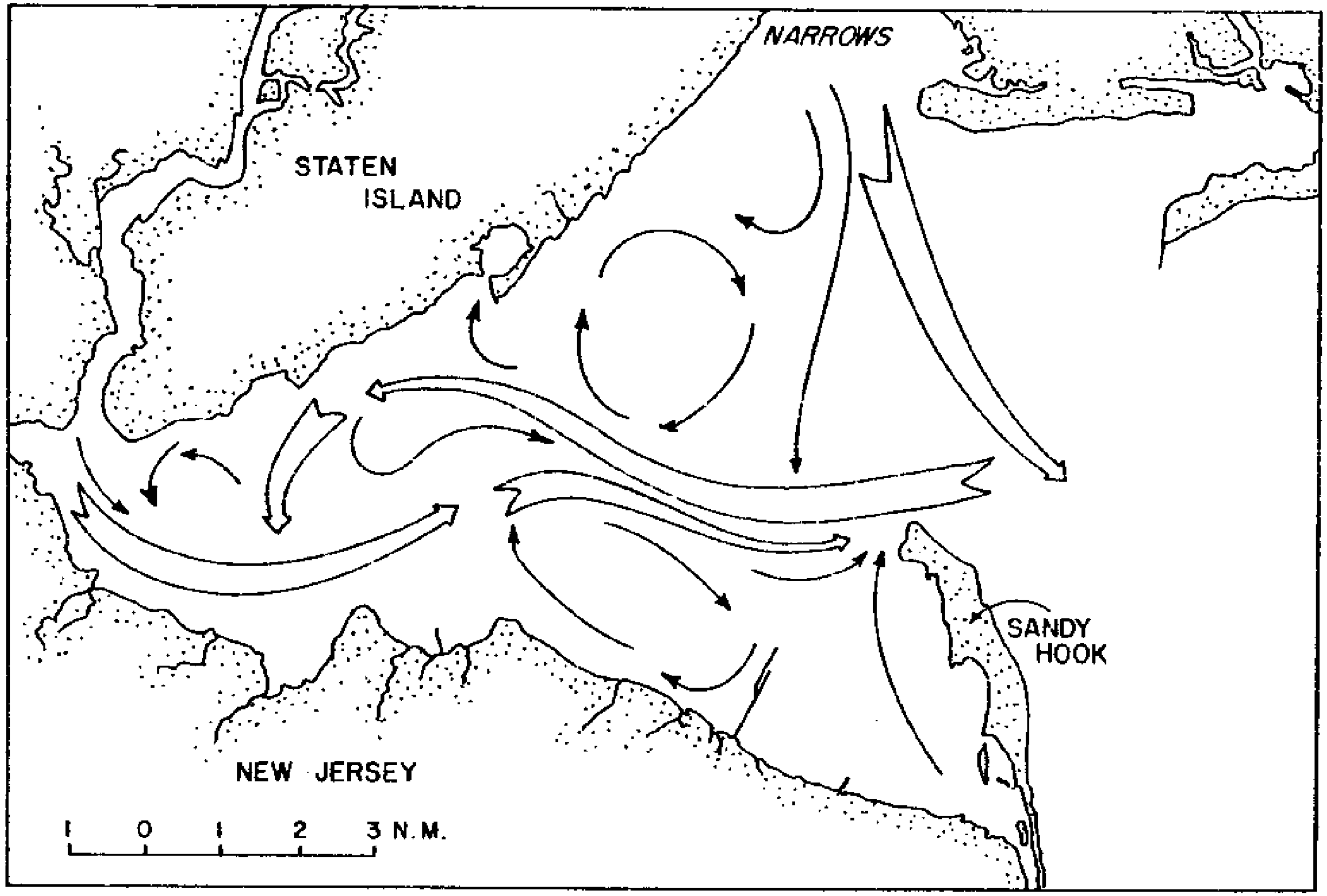
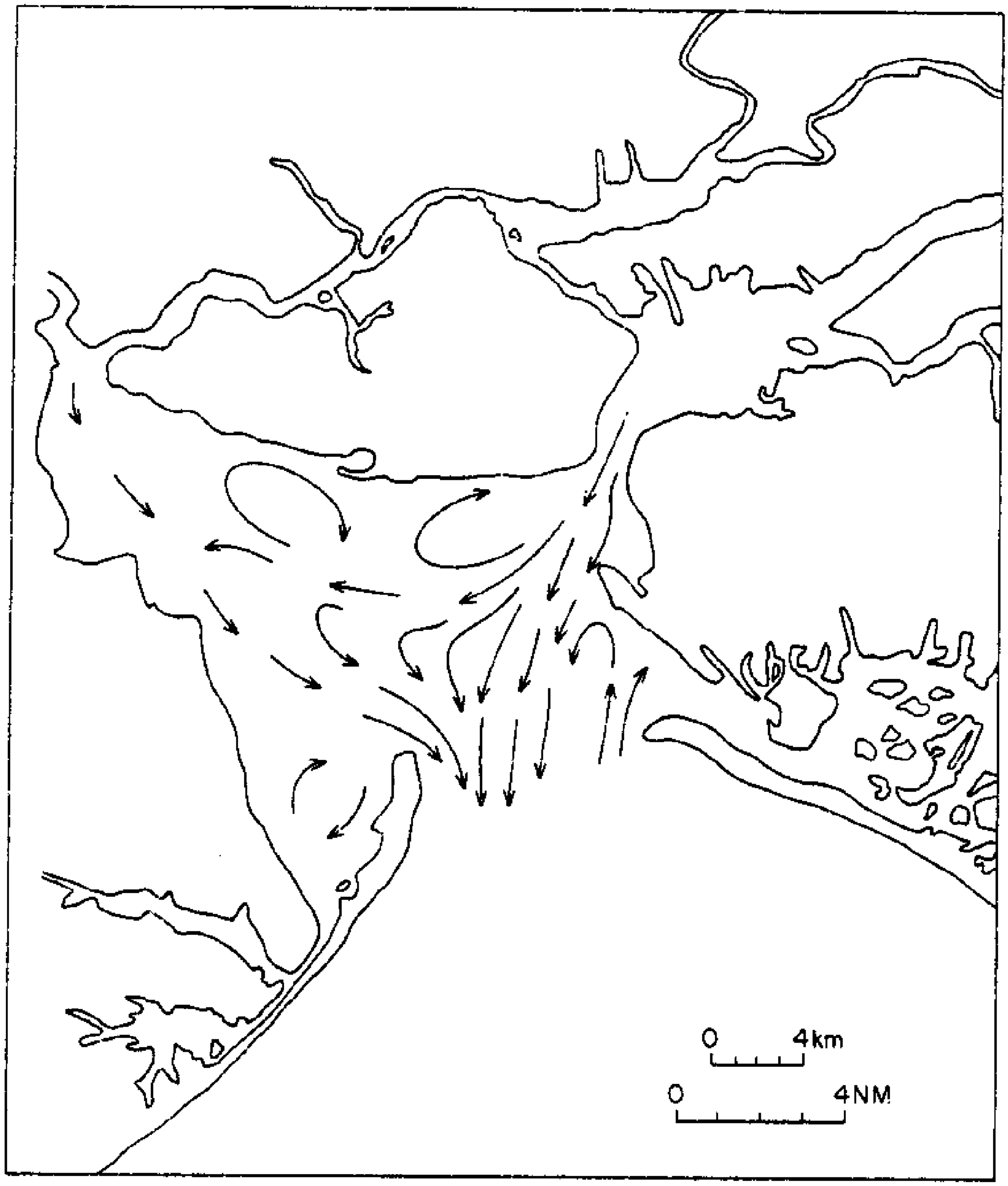


Fig. 4: Computed tidal current vectors for existing bathymetry (NOS hydrographic chart No. 12327, 70th Ed., July 1977) for maximum ebb at Sandy Hook. After Wong and Wilson (1979).

Fig. 5: Computed tidal current vectors for existing bathymetry (NOS hydrographic chart No. 12327, 70th Ed., July 1977) for maximum flood at Sandy Hook. After Wong and Wilson (1979).

Fig. 6: Nontidal circulation patterns from Duedall et al. (1979).



and depressions (Figs. 7 and 8). 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). Stewart (1958) and Abood (1974) further indicate that the Hudson River is a partially stratified estuary. Entrainment of saline bottom water into seaward-flowing surface waters increases downstream and is compensated by upstream bottom currents. Nontidal density west of the Ambrose Channel is characteristic of an estuary: isopycnals slope upward toward Rockaway Pt., and there is considerable vertical stratification (Doyle and Wilson, 1978). Vertical stratification in mined holes (e.g., Area C) is especially pronounced during the spring and summer months (Swartz and Brinkhuis, 1978). Water flowing into the Lower Bay near Rockaway Pt. is relatively homogeneous (Doyle and Wilson, 1978).

The general current patterns within the Lower Bay Complex are substantially influenced by changes in run-off volumes of fresh water from the Hudson and Raritan rivers, and strong winds (Walford, 1971). Because the estuary is shallow, it is susceptible to wind-driven circulation. No comparisons between the relative contributions of tidal and wind-driven circulation to mixing of these waters have been reported. However, inputs of fresh water from the Raritan and Hudson rivers under various run-off loads have been described by Parsons (1913), Schureman (1934), Giese and Barr (1967), Darmer (1969), Busby and Darmer (1970), Dunn (1970), Walford (1971), and Mueller et al. (1976). A subsurface patch of colder less saline water (3.5 m depth) occurs in parts of the Lower Bay near Staten Island during the summer (Bowman and Weyl, 1972). This patch is apparently formed by advection of cooler Hudson River water from the Ambrose Channel onto the shoals west of the channel by tidal oscillations. The tidal excursion varies from 3.8 to 9.6 km, depending on location in the estuary (Walford, 1971). A net seaward drift of 3.2 km occurs near Sandy Hook during a complete tide cycle. Ayers et al. (1949) calculated the average flushing time of the Lower Bay to be 8.1 tides. Residence time in Raritan Bay is considerably longer--Ketchum (1951) indicated 32 to 42 tides while Jeffries (1962) found 60 tides were required during his 1948 survey.

A number of ancillary circulation studies have been conducted in and near the Lower Bay Complex. Pritchard et al. (1962) investigated the movement and diffusion of an induced contaminant. Ketchum et al. (1951) reported on oceanographic features of the New York Bight, including the northern apex area, near the Lower Bay. Mueller et al. (1976) studied contaminant input leads to the New York Bight through the waters of New York Harbor. Wong and Wilson (1979) modelled the effects of bathymetric changes, resulting from sand mining, on circulation and tidal amplitudes in the Lower Bay Complex. Swartz and Brinkhuis (1978) described the effects of existing mining holes on oxygen dynamics and circulation problems on both sides of the Ambrose Channel. Jay and Bowman (1975) described some aspects of physical oceanography and water quality of New York Harbor and the exchanges of pollutants with Long Island Sound via the East and Harlem rivers. Some older information on tidal currents in the New York Harbor has been reported by the Metropolitan Sewerage Commission (1913) and the Interstate Sanitation Commission (1940).

Chemical Properties of Water and Sediments

Most of the studies on the chemistry of Lower Bay Complex waters and sediments resulted from pollution related concerns. Pollution related phenomena in New York Harbor were extensively investigated by the Metropolitan Sewerage Commission near the turn of the century (1912, 1913). Reeve (1922) indicated the need for

Fig. 7: Nontidal flow at sections in Lower Bay. Positive velocity is out of page. From Parker (1976).

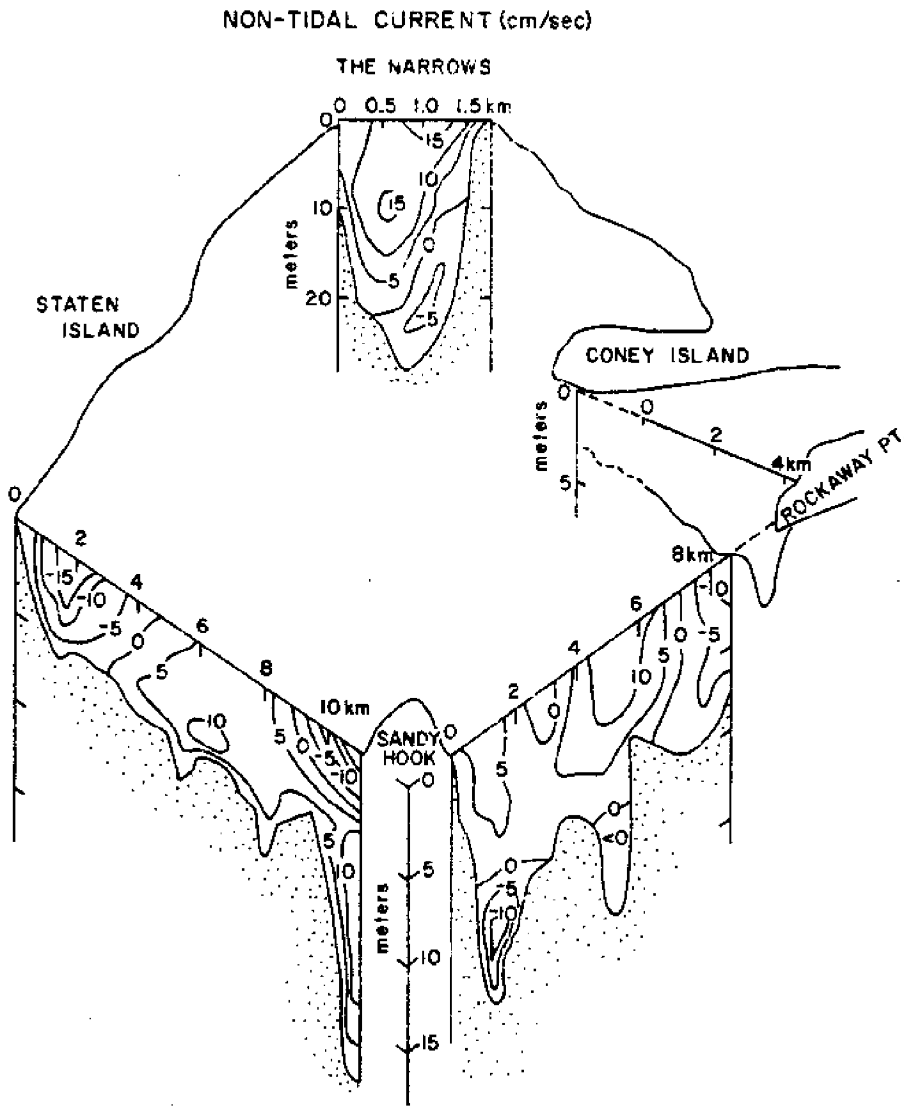
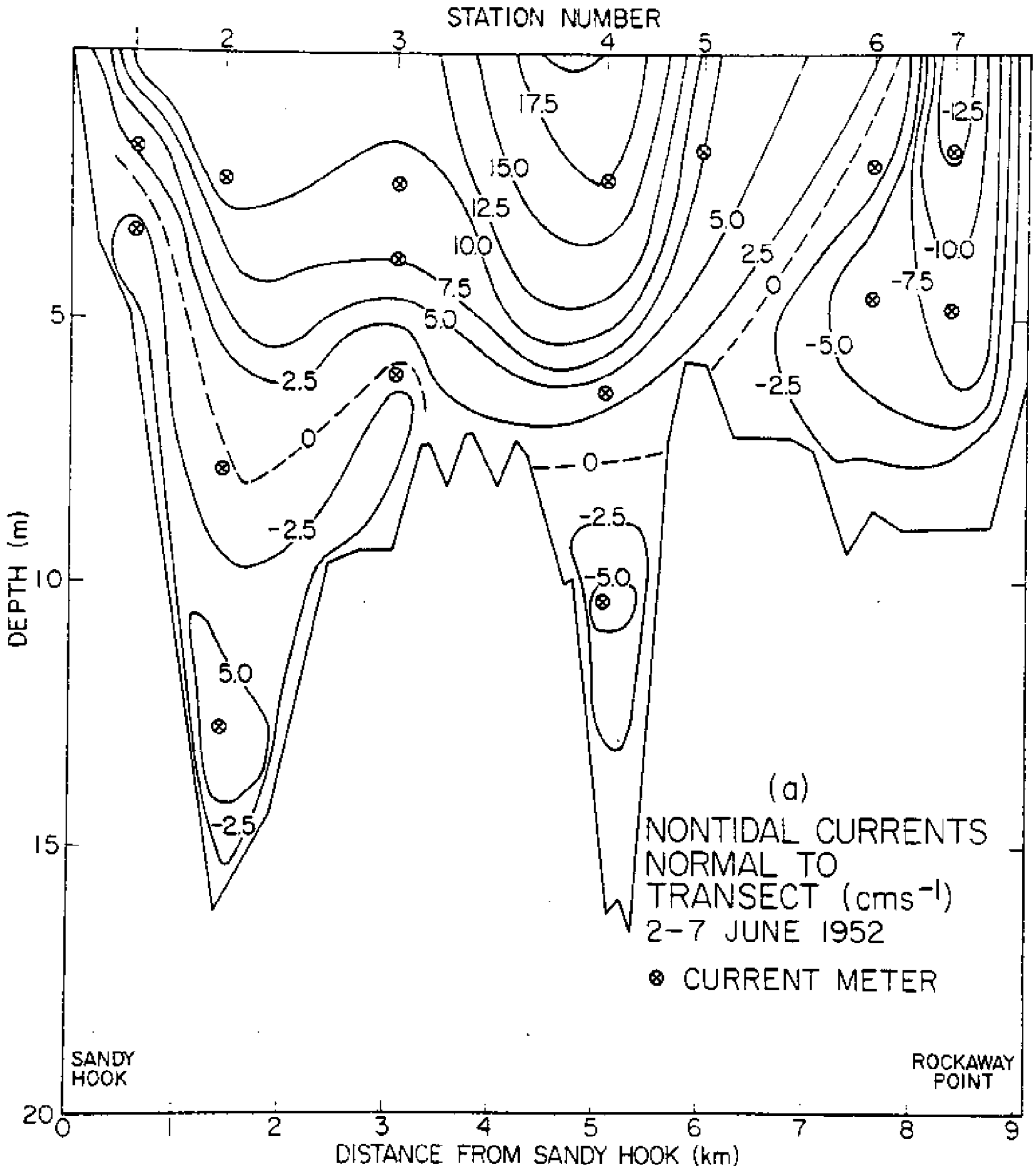


Fig. 8: Nontidal currents normal to the Sandy Hook to Rockaway Point Transect computed for 2-7 June 1952. Positive flow is seaward. From Doyle and Wilson (1978).



cleansing Harbor waters. Phelps and Velz (1933) and Ayers et al. (1949) described some of the pollution problems in New York Harbor and adjacent waters. The Interstate Sanitation Commission (1959, 1960, 1972) produced several reports relating to sewer overflow impacts on New York Harbor waters. Mytelka (1972) reported that some heavy metals occurred in high concentrations in sewage and waste water released from treatment plants in the New York metropolitan area. O'Conner (1962, 1971) also described organic pollution problems resulting from improper sewage treatment in the New York area. Ingram and Mitwally (1966), Suskowski (1973), and Ketchum (1974), recently summarized the history of sewage pollution problems in New York Harbor waters.

Naturally, pollution of New York Harbor has had significant impacts on the waters of the Lower Bay Complex, which is not to say that inputs from the Harbor are the most important in terms of effects on water quality in the Lower Bay Complex. Indeed, much of the input via Hudson River flow is transported out to sea due to the patterns of circulation (see *Physical Oceanography*). It appears that much of the deteriorated water and sediment chemical character of the Lower Bay Complex stems from inputs into Raritan Bay. Jeffries (1962) described environmental characteristics of Raritan Bay and indicated that many of its pollution problems also stemmed from sewage inputs via the Raritan River and treatment plants along the north Jersey and Staten Island shores. Clark (1963) and deFalco (1967) similarly described pollution characteristics of Raritan Bay and adjacent waters, including portions of the Lower and Sandy Hook bays. Gross (1970, 1972) analyzed dredge wastes and waste solids with respect to chemical composition. Searl et al. (1977) reported that the highest extractable organics and nonvolatile hydrocarbon concentrations occurred in New York Harbor waters, with lower concentrations occurring near Ambrose Channel. They suggest that much of the hydrocarbon in water is adsorbed onto particulate material which settles out in deeper areas of the Lower Bay.

One net impact of sewage inputs into the Lower Bay Complex is to provide an excess of ammonium which in turn supports phytoplankton biomass (Garside et al., 1976) during seasonal blooms. These blooms may in turn result in water column oxygen deficiencies in localized areas at certain times of the year (Swartz and Brinkhuis, 1978). O'Connors and Duedall (1975) and Parker et al. (1976a,b) indicated that there is a considerable ammonium and chlorophyll flux from the Lower Bay Complex across the Sandy Hook-Rockaway Pt. Transect into the New York Bight Apex. O'Connors and Duedall (1975) indicate the major source of this ammonium is sewage effluent from the New York metropolitan area. Mahoney and McLaughlin (1977) associated phytoflagellate blooms with hypertrophication of Lower Bay waters.

Carmody et al. (1973) and Alexander et al. (1978) reported on trace metals in sediments of the New York Bight and waters from the southern portions of the Lower Bay Complex. Lentsch et al. (1971), Hammond et al. (1975), Jinks and Wrenn (1975) and Simpson et al. (197) described studies on radionuclide distribution and sediment/water interactions in the Hudson estuary. Grieg and McGrath (1977) and Waldhauer et al. (1978) described trace metals in sediments and waters of Raritan Bay, respectively. Figures 9 and 10 indicate sampling stations of these respective studies. Seeliger and Edwards (1977) indicated that there was a high correlation between water column copper and lead concentrations and benthic algae in Raritan Bay, and that these metals in seaweeds were present in the highest concentrations reported to date. Generally, metal concentrations in water, sediment, and seaweed are highest at the western end of Raritan Bay. Lead and copper concentrations in water and sediment remain high in the center of the Lower Bay Complex in a band to the south of the Raritan Bay Reach Channel. Water and sediment to the north on the West Bank had lower concentrations.

Fig. 9: Stations sampled by Grieg and McGrath (1977) for trace metal content in surface sediments. After Grieg and McGrath (1977).

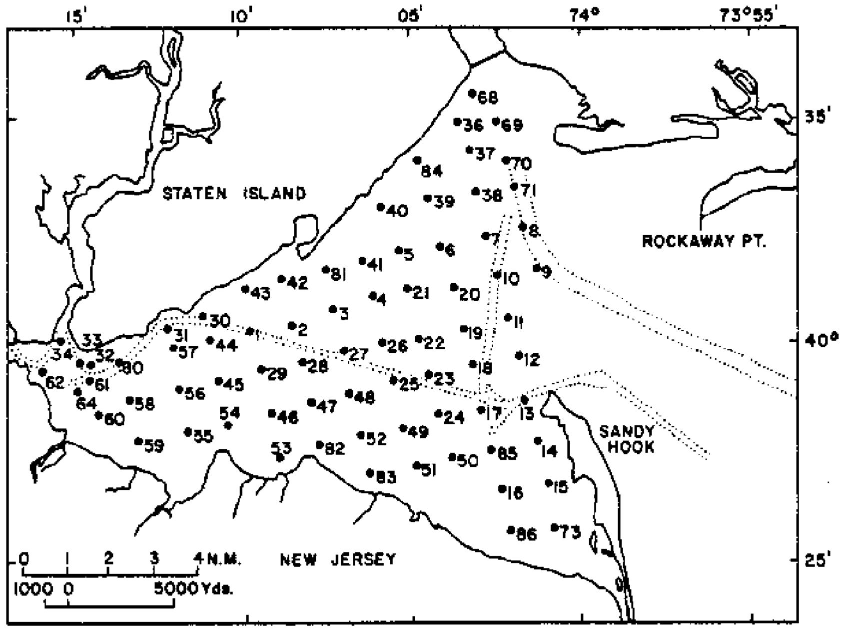
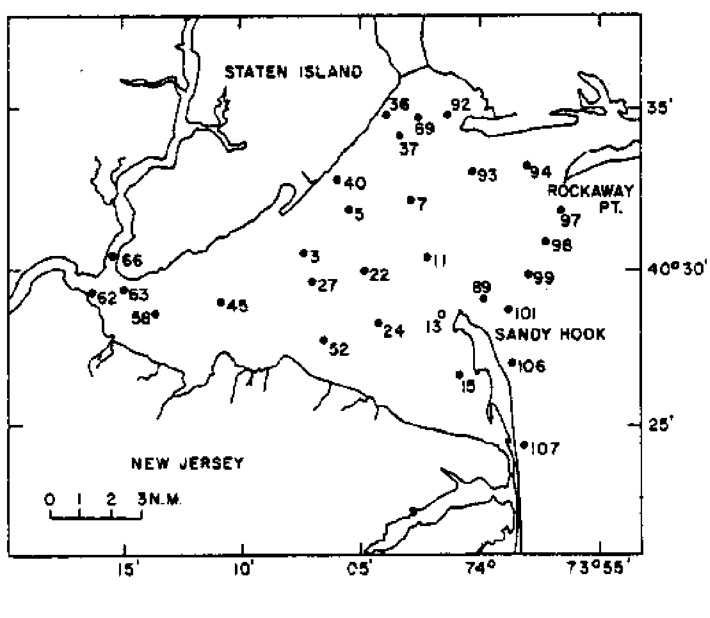


Fig. 10: Stations sampled by Waldhauer et al. (1978) for trace metal content in waters of the Lower Bay Complex. After Waldhauer et al. (1978).



Waters in Sandy Hook Bay had low, while sediments had high, metal concentrations. Regions on the East Bank had the lowest metal concentrations in the area.

Sediment Resources

The nature of sediment quality in the Lower Bay Complex has been reported by several investigators. Fray (1969) compiled data from a large number of surficial sediment samples reported by Dean and Haskin (1964), Nagle (1967), McMaster (1954), Taney (1961), and Woodward-Clyde (1975a). Kastens et al. (1978) included the above data along with a report on sediment quality in 48 samples collected during their study. Jones et al. (1979) described the textural properties of surficial sediments based on samples collected during their study and those reported by Kastens et al. (1978). The report by Jones et al. (1979) also includes 50 samples obtained by Brinkhuis on the East and West Banks, in and around dredged holes. The report presents a textural property map of sediments. Bokuniewicz and Fray (1979) prepared an updated version of the surficial sediment textural property map, and identified probable thicknesses of deposits that were surveyed by subbottom profiling.

Figure 11 presents the textural property index map produced by Bokuniewicz and Fray (1979). Table 3 identifies each of the deposits numbered in this figure with the type of sediments in the Lower Bay area. Other areas shown in the Lower Bay Complex were identified by Dean and Haskin (1964). Several points of interest may be noted. Deposits XII, XIII, and XVI represent locations *A*, *B*, and *C* from Swartz and Brinkhuis (1978)--see Figure 2. These are dredged holes on the West Bank that have filled in with mud since the time they were dredged (1966-1972) to a depth of 8 to 13 m. An overlying layer of mud up to 90 cm thick was indicated by core samples collected by Brinkhuis and Bokuniewicz (unpublished data). On the East Bank, Area IX represents the location of mining in that location (*D* in Fig. 2). Less mud has accumulated in holes on the East Bank, as noted by Swartz and Brinkhuis (1978). The difference in accumulation of mud on either Bank may be attributed to different circulation patterns. West Bank sites apparently receive more suspended material from the Hudson and Raritan rivers--material that is more easily deposited due to the tempered current velocities in the shallow waters of the West Bank and the effect that holes have in further reducing current velocities (Wong and Wilson, 1979). On the East Bank, circulation is more vigorous, keeping fine materials in suspension.

The majority of Hudson River flow bearing suspended material flows into Lower Bay on the west of Ambrose Channel. Figure 12 depicts the idealized sediment transport in the Lower Bay Complex as described by Fray (1969).

Generally, surficial sediments on the East Bank are coarser than material on the West Bank. Bokuniewicz and Fray (1979) indicate that the thickness of deposits varies considerably throughout the region. Thickness of deposits, determined by subbottom profiling and bore-hole data, are included in Table 3. Estimated volumes of deposits in each of the areas for which profiling and bore-hole data were available are also shown in Table 3. Deposits on the East Bank are between 9 and 13 m deep while those on the West Bank of Ambrose Channel are deeper, up to 25 m. Deposits of Lower Bay Sands south of Staten Island are about 8 m thick. Most of the surface deposits consist of fine to medium sand, with occasional patches of very fine or coarse material. Only for areas where bore-hole data are available can reliable estimates of exploitable resource material be made. Subbottom profiling alone can not describe the nature of particle sizes in subbottom deposits;

Fig. 11: Surficial sediment deposits described by Jones et al. (1979) and Bokuniewicz and Fray (1979).

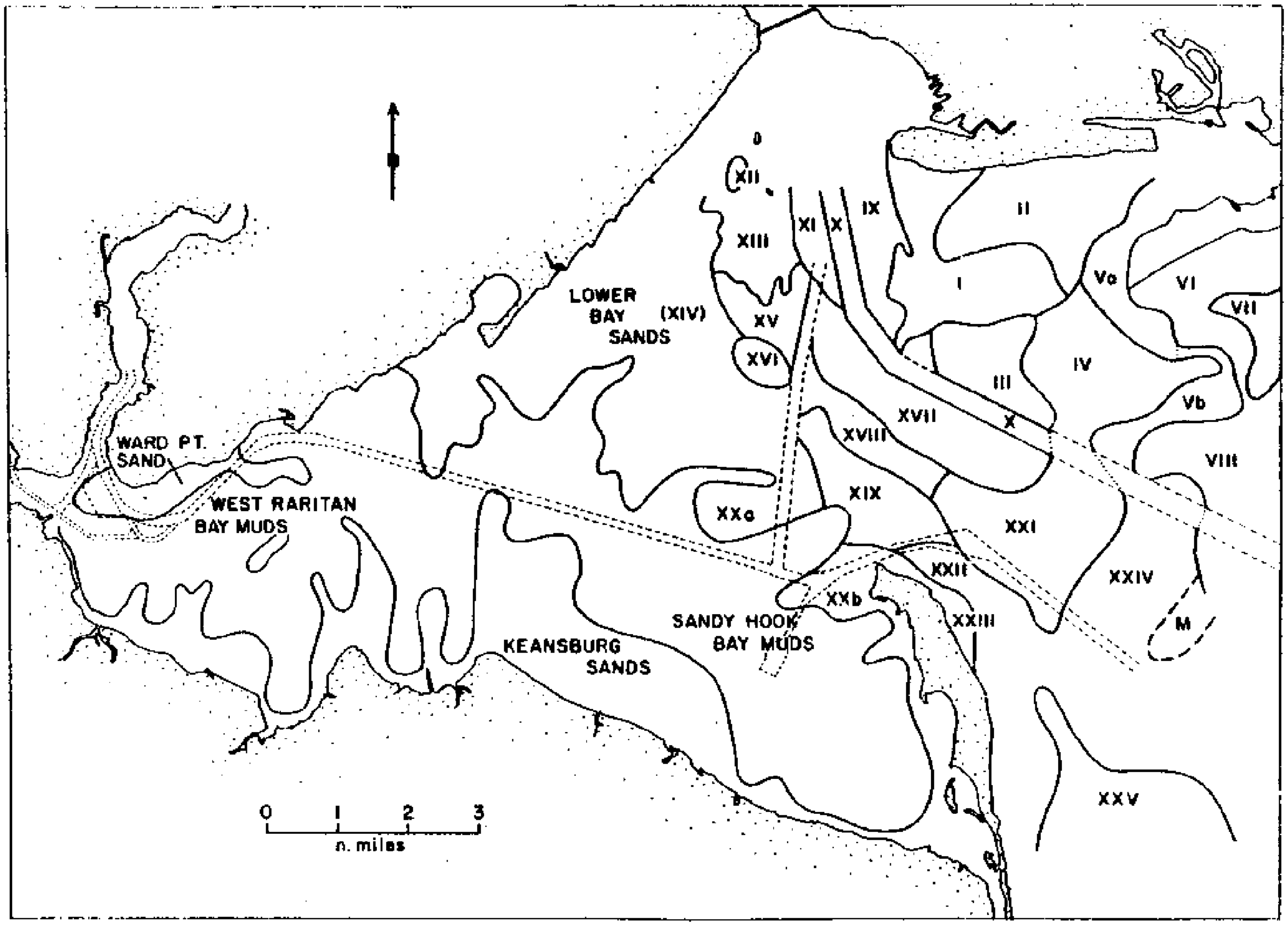


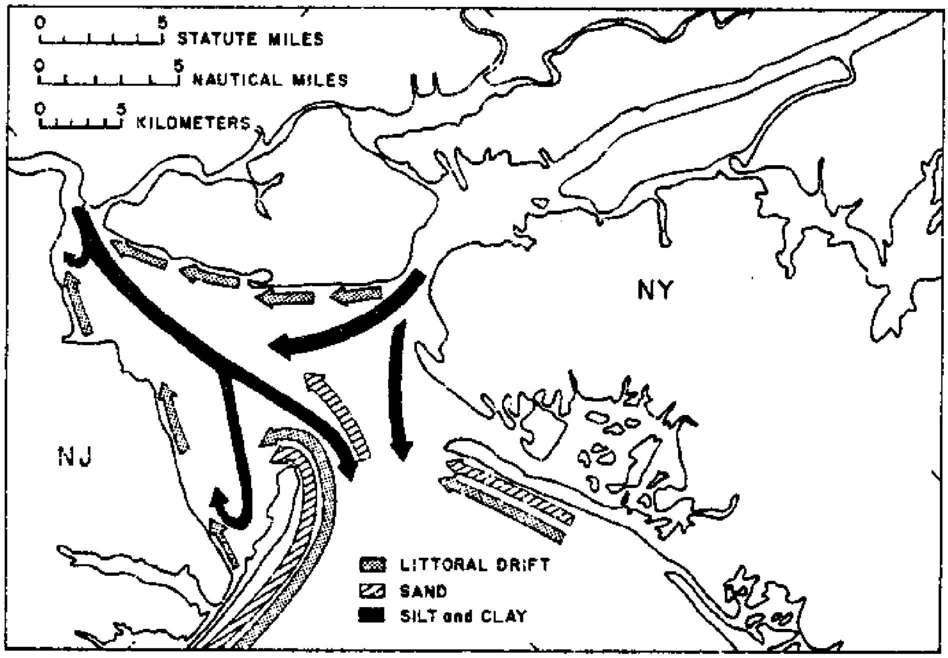
Table 3. Identification of deposits keyed in Figure 11 with surface sediment type, grain size, areal extent of deposit, thickness of deposit, and estimated volume [from Jones et al. (1979) and Bokuniewicz and Fray (1979)]. Note: Asterisk (*) indicates insufficient data to calculate parameter.

Deposit	Type	Grain-size range (mm)	Av. median dia. (mm)	Area (km^2)	Thick-ness (m)	Volume ($x10^6$. m^3)	Bore-hole data available?
I	medium sand	0.258-0.392	0.314	10.9	11.0	119.3	yes
II	fine sand	0.043-0.268	0.185	12.0	11.0	131.8	no
III	fine sand	0.157-0.245	0.201	5.1	12.2	61.7	yes
IV	coarse-very coarse sand	0.441-0.986	0.875	-	*	-	yes
Va	medium sand	0.281-0.412	0.362	4.86	9.1	44.2	no
Vb	medium sand	0.261-0.466	0.372	*	*	*	no
VIa	fine sand	0.143-0.304	0.178	*	*	*	no
VIb	very fine-medium sand	0.158-0.669	0.273	*	*	*	no
VII	very fine sand	0.102-0.116	0.112	*	*	*	no
VIII	fine sand	0.128-0.337	0.173	*	*	*	no
IX	fine sand and mud	0.053-0.426	0.227	5.8	13.4	77.0	no
X	fine-medium sand	0.156-0.376	0.257	5.8	9.1	52.5	no
XI	fine sand	0.154-0.235	0.189	2.3	9.1	21.0	no
XII	very fine sand-mud	0.008-0.236	0.068	*	*	*	no
XIII	mud	0.005-0.039	0.029	*	*	*	no
XIV	medium sand	0.310-0.460	0.389	*	*	*	no
XV	fine-very fine sand	0.110-0.182	0.133	4.0	24.1	97.5	no
XVI	very fine sand-mud	0.005-0.162	0.055	*	*	*	no
XVII	medium sand	0.218-0.316	0.298	10.2	18.3	185.9	yes
XVIII	mud-shell	*	*	4.2	19.5	80.9	no
XIX	medium sand	0.270-0.521	0.340	7.0	15.9	110.7	yes
XXa	mud, shell, medium sand	*	*	*	*	*	yes
XXb	mud, shell, fine sand	*	*	6.9	48.8	335.7	no
XXI	medium-very coarse sand	0.361-1.000	0.738	12.0	2.4	28.9	yes
XXII	medium sand	0.274-0.438	0.354	140.2	42.7	598.4	yes

Table 3 - continued

Deposit	Type	Grain-size range (mm)	Av. median dia. (mm)	Area (km^2)	Thick-ness (m)	Volume ($x10^6 . m^3$)	Bore-hole data available?
XXIII	fine sand	0.102-0.230	0.176	2.1	42.7	88.1	yes
XXIV	medium sand	0.171-0.669	0.428	*	*	*	no
XXV	coarse sand	0.525-1.117	0.730	*	*	*	no
Lower Bay Sands	fine-medium sand	*	*	52.1	7.9	413.1	yes
Keansbury Sands	fine sands	*	*	35.7	6.1	217.5	yes
Ward Pt. Sands	fine-medium sand	*	*	5.38	4.0	23.1	yes

Fig. 12: Idealized transport of sediments in the Lower Bay Complex. After Fray, 1969.



however, it can be helpful in determining thickness of sediments as a whole.

DISTRIBUTION AND ABUNDANCE OF ORGANISMS

Phytoplankton

A number of studies has been conducted on phytoplankton distribution, abundance, and productivity in the Lower Bay Complex. (Patten (1959, 1961, 1962) conducted detailed investigations on species composition and diversity of the phytoplankton community in Raritan Bay and adjacent Lower Bay waters. McCarthy (1965) conducted a follow-up study of phytoplankton in Raritan Bay. Kawamura (1966) reported on phytoplankton distribution in Sandy Hook Bay and adjacent waters. O'Reilly et al. (1976) and Malone (1976) reported on annual productivity in the Lower Bay Complex and the New York Bight Apex, respectively. Mahoney and McLaughlin (1977, 1979) investigated phytoflagellate blooms in the Lower Bay Complex.

A list of the more common phytoplankton reported in the Lower Bay Complex (by season) is presented in Table 4. Patten (1962) indicated that diversity increased downbay in association with diminishing pollution and that the spatial distribution was strongly correlated with general patterns of water mass circulation. Most of the species listed in Table 4 were reported by Patten (1962). Diatoms (mainly *Skeletonema costatum*) dominated the cold-water flows while dinoflagellates and *Nannochloris atomus* were dominant during warmer seasons. The summer and early fall were dominated by other nannoplanktonic flagellates as well. Patten (1962) indicates that, based on redundancy and diversity indices, Raritan Bay at that time was a generally poor quality ecosystem.

Productivity studies by O'Reilly et al. (1976) indicated that phytoplankton were highly concentrated during the summer and sparse during late fall and early winter. Despite a thin euphotic layer (2.3-6 m) resulting from terrigenous-, sewage-, and phytoplankton-derived sources of particulate matter, the annual primary production in the Lower Bay is 817 g $C/m^2/yr$ (O'Reilly et al., 1976). This annual value is among the highest reported for estuarine regions. Nannoplankton and netplankton accounted for approximately 67 and 20% of annual plant production, respectively. This high productivity is supported by sewage nutrient inputs (primarily ammonium) and is principally light-limited. During the summer months of high productivity, ammonium regeneration in the water column and from sediments further supplements phytoplankton demand (Malone, 1976). At no time did production appear nitrogen-limited, in contrast to Ryther and Dunstan's (1971) findings in other coastal New York waters. Kawamura (1966) reported that phytoplankton productivity in Sandy Hook Bay is moderate. Patten's (1962) phytoplankton productivity figures indicate that Raritan Bay has high production. Garside et al. (1976) found that much of the nutrient input to Raritan Bay is consumed by the high productivity of phytoplankton. Studies by Mahoney and McLaughlin (1977, 1979) indicate that cyclic blooms of phytoflagellates and other phytoplankton are the result of interactions between salinity, nutrients, and species specific growth ability. The dominant species appear to be unchanged over a period of 20 years of study.

Zooplankton

Relatively few studies have reported zooplankton observations in the Lower Bay Complex. Reports by Jeffries (1959, 1962, 1964) and Yamazi (1966) indicate that zooplankton populations in the Lower Bay Complex are similar to other protected estuaries along the east coast of the United States. Two genera of copepods, *Acartia* and *Eurytemora*, dominate the

Table 4. Phytoplankton species of Lower Bay Complex

Time of Year	Species	Type	Reported by
Constants	*Coscindiscus asteromphalus*	Diatom	Patten, 1961, 1962
(Year round)	*Coscindiscus subtilis*	Diatom	Patten, 1961, 1962
	Lithodesmium undulatum	Diatom	Patten, 1961, 1962
Vernal-serotinal	*Skeletonema costatum*	Diatom	Patten, 1961, 1962; McCarthy 1965
(Spring-late summer)	*Thalassiosira gravida*	Diatom	Patten, 1961, 1962
	Chaetoceros decipiens	Diatom	Patten, 1961, 1962
	Gyrosigma acuminatum	Diatom	Patten, 1961, 1962
	Asterionella japonica	Diatom	Malone, 1976
	Phaeodactylum tricornutum	Diatom	Malone, 1976
	Leptocylindrus danicus	Diatom	Malone, 1976
	Cerataulina bergonii	Diatom	Malone, 1976
	Ceratium longipes	Diatom	Malone, 1976
Serotinal	*Nannochloris atomus*	Green alga	Patten, 1961, 1962
(Late summer)	*Prorocentrum micans*	Dinoflagellate	Patten, 1961, 1962; Mahoney and McLaughlin, 1977
	Peridinium trochoideum	Dinoflagellate	Patten, 1961, 1962
	Peridinium breve	Dinoflagellate	Patten, 1961, 1962
	Peridinium divaricatum	Dinoflagellate	Patten, 1961, 1962
Hiemal	*Nitzschia seriata*	Diatom	Patten, 1961, 1962
(Winter)	*Leptocylindricus danicus*	Diatom	Patten, 1961, 1962
	Rhizosolenia setigera	Diatom	Patten, 1961, 1962
	Rhizosolenia imbricata	Diatom	Patten, 1961, 1962
	Rhizosolenia alata	Diatom	Patten, 1961, 1962

Table 4 - continued

Time of year	Species	Type	Reported by
	Rhizosolenia delicatula	Diatom	O'Reilly, 1976
	Asterionella japonica	Diatom	Patten, 1961, 1962
	Thalassionema nitzschioides	Diatom	Patten, 1961, 1962
	Guinardia flaccida	Diatom	Patten, 1961, 1962
	Melosira sulcata	Diatom	Patten, 1961, 1962
	Actinoptychus undulatus	Diatom	Patten, 1961, 1962
	Tropidoneis lepidoptera	Diatom	Patten, 1961, 1962
	Goniaulax sp.	Dinoflagellate	Patten, 1961, 1962
	Rhodomonas minuta	Red flagellate	O'Reilly, et al., 1976
Aestival	*Olisthodiscus leuteus*	Diatom	Mahoney and McLaughlin, 1977
(Early summer)	*Massartia rotundata*	Dinoflagellate	Patten, 1961, 1962 Mahoney and McLaughlin, 1977
	Eutreptia sp.	Green flagellate	Malone, 1976
	Pyramimonas sp.	Green flagellate	Malone, 1976
Autumnal	*Oxyrrhis marina*	Dinoflagellate	Patten, 1961, 1962
	Rhizoselenia faeroense	Diatom	Malone, 1976

zooplankton record. Table 5 lists the taxa of zooplankton reported during various seasons in the Lower Bay Complex. It may be noted that many meroplanktonic larvae of other invertebrates are found in zooplankton during the spring and summer. At times, these larval forms may dominate the record.

Two species of *Acartia* are the most common copepods found in the Bay. *Acartia clausii* dominates in the winter and is gradually replaced by *A. tonsa* during the summer. During the winter-spring transition, two species of *Eurytemora* increase in abundance, *E. americana* and *E. hirundoides* (Jeffries, 1959). Jeffries (1959) linked an increase in *Pseudodiaptomus coronatus* in Raritan Bay over previous years to a reduction in sewage effluent in the Bay.

Invertebrates

Overview

A fairly complete inventory of invertebrate infauna and epifauna identified in the following studies, including work in progress by the author, is presented in Table 6. Species are listed with their phylogenetic identities according to the scheme presented by Gossner (1971). Species collected thus far in a benthic survey south of Fire Island, New York [Coal Waste Artificial Reef Project (CWARP)] by investigators at the Marine Sciences Research Center, State University of New York (S.U.N.Y.) at Stony Brook are included for comparison purposes.

Approximately 180 invertebrate taxa have been reported for the waters of the Lower Bay Complex, including only the one transect line *(A)* described by Steimle and Stone (1967), that lies on the East Bank. Pearce (1974) reported only 78 taxa. The number of taxa found at any one station varies considerably, as well as between bays. The time of year samples are collected accounts for further differences between and within studies [e.g., Steimle and Stone (1973) - Appendix Table 7). Differences in sampling techniques between studies also account for discrepancies in species commonly found in the area. For example, Dean (1975) reported few species and numbers of gammarid Amphipoda. This might be attributed to his use of 1.5 mm screens as opposed to finer meshes used by others who reported greater numbers of species and abundance. The number of taxa found in any one study is typically 10 to 35 at the more productive stations. However, in many locations investigators have reported very few species or numbers of organisms.

Walford (1971) Study

Walford (1971) found a total of 31 taxa in his study of eight Lower, Raritan, and Sandy Hook bay quantitative stations (see Fig. 13). The most diverse and dense community was found 400 yards northeast of Swinburne Island, where 19 taxa were found at his Station 38 in two samples obtained by an 0.1 m^2 Smith-McIntyre grab. The smallest standing crop was found at Station 10, immediately east of the Chapel Hill North Channel, represented by three species (*Cerebratulus* sp., *Nephtys incisa*, and *Pectinaria gouldii*) and three animals. Low diversity and density were ascribed to dredging and shipping activity. The area sediments were coarse sands and gravel. A total of five taxa was found at Station 12, two miles south of Station 10. This station was also characterized by shoaling coarse sediments. Stations 2, 5, 6, and 21 were located west of 10, 12, and 38 in 12 to 15 feet of water. Walford found that the sand-mud sediments at these stations supported a less diversified fauna. Station 2 had the least biomass and diversity of any stations sited on sand-mud sediments. The last station described in the text, 27, was located in the center of Lower Bay in water 23 feet deep. The sediments had more fine mud and exposed mussel shell. Walford concluded that the fauna in the Lower Bay was impoverished, citing as one example the number of

Table 5. Zooplankton reported in waters of the Lower Bay Complex

Taxon	Seasonal occurrence
Copepod	
Acartia clausi	Winter-spring
Acartia tonsa	Summer-fall
Eurytemora americana	Winter-spring
Eurytemora hirundoides	Spring
Pseudodiaptomas coronatus	Winter-spring
Temora longicornis	Winter-spring
Temora stylifera	Winter-spring
Tortanus discaudatus	Winter-spring
Centropages typicus	Winter-spring
Centropages hematus	Winter-spring
Labidocera aestiva	Winter-spring
Cithona bervicornis	Winter-spring
Cithona similis	Winter-spring
Pseudocalanus minutus	Winter-spring
Paracalanus crassirrotris	Winter-spring
Calanus finmarchius	Winter-spring
Polychaeta	
Polydora spp.	Summer
Nerinides agilis	Summer
Nereis spp.	Summer
Sabellaria spp.	Summer
Mollusca	
Mercenaria mercenaria	Summer
Mya arenaria	Spring-summer
Nassa spp.	Summer
Crustacea	
Balanus eburneus	Summer
Balanus improvisus	Summer
Callinectes sapidus	Summer
Cancer sp.	Summer
Carcinides maenas	Summer
Crangon septemspinosa	Summer
Eurypanopeus depressus	Summer
Neopanope texana	Summer
Pagurus longicarpus	Summer
Panopeus herbstii	Summer
Uca sp.	Summer

Table 6. Invertebrate taxa found in Lower Bay Complex and adjacent waters.

Taxon	a CWARP (1979)	b Brinkhuis (1978)	c Woodward-Clyde (1975)	d Dean (1975)	e McGrath (1975)	f Walford (1971)	g A (Steimle and Stone (1973))	h Others (Steimle and Stone (1973))	i Dean and Haskin (1964)
P. Cnidaria (Coelenterates)									
C. Hydrozoa	x								
O. Athecata									
F. Tubulariidae									
Tubularia sp.				x					
F. Pennariidae									
Pennaria tiarella								x	
F. Hydractiniidae									
Hydractinia echinata		x		x	x	x			
O. Thecata									
F. Campanularidae									
Obelia sp.								x	
C. Anthozoa									
O. Actiniaria									
F. Sagartidae									
Sagartia modesta								x	x
F. Metridiidae									
Metridium senile	x	x		x			x	x	

Table 6 - continued

Taxon	a	b	c	d	e	f	g	h	i
O. Ceriantharia									
Ceriantheopsis americanus				x				x	
P. Platyhelminthes (Flatworms)									
C. Turbellaria									
unidentif. spp.				x				x	x
P. Rhynchocoela (Nermertean Worms)									
unidentif. spp.	x		x	x		x		x	x
C. Anopla									
O. Paleonemertea									
F. Cephalothricidae									
Procephalothrix spiralis		x							
O. Heteronemertea									
F. Lineidae									
Zygeupolia rubens		x							
Micrura leidyi		x							
C. Enopla									
O. Hoplonemertea									
unidentif. spp.		x							
P. Aschelminthes (Pseudocoelenterates)									
C. Nematoda									
unidentif. spp.	x	x	x		x		x	x	
P. Annelida (Segmented Worms)									
C. Oligochaeta									
unidentif. spp.	x		x	x			x	x	
C. Polychaeta									
O. Phyllodocida									
F. Phyllodocidae									
Eteone lactea				x					x
Eteone flava								x	x
Eteone heteropoda				x					
Eumida sanguinea			x	x			x	x	x
Paranaitis kosteriensis								x	
Paranaitis speciosa			x	x					

Table 6 - continued

Taxon	a	b	c	d	e	f	g	h	i
Phyllodoce mucosa							x	x	
Phyllodoce groenlandica				x					
Eulalia viridis			x	x	x			x	
F. Polynoidae									
Harmothoe extenuata	x		x	x			x	x	
Harmothoe imbricata				x			x	x	
Lepidonotus squamatus		x		x			x	x	
F. Sigalionidae									
Sthenelais limicola	x						x	x	
Sigalion arenicola	x						x	x	
F. Glyceridae									
Glycera dibranchiata	x			x			x	x	x
Glycera americana	x	x		x		x			x
Glycera capitata	x		x						
F. Goniadidae									
Goniadella gracilis			x				x	x	
Goniadia maculata	x								
F. Nephtyidae									
Aglaophamus circinata								x	
Nephtys bucera	x		x				x	x	
Nephtys incisa	x			x	x	x	x	x	
Nephtys picta			x	x			x	x	
Nephtys caeca					x				
F. Syllidae									
Autolytus cornutus			x	x			x	x	
Exogone sp.				x				x	
F. Hesionidae									
Podarke obscura				x					
F. Nereidae									
Nereis acuminata			x						
Nereis grayi							x	x	
Nereis pelagica					x		x	x	
Nereis succinea				x			x	x	x
Nereis virens				x			x		
Nereis spp.			x	x			x	x	x
O. Capitellida									
F. Capitellidae									
Heteromastus filiformis				x					x
Capitella capitata			x	x				x	

Table 6 - continued

Taxon	a	b	c	d	e	f	g	h	i
F. Scalibregmidae									
Scalebregma inflatum	x							x	
F. Maldanidae									
Clymenella torquata								x	
Clymenella zonata	x								
F. Opheliidae									
Ammotrypane aulogaster	x								
Ophelia bicornis							x	x	
Ophelia denticulata								x	
Travisia carnea	x							x	
O. Spionida									
F. Spionidae									
Polydora ligni		x	x	x			x	x	x
Polydora ciliata		x							
Polydora sp.	x	x					x	x	x
Prionospio malmgreni								x	
Scolelepis squamata		x	x	x			x	x	
Scolecolepides viridis		x			x				
Spio filicornis			x	x	x				x
Spio setosa				x	x		x	x	x
Spiophanes bombyx	x	x	x	x	x		x	x	
Streblospio benedicti				x	x				x
F. Paraonidae									
Aricidea suecica		x	x						
Paraonis lyra								x	
F. Chaetopteridae									
Chaetopterus variopedatus	x								
F. Sabellariidae									
Sabellaria vulgaris		x		x	x	x			
O. Eunicida									
F. Onuphidae									
Diopatra cuprea	x		x	x					
Onuphis eremita								x	
F. Lumbrinereidae									
Lumbrineris fragilis	x		x	x			x	x	
Lumbrineris impatiens								x	

Table 6 - continued

Taxon	a	b	c	d	e	f	g	h	i
Lumbrineris tenuis	x			x			x	x	
Lumbrineris acuta								x	
Lumbrineris brevipes	x								
Ninoe nigripes								x	
F. Arabellidae									
Drilonereis longa	x			x				x	
Notocirrus spiniferus								x	
O. Magelonida									
F. Magelonidae									
Magelona rosea	x	x	x					x	
O. Ariciida									
F. Orbiniidae									
Orbinia ornata	x							x	
Orbinia swani								x	
Scoloplos robustus	x	x					x	x	
Scoloplos fragilis									x
Scoloplos armiger				x					
O. Cirratulida									
F. Cirratulidae									
Cirratulus grandis	x				x		x	x	
Cirratulus cirratus	x								
Tharyx acutus	x		x	x			x	x	x
Dodecaceria coralii				x					
O. Terebellida									
F. Pectinariidae									
Pectinaria hyperborea				x					
Pectinaria gouldii			x	x	x	x			x
F. Ampharetidae									
Ampharete arctica	x							x	
Asabellides oculata	x	x	x	x			x	x	
Amphicteis gunneri									x
F. Terebellidae									
Nicolea venustula								x	
Polycirrus phosphoreus				x			x	x	
Polycirrus eximius				x					
O. Flabelligerida									
Pherusa affinis			x	x	x		x	x	

Table 6 - continued

Taxon	a	b	c	d	e	f	g	h	i
O. Sabellida									
F. Sabellidae									
Sabella microphthalama				x					
Euchone rubrocincta								x	
Potamilla reniformis								x	
F. Serpulidae									
Hydroides dianthus				x				x	
Protula tubularia				x					
P. Arthropoda (Crustaceans)									
Sp. Chelicerata									
C. Merostomata									
O. Xiphosurida									
F. Limulidae									
Limulus polyphemus		x	x	x					x
Sp. Mandibulata									
C. Crustacea									
Sc. Cirrepedia									
O. Thoracica									
So. Balanomorpha									
F. Balanidae									
Balanus eburneus				x					
Balanus crenatus				x					
Balanus improvisus				x	x	x			x
Sc. Malacostraca									
SO. Peracarida									
O. Cumacea									
F. Bodotriidae									
Leptocuma minor	x		x				x	x	

Table 6 - continued

Taxon	a	b	c	d	e	f	g	h	i
F. Diastylidae									
Diastylis polita	x						x	x	
Diastylis sculpta					x			x	
Oxyurostylis smithi	x				x				
O. Tanaidacea									
F. Paratanaidae									
Leptochelia filum			x		x		x	x	
O. Isopoda									
So. Anthuridea									
F. Anthuridae									
Cyathura polita		x	x	x					x
So. Flabellifera									
F. Cirolanidae									
Cirolana concharum	x							x	
So. Valvifera									
F. Idoteidae									
Chiridotea coeca	x								
Chiridotea tuftsi	x						x	x	
Edotea triloba	x			x				x	x
O. Amphipoda									
So. Gammaridea									
F. Ampeliscidae									
Ampelisca macrocephala				x				x	
Ampelisca vadorum								x	
Byblis serrata								x	
F. Aoridae									
Microdeutopos gryllotalpa				x					
F. Corophiidae									
Corophium tuberculatum				x				x	

Table 6 - continued

	Taxon	a	b	c	d	e	f	g	h	i
	Unciola serrata			x	x	x	x		x	
	Unciola irrorata	x		x				x	x	
F.	Gammaridae									
	Elasmopus laevis			x	x			x	x	
	Gammarus mucronatus				x					x
	Gammarus annulatus	x		x						
	Gammarus oceanicus		x							
F.	Haustoriidae									
	Bathyporeia quoddyensis	x		x					x	
	Bathyporeia parkeri		x							
	Protohaustorius deichmannae	x	x	x		x		x	x	
	Protohaustorius wigleyi	x	x	x					x	
	Parahaustorius attenuatis		x	x				x	x	
	Parahaustorius holmesi		x					x	x	
	Parahaustorius longimerus	x	x	x				x	x	
	Acanthohaustorius intermedius	x	x						x	
	Acanthohaustorius millsi		x	x		x		x	x	
	Acanthohaustorius spinosus							x	x	
	Pseudohaustorius borealis								x	
	Pseudohaustorius caroliniensis	x								
F.	Ischyrocerida									
	Ischyroceros anguipes							x	x	
	Jassa falcata				x	x		x	x	
F.	Lilljeborgiidae									
	Listriella sp.			x						
F.	Lysianassidae									
	Tmetonyx nobilis								x	
	Hippomedon serratus								x	
	Anonyx lilljeborgi	x							x	

Table 6 - continued

Taxon	a	b	c	d	e	f	g	h	i
F. Oedicerotidae									
Monoculodes edwardsi	x							x	
F. Photidae									
Photis macrocoxa	x							x	
Podoceropsis nitida								x	
Leptocheiris pinguis								x	
F. Phoxocephalidae									
Phoxocephalus holbolli		x						x	
Paraphoxus spinosus	x	x	x	x					
Trichophoxus epistomus	x	x	x		x		x	x	
F. Stenothoidae									
Stenothoe cypris				x					
Stenothoe minuta				x				x	
O. Caprellidea									
F. Caprellidae									
Aeginella spinosa								x	
O. Mysidacea									
F. Mysidae									
Neomysis americana	x						x	x	
Heteromysis formosa							x	x	
Mysis mixta	x	x							
SO. Eucarida									
O. Decapoda									
Io. Caridea									
F. Crangonidae									
Crangon septemspinosa	x	x	x	x	x		x	x	x
Io. Astacidea									
F. Nephropsidae									
Homarus americanus		x							

Table 6 - continued

Taxon	a	b	c	d	e	f	g	h	i
Io. Anomura									
SF. Paguroidea									
F. Paguridae									
Pagurus longicarpus				x				x	
Pagurus pollicaris		x	x	x		x	x	x	
Io. Brachyura									
S. Oxyrhyncha									
F. Majidae									
Libinia emarginata		x	x	x				x	
S. Cancridea									
F. Cancridae									
Cancer irroratus	x	x	x	x		x	x	x	
Cancer borealis								x	
S. Brachyrhyncha									
Carcinus maenas				x					
Ovalipes ocellatus		x	x	x		x	x	x	
Callinectes sapidus			x	x		x			x
F. Xanthiidae									
Panopeus herbstii				x					
Neopanope texana sayi		x		x			x	x	
Hexapanopeus angustifrons				x					
Rithropanopeus harrisii				x					x
Eurypanopeus depressus				x					
P. Mollusca									
C. Gastropoda									
Sc. Prosobranchia									

Table 6 - continued

Taxon	a	b	c	d	e	f	g	h	i
O. Mesogastropoda									
F. Lacunidae									
Lacuna vincta								x	x
F. Littorinidae									
Littorina littorea				x					
F. Pyramidellidae									
Turbonilla elegantula								x	
Pyramidella fusca				x					
Odostomia sp.				x					
F. Calyptraeidae									
Crepidula fornicata		x		x		x	x	x	
Crepidula plana		x		x		x	x	x	
Crucibulum striatum								x	
F. Naticidae									
Polinices duplicatus				x					
Lunatia heros	x		x	x	x		x	x	
O. Neogastropoda									
F. Muricidae									
Urosalpinx cinereus				x					x
Eupleura caudata				x					
F. Columbellidae									
Mitrella lunata				x				x	
F. Melongenidae									
Busycon caudata				x					
Busycon canaliculatum			x	x					
F. Nassariidae									
Nassarius trivittatus	x			x	x	x		x	
Nassarius obsoletus				x					
Sc. Opisthobranchia									
O. Cephalaspidea									
F. Retusidae									
Retusa canaliculata				x					
Retusa obtusa				x					
O. Nudibranchia									

Table 6 - continued

Taxon	a	b	c	d	e	f	g	h	i
So. Doridacea									
F. Corambidae									
Corambe obscura				x					
F. Lamellidorididae									
Adalaria proxima				x				x	
Acantnodoris pilosa								x	
C. Bivalvia									
Sc. Prionodesmata									
O. Protobranchia									
F. Nuculidae									
Nucula proxima			x	x					
F. Nuculanidae									
Yoldia limatula				x					
Sc. Pteriomorphia									
O. Pteroconchida									
F. Mytilidae									
Mytilus edulis		x	x	x			x	x	x
Modiolus demissus				x					x
Modiolus modiolus		x		x					
Crenella decussata		x						x	
F. Ostreidae									
Crassostrea virginica				x					
F. Anomiidae									
Anomia simplex				x		x			
Sc. Teleodesmata									
O. Heterodontida									
F. Astartidae									
Astarte castanea	x							x	x
Astarte undata								x	
Astarte borealis					x				
F. Arcticidae									
Arctica islandica								x	

Table 6 - continued

Taxon	a	b	c	d	e	f	g	h	i
F. Cardiidae									
Cerastoderma pinnulatum								x	
F. Veneridae									
Mercenaria mercenaria				x	x	x		x	
Gemma gemma		x		x					
F. Petricolidae									
Petricola pholadiformis				x					
F. Mactridae									
Spisula solidissima			x	x	x	x	x	x	
Mulinia lateralis				x	x				x
F. Tellinidae									
Tellina agilis	x	x	x	x	x	x	x	x	
Macoma balthica				x					x
F. Solenidae									
Solen viridis		x					x		
Ensis directus	x			x			x		x
Siliqua costata							x		
F. Myidae									
Mya arenaria				x	x	x			x
Sc. Anomalodesmata									
O. Eudesmodontida									
F. Pandoridae									
Pandora gouldiana							x	x	
F. Lyonsiidae									
Lyonsia hyalina							x	x	
C. Cephalopoda									
Sc. Coleoidae									
O. Teuthidida									
F. Loliginidae									
Loligo pealei		x	x						
P. Echinodermata									
C. Echinoidea									

Table 6 - continued

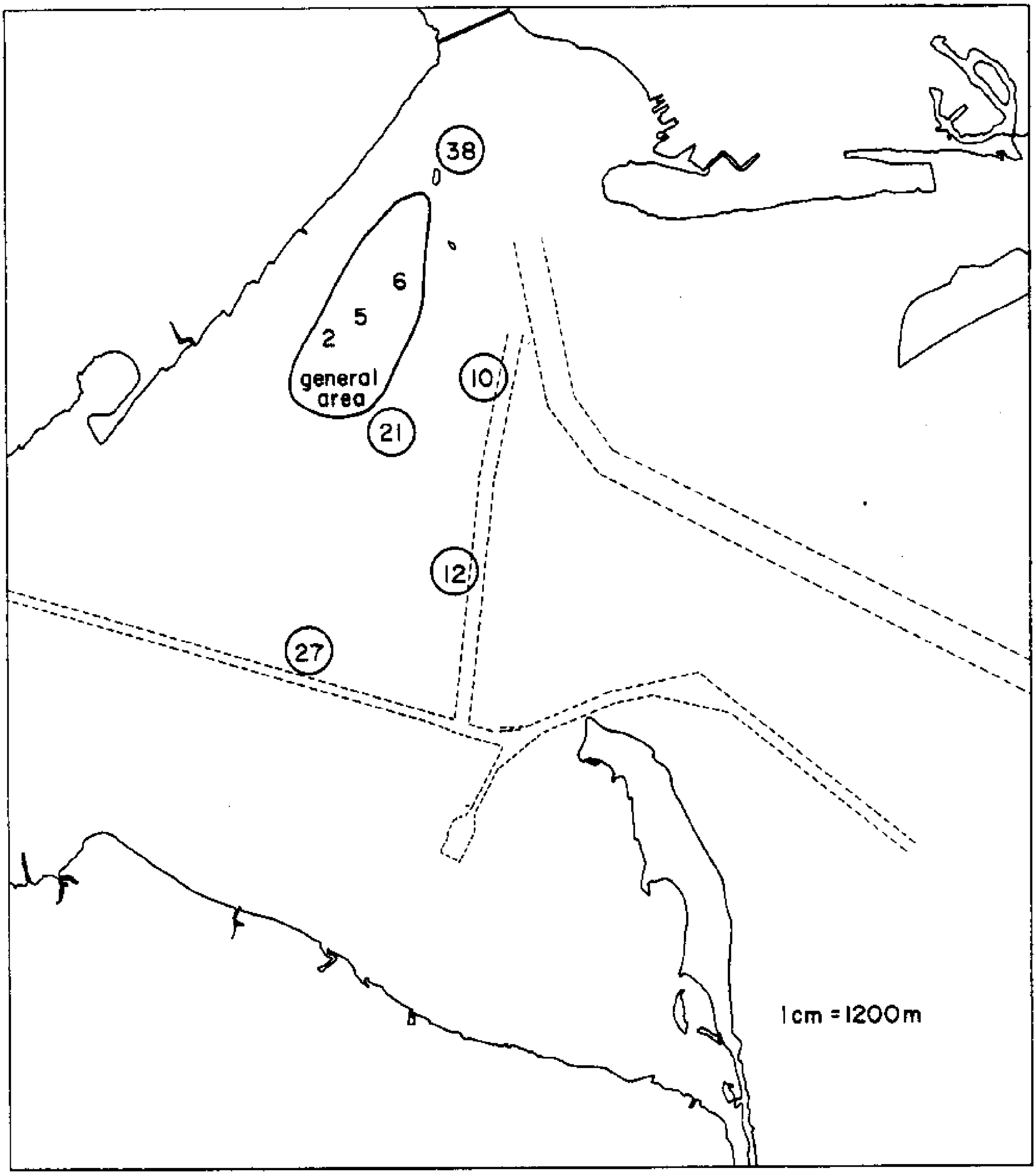
Taxon	a	b	c	d	e	f	g	h	i
O. Arbacioida									
F. Arbaciidae									
Arbacia punctulata			x	x					
O. Clypeasteroida									
F. Echinarachnidae									
Echinarachnius parma	x						x	x	
C. Stelleroidea									
Sc. Asteroidea									
O. Forcipulatida									
F. Asteriidae									
Asterias forbesi	x	x	x	x			x	x	
P. Ectoprocta (Bryozoa)									
C. Gymnolaemata									
O. Ctenostomata									
F. Alcyonidiidae									
Alcyonidium polyoum				x					
F. Vesicularidae									
Bowerbankia gracilis				x					x
Amathia vidovici				x					
O. Cheilostomata									
So. Anasca									
F. Membraniporidae									
Membranipora tenuis				x					x
Conopeum reticulum				x					
F. Electridae									
Electra sp.				x					
F. Bugulidae									
Bugula turrita									x
Bugula sp.	x			x					x

Table 6 - continued

Taxon	a	b	c	d	e	f	g	h	i
So. Ascophora									
F. Schizoporellidae									
Schizoporella unicornis				x					
F. Cheiloporinidae									
Cryptosula pallasiana				x					
Unidenti. spp.		x		x			x	x	

P = Phylum; C = Class, Sc = Subclass; SO = Superorder; O = Order; So = Suborder; Io = Infraorder; SF = Superfamily; S = Section; F = Family

Fig. 13: Approximate locations of stations sampled by Walford (1971). Original map not available.



gammarid Amphipoda species (1 - *Unciola serrata*) compared to other unpolluted environments which commonly report 21 to 200 species (Note: 1 mm screen used). In a number of other qualitative stations sampled by dredge hauls, Walford found approximately one *Mercenaria mercenaria* (hard clam) per 170 ft^2 (16 m^2). Haskin (1962) and Campbell (1967) also report that hard clams are not uniformly distributed in Lower and Raritan bays. Walford indicates that Ropes and Martin (1960) working on the Nantucket Shoals found similar densities, which they considered as being very low. Walford found extensive beds of empty *Mya arenaria* (soft clam) shells and only one live individual. In contrast, Dean (1975) reported that this species was very abundant in his 1957 to 1960 surveys.

Presence of species recorded by Walford (1971) are checked in Table 6 and his data are tabulated in Appendix Table 1.

Dean and Haskin (1964) Study

Dean and Haskin (1964) reported on invertebrate distributions at 20 stations taken in the lower 20 km of the Raritan River estuary between 1957 and 1960 (Fig. 14). They obtained a total of 69 samples by Petersen and vanVeen grabs. During 1957, prior to sewage abatement, 17 marine species were found. In 1958, a sewer system began operation in the lower Raritan Valley. The 12 stations sampled in both 1958 and 1959 yielded 21 and 28 marine species, respectively. In 1960, the number of marine species declined slightly. All of the marine taxa (17 total) they recorded during the study are checked in Table 6. The quantitative distributions of marine species ($\# \cdot m^{-2}$) are listed in Appendix Table 2. All of their quantitative samples were collected during the summer months (June to August). The authors indicate that it is tempting to conclude that pollution abatement caused the increase in diversity and abundance.

Dean (1975 Study

Dean (1975) sampled the macrobenthos at 193 stations (Fig. 15a,b and 16a,b) in the Lower Bay Complex by Petersen and vanVeen grabs between 1957 and 1960. All of the stations were sampled during the summer months. Dean reported in detail on the abundance (or presence) of the 30 most prevalent species encountered in his survey, by station number (see Appendix Table 3). He separately listed the occurrence and abundance of less common species and the stations at which they were noted (see Appendix Table 4). The data at the bottom of each station listed in Appendix Table 3 (Total $\# \cdot m^{-2}$, # species quantitative, Total # species) were compiled by this author from both of these appendix tables. Forty-nine of these stations were sampled for three or four consecutive summers (see Appendix Table 5). The total number of species at each of Dean's stations was used to draw a species richness map of the Lower Bay Complex (Fig. 17). Included in this map are data from Transect *A* from Steimle and Stone (1973) and Brinkhuis (1977-1978 unpublished samples). The species richness map indicates that most of the Lower Bay area, bounded by Staten Island, Chapel Hill Channel, and the Raritan Bay Reach, has greater than 20 species$\cdot m^{-2}$ of station sampled. The principal exceptions are three areas (labelled *A*, *B*, and *C* on Fig. 17), where less than five species (often zero) were reported at stations sampled by the present author (see Brinkhuis Study for discussion). In contrast, two stations (166 and 251) sampled by Dean before dredging in areas *B* and *C* each contained 29 species$\cdot m^{-2}$. Most of the lower Raritan Bay contains 10 to 14 species per station square meter. Species richness in western Raritan Bay is highly variable, ranging from pockets of < 5 species$\cdot m^{-2}$ near the Raritan River and Arthur Kill to pockets of < 25 species$\cdot m^{-2}$. Generally, the number of species$\cdot m^{-2}$ is between 10

Fig. 14: Stations sampled by Dean and Haskin (1964) in and at the mouth of the Raritan River. After Dean and Haskin (1964).

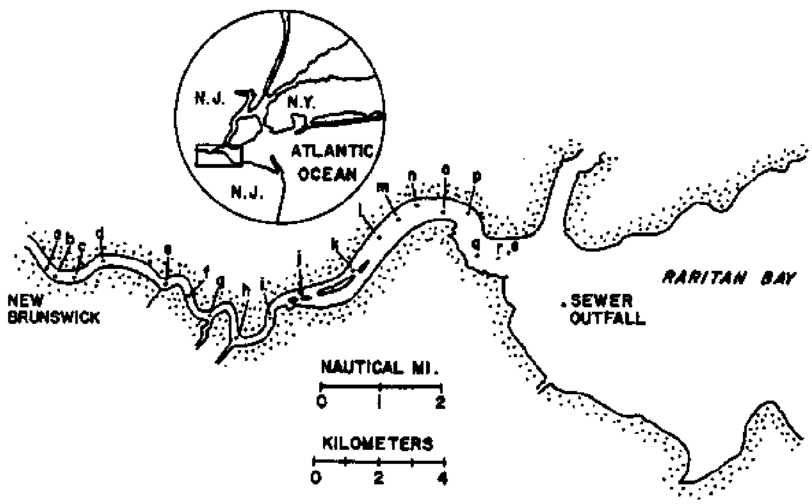


Fig. 15: Raritan Bay macrobenthos survey, 1957, 1958 station locations. From Dean (1975).

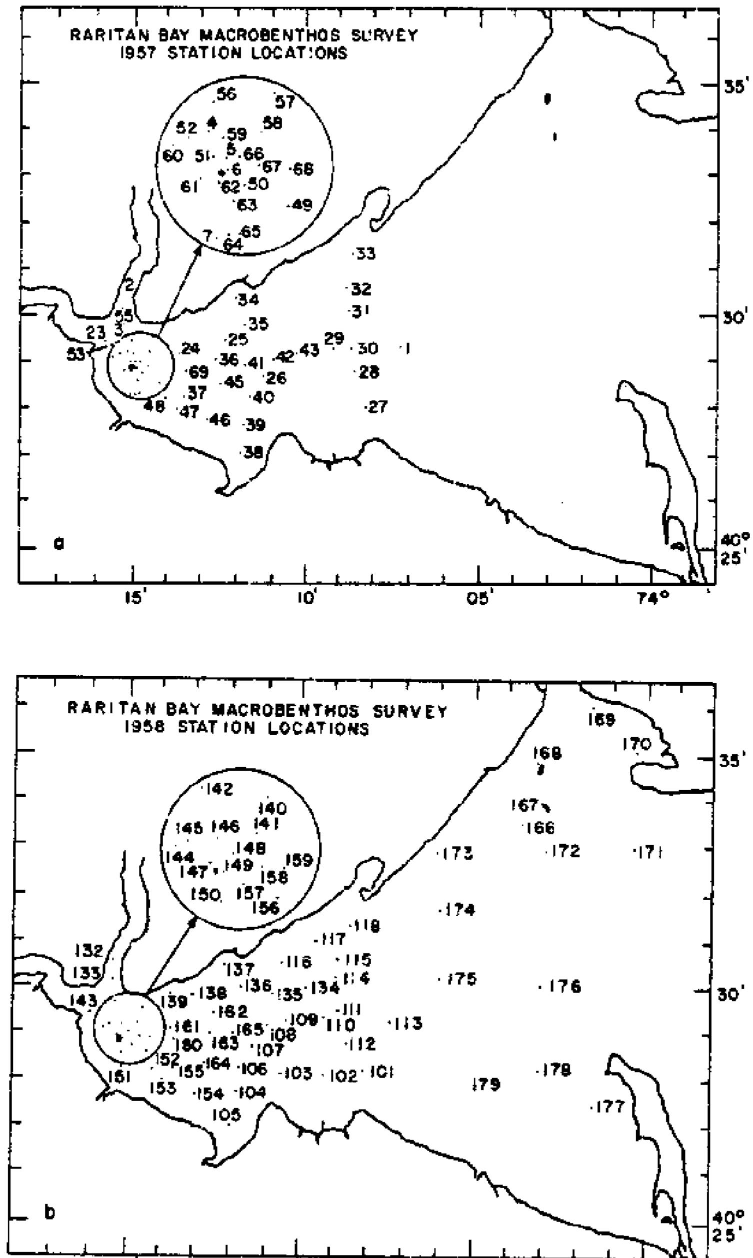
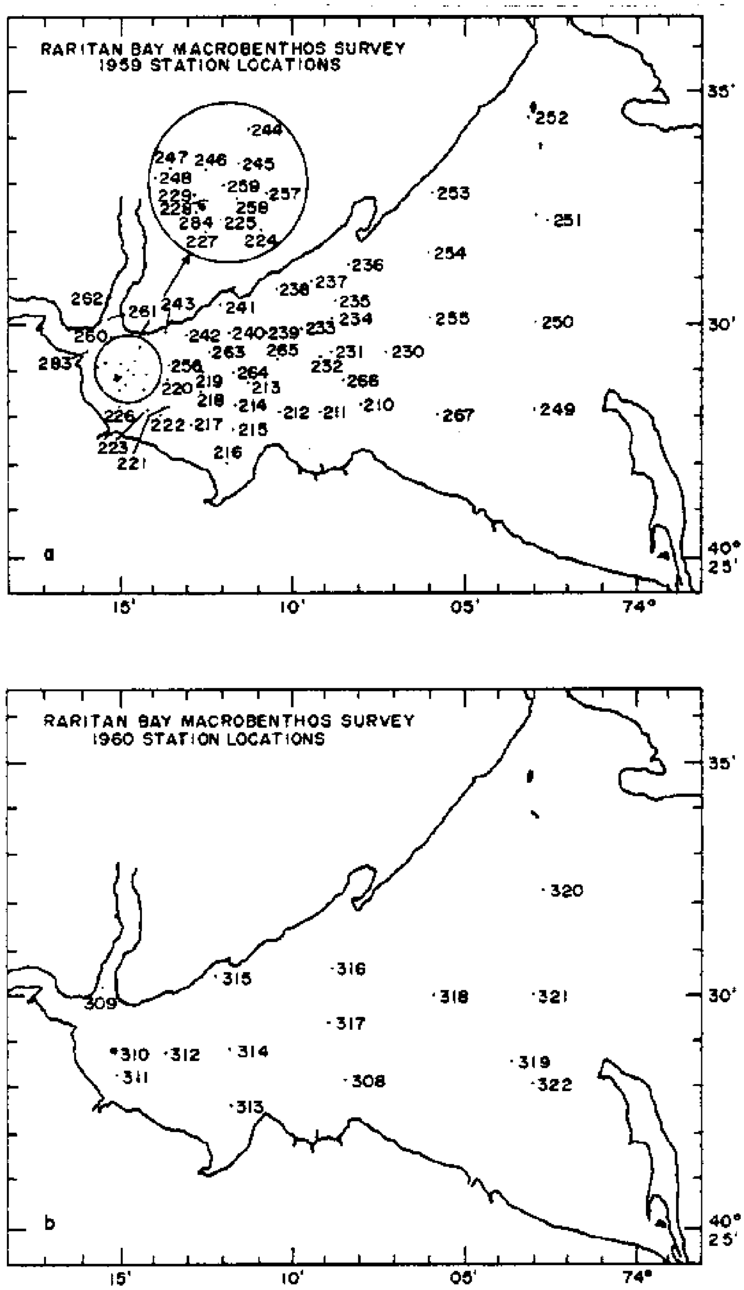


Fig. 16: Raritan Bay macrobenthos survey, 1959, 1960 station locations. From Dean (1975).



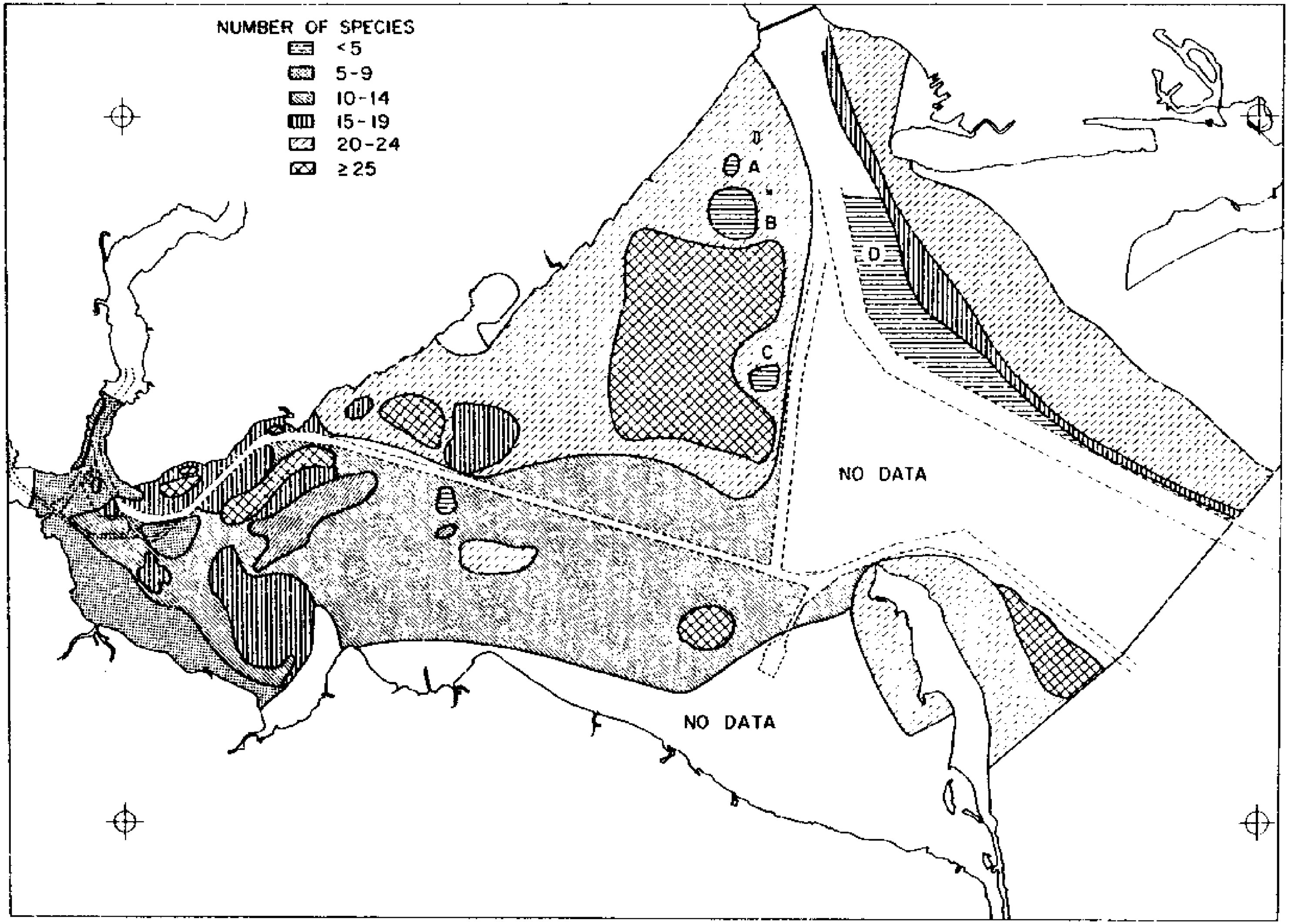


Fig. 17: Species richness map based on data compiled from Steimle and Stone (1973), Dean (1975), and Brinkhuis (1977-1978).

and 20 in most of western Raritan Bay. The East Bank area, east of the Ambrose Channel, contains 15 to 25 species·m^{-2}, with the exception of the area extending from Buoys R *16* to R *8* and 1,000 yards to the East. Here too, < 5 species·m^{-2} are found in an area actively dredged between 1972 and 1976 (see Brinkhuis Study for discussion). One station (171) sampled by Dean before dredging contained 44 species·m^{-2}, the highest richness reported in the Lower Bay Complex. Insufficient data are available to plot species richness for other areas shown in Figure 17.

McGrath (1974) Study)

McGrath (1974) presented preliminary results of a continuing survey of 78 stations in the Lower Bay Complex (Fig. 18). The data reported only represent 40 samples collected in January and February, 1973. Three additional seasonal samplings were planned, but to my knowledge have not been reported on. Each of the stations was sampled by replicate (2) 0.1 m^2 Smith-McIntyre grabs and samples from one grab were seived through 1.0 mm screens. A species list is presented by McGrath, and is included in Table 6. No data are presented by McGrath on total species or density per station. Interestingly, Pearce et al. (1979) include a figure (Fig. 19) based on McGrath's data. This figure illustrates the patterns of species diversity (H') in Raritan, Lower, and Sandy Hook bays. The number of points (stations) illustrated number 56, not 40, samples as reported in McGrath (1974). The patterns of species diversity in Figure 19 are similar to the patterns of species richness presented in Figure 17.

McGrath reported that the average number of species per sample was 4 and the average number of individuals was 11. No sample contained more than 138 individuals (1,380·m^{-2}) and one station (61) was completely azoic at the 1.0 mm level. McGrath calculated an index of common percentage overlap between stations, from which he determined that there were three areas of generally higher affinities (in nearly all cases, replicate samples showed a common overlap of greater than 50%). The first area (Stations 67, 34, 33, and 62) was the extreme western end of Raritan Bay, near the mouth of the Raritan River. The second area was north of the Raritan Bay Reach channel. The final group of stations (52, 49, 17, 85, 87, and 88) lay south of a line from the tip of Sandy Hook to Point Comfort. Further, the groups in Sandy Hook Bay and Raritan Bay proper were faunistically similar, although spatially separated.

McGrath prepared community lists from those species which occurred at least once as a major fraction (> 10%) of a station sample. He concluded that two principal communities may be found in the Lower Bay Complex. One community *(A)*, in the central portion of Lower Bay, is dominated by the deposit-feeding bivalve *Tellina agilis* and two polychaete worms *Streblospio benedicti* and *Nephtys bucera*. The only other bivalves in this community are juvenille *Spisula solidissima* and a few *Mulinia lateralis*. Sixteen species occur as a major fraction of at least one station in the community (Table 7).

McGrath's Community *B* is impoverished in both density and diversity (Table 8). Only 10 species, of which 4 regularly, form a major fraction of the fauna. The community is dominated by *Mulinia lateralis*. *Nephtys bucera*, present in Community *A*, is replaced by its congeners. The mud snail *Nassarius trivittatus* is the only organism abundant in both communities. Community *A* is prevalent in the area defined as *Lower Bay Sands*, while *B* occupies west Raritan and Sandy Hook Bay muds (see Fig. 18).

McGrath found no *Ampelisca* (amphipoda) in his winter samples. He indicates that their absence may be due to presence of oil in sediments, especially in western Raritan Bay. Blumer et al. (1970) describe the sensitivity of Ampeliscid amphipods to low concentrations of oil. The

Fig. 18: Stations locations, benthic microfaunal census of Raritan Bay. From McGrath (1974).

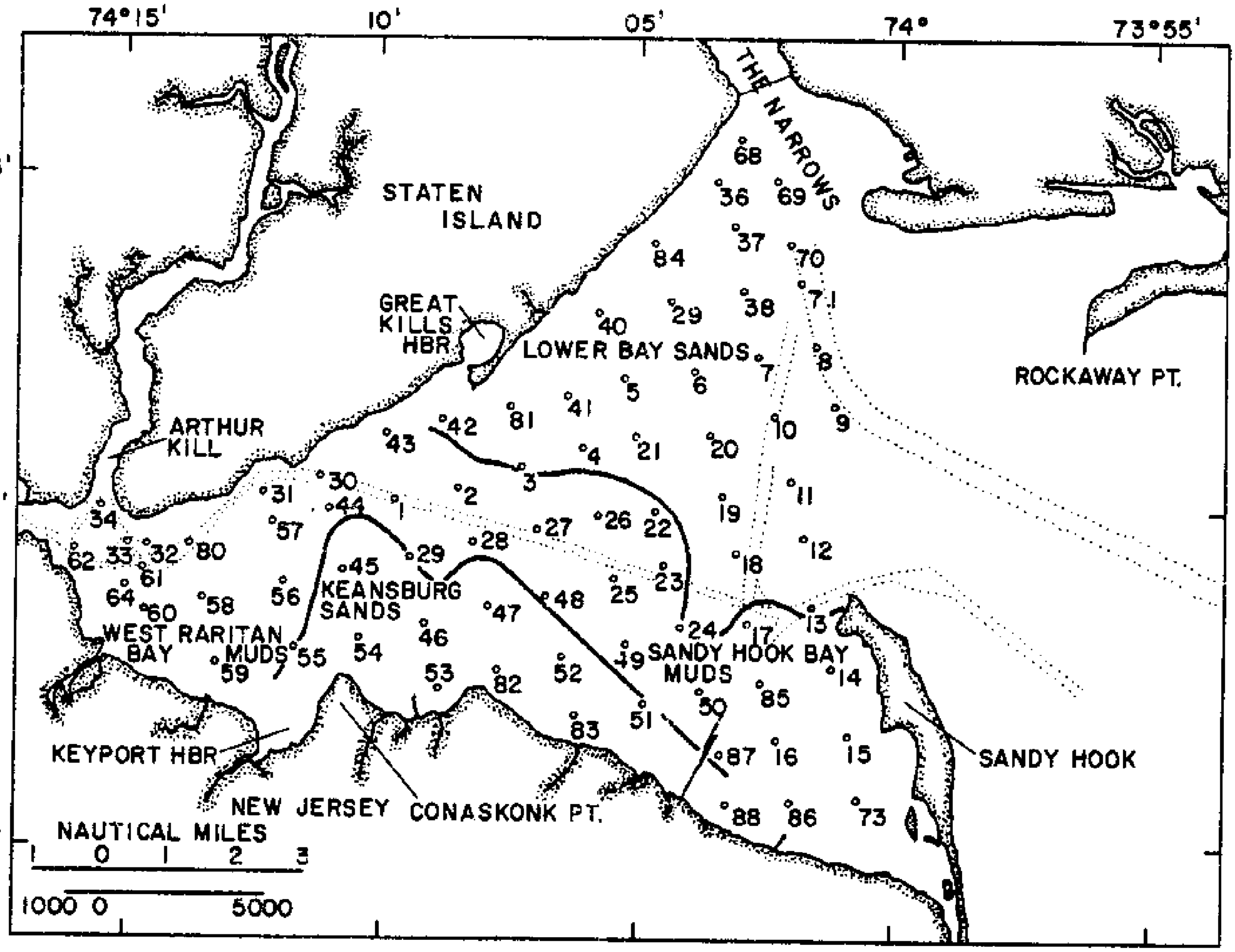


Fig. 19: Species diversity (H') in the Lower Bay Complex based on data from McGrath (1974) and reported by Pearce and Radosh (1979).

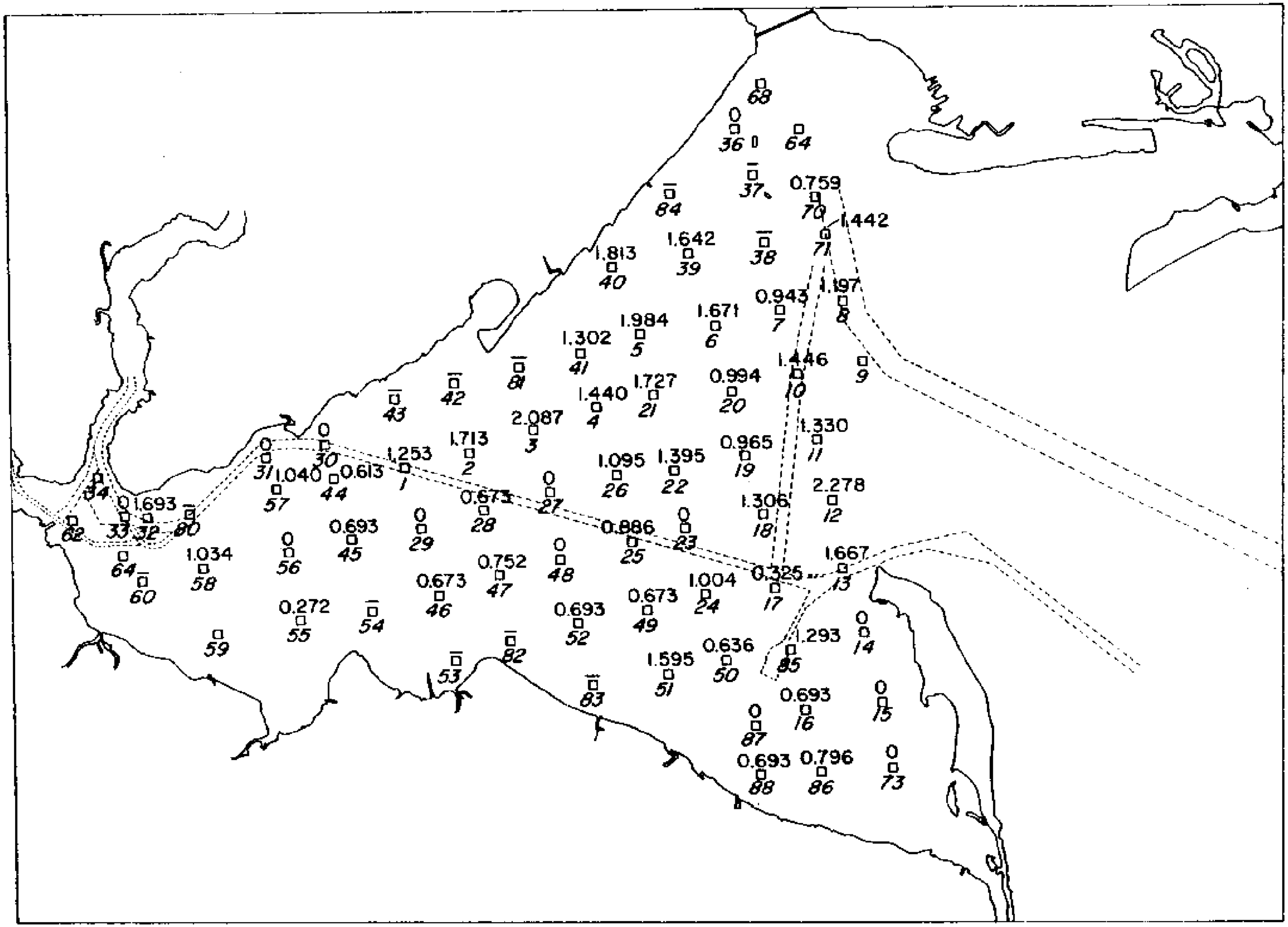


Table 7. Composition of Raritan Bay (and Lower Bay) *sand community A*. Percent occurrence as major (> 10%) fraction of sample (from McGrath, 1974).

Species	% Major fraction
Tellina agilis	63.6
Streblospio benedicti	36.4
Nephtys bucera	31.8
Nemertea spp.	22.7
Nassarius trivittatus	22.7
Glycera dibranchiata	22.7
Protohaustorius ? deichmannae	18.2
Spio ? setosa	13.6
Polydora ligni	9.1
Scolecolepides viridis	9.1
Nephtys incisa	9.1
Mulinia lateralis	4.5
Edotea montosa	4.5
Paraphoxus epistomus	4.5
Acanthohaustorius millsi	4.5
Spisula solidissima	4.5

Table 8. Composition of Raritan Bay *mud community*. Percent occurrence as major (> 10%) fraction of sample (from McGrath, 1974).

Species	% Major fraction
Mulinia lateralis	68.7
Nassarius trivittatus	25.0
Nephtys incisa	18.7
Nephtys picta	12.5
Nephtys caeca	6.3
Nephtys bucera	6.3
Astarte borealis	6.3
Pectinaria gouldii	6.3
Leptochelia savignyi	6.3
Mercenaria mercenaria	6.3

lack of *Ampelisca* in his samples seems to contradict the findings of Dean (1975) who found large numbers at some of his stations sampled between 1957 and 1960 (see Appendix Table 3). However, Dean's data do show a trend of decreased abundance of *Ampelisca* in western Raritan Bay. The lack of *Ampelisca* in McGrath's study may be due solely to the fact he only collected (reported on) winter samples.

Steimle and Stone (1973) more commonly found *Ampelisca* between April and October, with few reported during winter months. The greatest densities found by Dean were at stations just south of Great Kills Harbor (Staten Island). Further, Dean found that the bivalve *Mya arenaria* was much more common in West Raritan Bay Muds than *Mulinia lateralis*. Both of these species are known to undergo large annual variations in density. *Mulinia* is especially known as an *opportunistic* species, which may be present one year in 100,000/m^2 and gone the next (Calabrese, 1970). McGrath concludes that the area he sampled is an impoverished one.

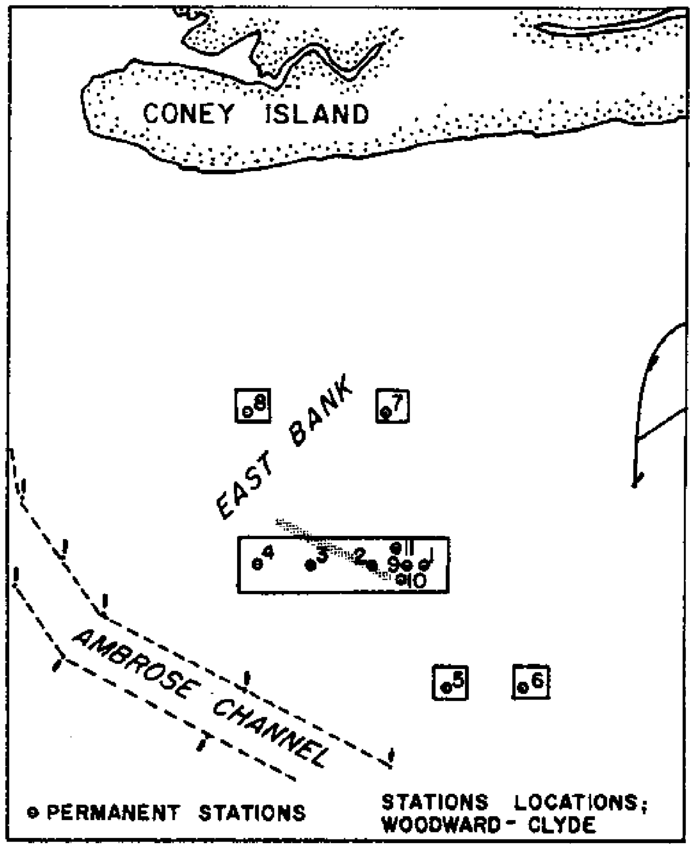
Woodward-Clyde (1975) Study

Woodward-Clyde (1975a) sampled a sand borrow and adjacent area on the East Bank, south of Coney Island, as part of a pre-dredging study for the Rockaway Beach erosion control project. Part of the survey was actually conducted while dredging was in progress. Woodward-Clyde (1975b) also conducted a post-dredging study, which will be considered in the section of this report dealing with environmental effects of mining/dredging.

Woodward-Clyde sampled the benthos by Shipek grab, clam dredge, and otter trawl at eight stations (Fig. 20). Station 2 was apparently directly disturbed by dredging activity that had taken place by June, 1975. Sampling for fauna was begun at these eight stations in June, 1975. The 24 samples (3 each station) obtained by Shipek grabs (0.04 m^2) were screened through an 0.5 mm mesh. Species richness ranged from 4 to 25 taxa per sample, with a mean of 11. Densities ranged from 8 to 6,604 individuals (not per species) per sample, with a mean of 649.

The 24 trawl samples (3 each station) retained (by an 0.5 inch bar mesh) 11 benthic species. Diversity ranged from 1 to 5 species per trawl (mean = 3) and densities ranged from 1 to 50 individuals (not per species) per trawl. The 22 clam dredge samples retained (by 2.5 inch mesh)

Fig. 20: Stations samples by Woodward-Clyde (1975a) for predredging studies on the East Bank. Shaded area was actually mined during June, 1975. From Woodward-Clyde (1975a).



only 9 species. Only 14 of 22 samples contained any invertebrates. Individual hauls contained as many as 3 species and 45 individuals (not per species).

A total of 51 invertebrate taxa was identified to genus or species and these are included in Table 6. The infaunal and epifaunal invertebrates were dominated by bivalves and polychaetes. The number of organisms$\cdot m^{-2}$ and number of species at each station are summarized in Appendix Table 6. The data reported for the borrow area (Stations 1-4) indicate fewer numbers of organisms per sample as well as fewer species. Collections from Stations 6 and 7 were different from other stations. The high density at Station 6 can be ascribed to a dense bed of small blue mussels, along with a host of predators (small decapods). The remaining fauna at Station 6 was rather sparse and typical of other stations. Station 7 contained 50% more species than the most diverse samples from other stations. Polychaetes and amphipods were diverse and numerous. Possibly the high level of organic carbon in the sediments at this station is the reason. Woodward-Clyde conclude that the other station samples yielded diversity and density comparable to other sand communities reported in the literature, and that this area of the East Bank was not impoverished.

Steimle and Stone (1973) Study

Steimle and Stone (1973) reported on a study conducted by the Sandy Hook-Northeast Fisheries Center along the south shore of Long Island (Fig. 21). A total of 39 stations was sampled by Petersen grab repeatedly at monthly intervals between 1966 and 1967. Only one transect, *A*, of six stations lies within the Lower Bay Complex boundaries. This area is commonly referred to as the East Bank. Steimle and Stone reported a total of 145 taxa for their entire transect study, encompassing 11 monthly samplings. In Area *A*, a total of 70 taxa was found. The taxa recorded in both *A* and the remainder of their survey are checked in Table 6.

Transect *A* had the greatest abundance of organisms recorded (see Appendix Table 7). The area was not, however, the most diverse. In all transects, there generally was an increase in diversity with an increase in water depth (i.e., distance offshore). Transect *A* Stations 1, 2, and 5 exhibited the greatest abundances for one reason only--extensive blue mussel beds (*Mytilus edulis*). If mussels are disregarded Transect *A* would, in fact, have abundances comparable to other stations. The range in number of taxa in *A* was 19 to 35 species. The greatest number of taxa recorded at any station for the year was 54. The total number of taxa recorded in *A* was similar to that reported by Woodward-Clyde (1975a); however, there were differences in the taxa recorded. The greatest number of taxa and individuals in *A* was generally found between June and September. Again, this period's greatest abundance was dominated by blue mussels.

Steimle and Stone describe two assemblages that occur in the East Bank area--the medium sand assemblage and the *Mytilus edulis* aggregation. One other, the fine silty sand assemblage, was not found in Transect *A*. The dominant organisms in the medium sand assemblage are presented in Table 9 and the species associated in the *Mytilus edulis* aggregation are listed in Table 10. Usually, the medium sand assemblage inhabited the sands under the mussel clumps. Most of the mussels collected (95%) were approximately 1 cm in length. The mean number of animals$\cdot m^{-2}$ in the medium sand assemblage of *A* was 209, with a mean of 24 species.

Brinkhuis (1977-1978) Study

Between 1977 and 1978, Brinkhuis obtained Shipek grab samples at a number of locations on the East and West banks of the Ambrose Channel (Fig. 22). Six grabs were obtained at each of 40 stations. The samples from each station were pooled and

Fig. 21: Station locations, *R/V CHALLENGER* survey, 1966-67. From Steimle and Stone (1973).

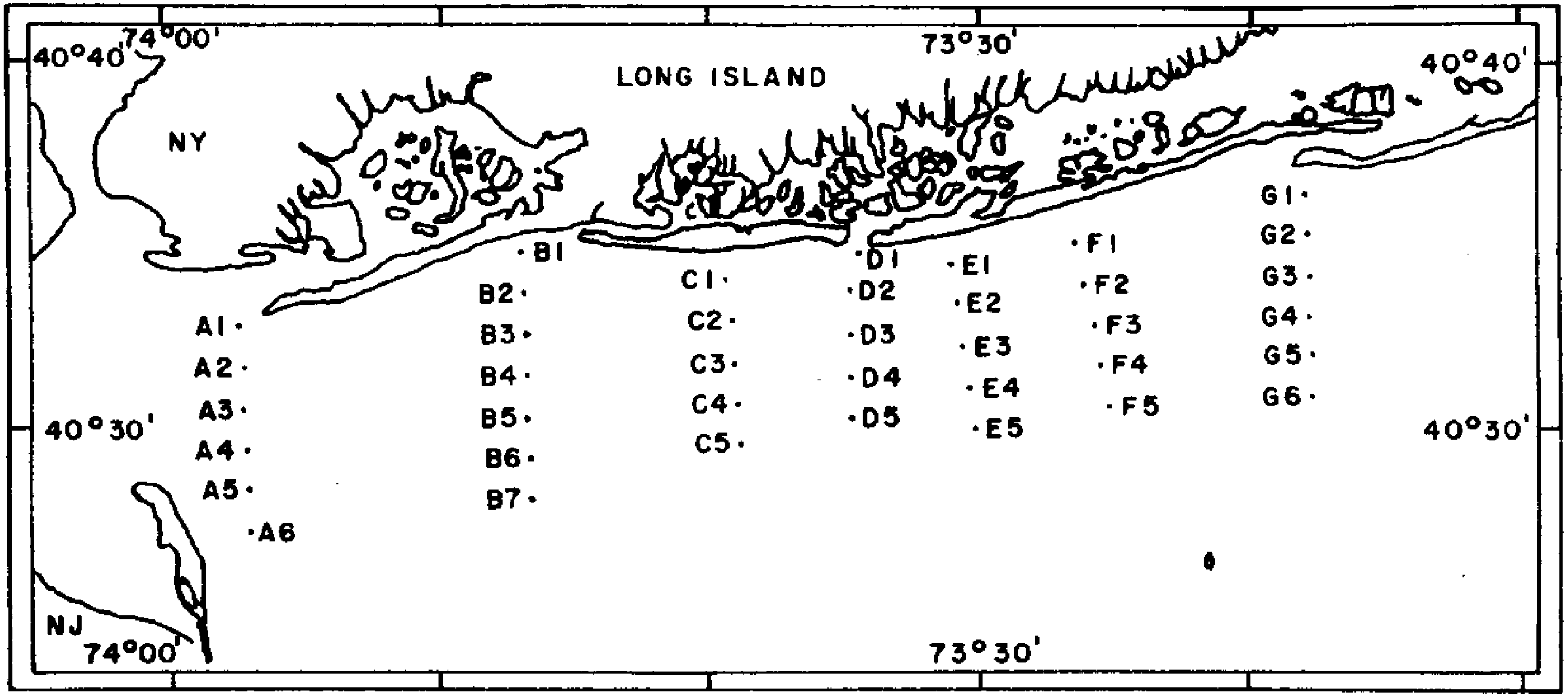


Fig. 22: Shipek grab samples screened for invertebrates by Brinkhuis between 1977 and 1976. From Swartz and Brinkhuis (1978).

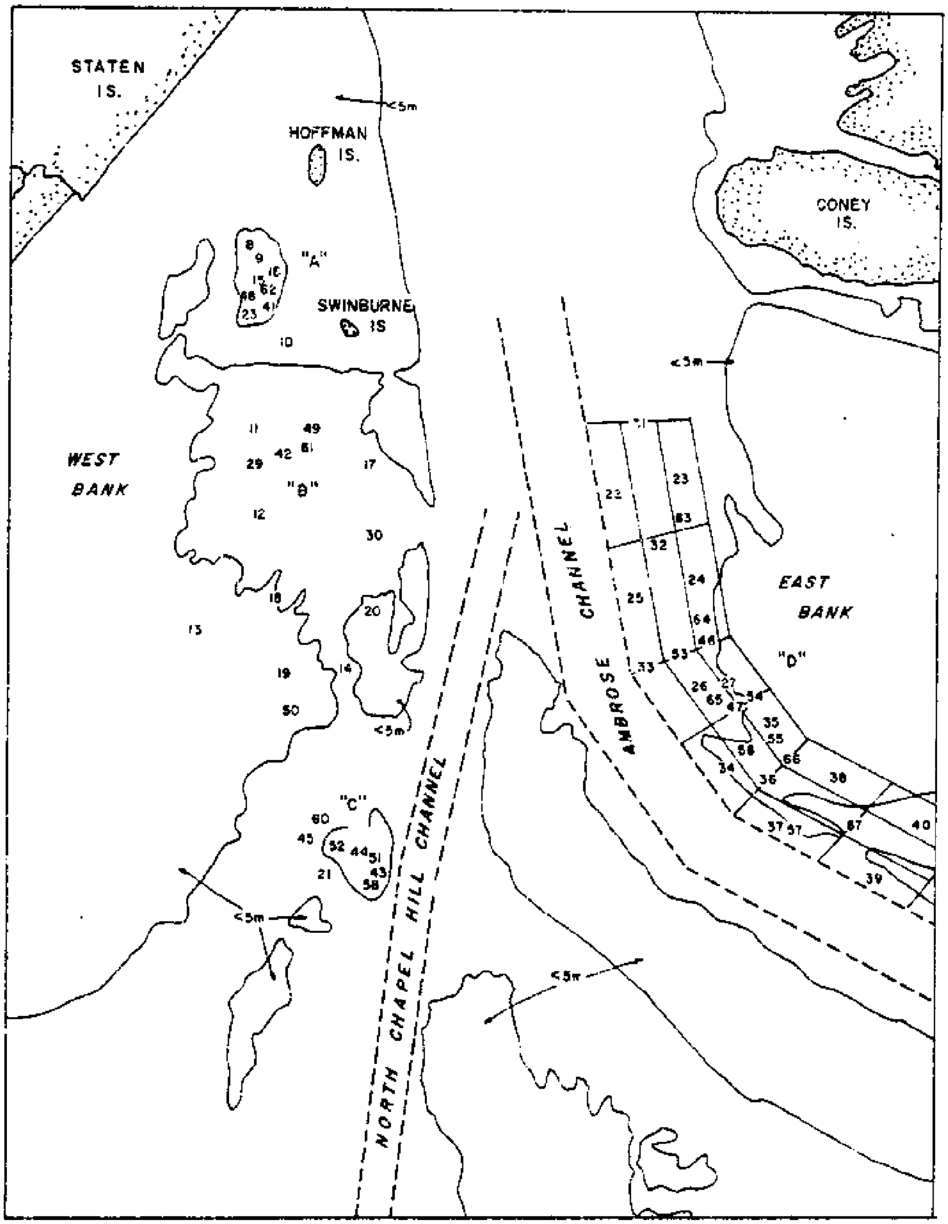


Table 9. Steimle and Stone's (1973) medium sand assemblage found in Area *A* on the East Bank, Stations 3 and 6 (and possibly 4).

Species	
Tellina agilis	bivalve
Protohaustorium deichmannae	burrowing amphipod
Eschinarachius parma	sand dollar
Unciola irrorata	tube-dwelling amphipod
Spisula solidissima	surf clam
Also frequently associated:	
Leptocuma minor	cumacean
Acanthohaustorius millsi	amphipod
Trichophoxus epistomus	amphipod
Monoculodes edwardsi	amphipod
Sthenelais limicola	polychaete
Lumbrineris fragilis	polychaete
Spiophanes bombyx	polychaete

Table 10. Steimle and Stone's (1973) *Mytilus edulis* assemblage found in Area *A* on the East Bank, Stations 1, 2, and 5.

Species	
Mytilus edulis	blue mussel
Harmothoe extenuata	polychaete
Harmothoe imbricata	polychaete
Nereis succinea	polychaete
Lepidonatus squamatus	polychaete
Neopanope texana	crab
Metridium senile	anemone

sieved through 1 mm screens. These samples were collected with the strategy to determine if there were any long-term effects of dredging (mining) that took place in Areas *A*, *B*, *C*, and *D*. Some of the stations sampled were located in holes that remained after mining, as well as in adjacent sediments. These samples were collected incidental to the study reported by Swartz and Brinkhuis (1978).

Invertebrate taxa recovered from these samples are listed in Table 11 and 12 (East and West banks, respectively). Each table is subdivided into stations affected by dredging (in actual holes themselves) and those unaffected. The presence of dredging activity was determined from dredging activity reports (Sanko, personal communication) as well as bathymetric changes determined from depth recordings that were compared to older nautical charts. No distinct trends are discernible from the data comparing dredged and undredged areas on either the East or West bank. Dredged holes on the West Bank had filled in with up to 80 cm of silt-clay (70-90%) which had organic carbon levels of up to 25% by weight. The holes on the West Bank most frequently were azoic. Undredged sediments nearby did not appear to contain significantly more species or numbers; however, the undredged stations were in close proximity to the holes. There may have been effects of the holes on adjacent water quality (Swartz and Brinkhuis, 1978). Dredged and undredged sediments on the East Bank had comparable fauna. The number of taxa and abundance was greater than on the West Bank. Few areas were azoic on the East Bank. Holes on the East Bank seldom contained large amounts of silt-clay. Again, undredged stations were within the confines of an area designated for sand mining between 1971 and 1974. Their close proximity to dredged areas may explain the lower diversity and abundance than that reported by Woodward-Clyde (1975a) and Steimle and Stone (1973).

Brinkhuis (1979-1980) Study

Brinkhuis is currently conducting a faunal survey in three areas of the Lower Bay (Fig. 23). Starting in June, 1979, these three locations are being surveyed every three months for one year. Two sampling grids for repeated sampling have been established: a coarse grid, consisting of stations every 800 m at the nodes of the triangles in Figure 23, and a fine grid in the shaded triangles with stations spaced at 200 m intervals. Three Shipek grabs are obtained at each station. Each station's samples are pooled and sieved through 1 mm screens. Samples are

Table 11. Taxa found by Brinkhuis (1977, 1978) in East Bank stations. Data are $\# \cdot m^{-2}$ from six pooled Shipek grabs per station. Numbers in ( ) below station numbers are depths in feet below mean low water.

	Stations									
Dredged	5 (59)	6 (56)	7 (53)	24 (45)	25 (37)	26 (70)	32 (48)	36 (55)	37 (65)	39 (50)
Nematoda		15	5	10			20			15
Eteone sp.		5	5		5					
Goniadia sp.										
Nephtys sp.		20		10		5				
Nereis sp.							5			
Cyathura polita										
Amphipoda			5							
Crargon septemspinosa						15				
Ovalipes ocellatus		5		5		10		5		
Rhithropanopeus harrisei				5						
Mytilus edulis										
Nassarius obsoletus					5		20			
Asterias forbesi						5				
Ammodytes americanus (sand lance)						15				
Total # species	1	4	3	4	2	5	3	1	0	1
Total $\# \cdot m^{-2}$	5	40	15	30	10	50	45	5	0	15

Table 11 - continued

Not dredged	Stations 22 (26)	23 (35)	27 (25)	31 (26)	33 (18)	34 (75)	35 (12)	38 (25)	40 (18)
Nematoda						40			
Eteone									
Goniadia sp.									
Nephtys sp.		15		5				10	
Nereis sp.		25					5		
Cyathura polita							10		
Amphipoda									
Crangon septemspinosa									
Ovalipes ocellatus								5	
Rhithropanopeus harrissi		5							
Mytilus edulis									
Nassarius obsoletus				10	25				
Asterias forbesi									
Ammodytes americanus (sand lance)			25						
Total # species	0	3	1	2	1	1	2	2	0
Total #·m^{-2}	0	45	25	15	25	40	15	15	0

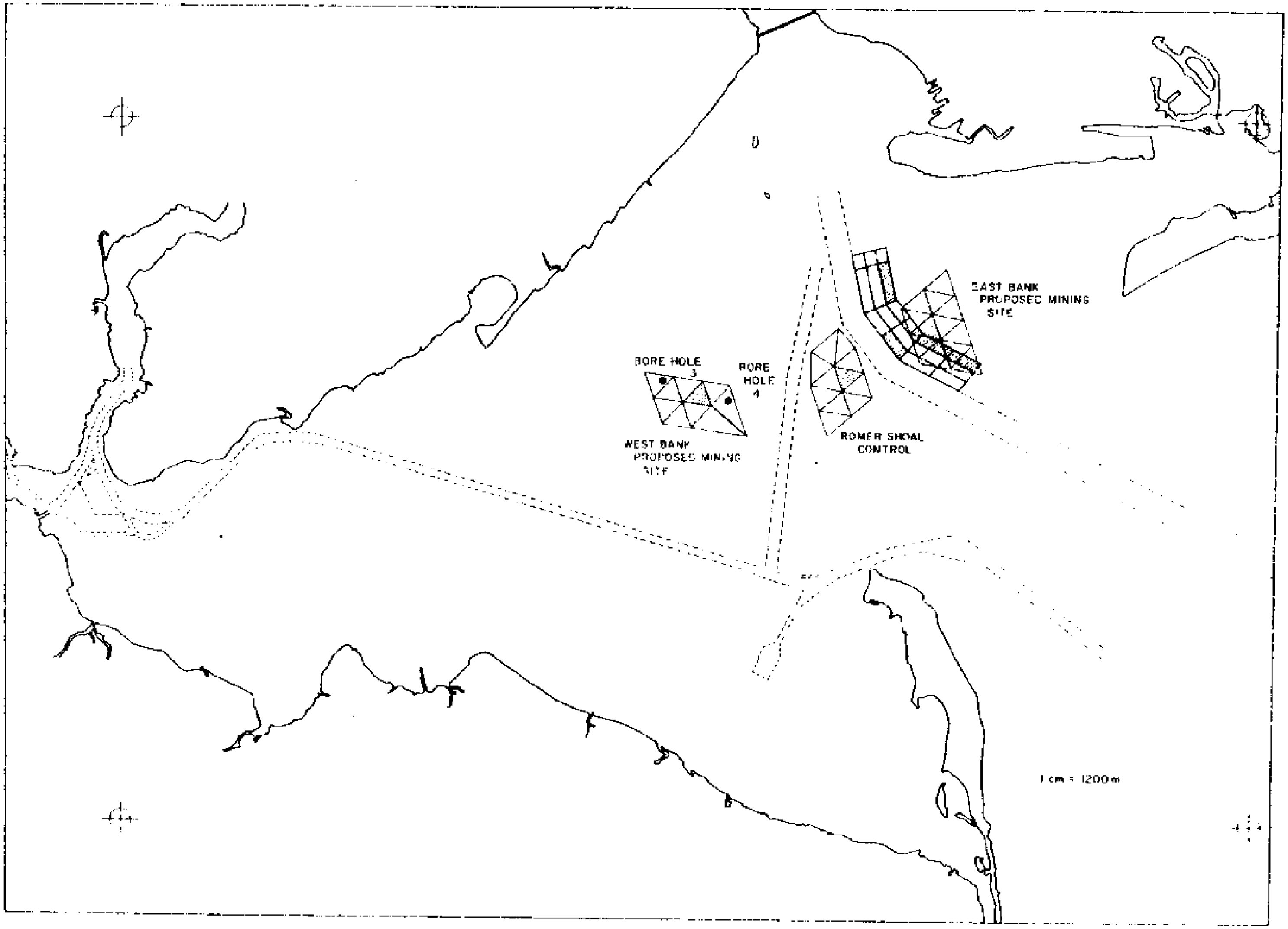
Table 12. Taxa found by Brinkhuis (1977, 1978) in West Bank stations. Data are $\# \cdot m^{-2}$ from six pooled Shipek grabs per station. Numbers in ( ) below stations are depths in feet below mean low water.

Dredged	Stations															
	2 (26)	3 (22)	4 (22)	8 (33)	9 (37)	11 (30)	12 (33)	15 (40)	16 (40)	17 (28)	18 (35)	20 (40)	21 (60)	28 (25)	29 (25)	30 (40)
Nematoda																
Eteone sp.																
Goniada sp.																
Nephtys sp.					10		10				10	5		15		10
Nereis sp.		5											10			
Cyathura polita					5											
Amphipoda																
Crangon septemspinosa																
Rhithropanopeus harrisii																
Nassarius obsoletus														10		20
Mytilus edulis																
Asterias forbesi																
Ammodytes americanus (Sand lance)																
Total # species	0	1	0	0	2	0	1	0	0	0	1	1	1	2	0	2
Total $\# \cdot m^{-2}$	0	5	0	0	15	0	10	0	0	0	10	5	10	25	0	30

Table 12 - continued

Not dredged	Stations 1 (16)	10 (11)	13 (12)	14 (16)	19 (16)
Nematoda					
Eteone sp.					
Goniadia sp.				10	
Nephtys sp.		15		10	
Nereis sp.				10	
Cyathura polita					
Amphipoda		15			
Crangon septemspinosa					
Rhithropanopeus harrisei					
Nassarius obsoletus					
Mytilus edulis			5		
Asterias forbesi					
Ammodytes americanus (sand lance)					
Total # species	0	2	1	3	0
Total $\#\cdot m^{-2}$	0	30	5	30	0

Fig. 23: Stations being sampled by Brinkhuis between 1979 and 1980 for benthic invertebrates and fishes. Stations are at nodes of each triangle (every 800 m) and every 200 m in shaded triangles.



currently being sorted to species and enumerated.

Preliminary analysis of some samples, mainly East Bank stations, indicates the presence of at least 53 taxa, including 12 species of gammarid Amphipoda. Woodward-Clyde (1975a) reported 13 and Dean (1975) reported 6 species of gammarids. These preliminary results indicate that 10 to 35 taxa are found at East Bank stations. An insufficient number of other area stations have been analyzed thus far to observe any trends. The stations in the northern half of Romer Shoal, however, are represented by extensive beds of dead mussel shells (*Mytilus edulis* and *Modiolus modiolus*).

Miscellaneous Reports

A number of sporadic samplings, primarily to determine shellfish distribution and abundance (*Mercenaria mercenaria* and *Mya arenaria*) has been reported. In the early to middle 1800s, the hard clam *Mercenaria mercenaria* was harvested commercially from Raritan and Lower bays. Goode (1887) indicates that by 1880 shellfishes obtained from Newark Bay tasted of coal oil and were unsuitable for sale. Jacobson and Gharrett (1967) report that the harvest of shellfishes in Raritan Bay peaked in the late 1880s and maintained a high level until about 1945, when a gradual decline in the harvest was noted. Cluming (1917) stated that significant populations of oysters (*Crassostrea virginica*) were under cultivation in the late 1800s and early 1900s. Nelson (1916) predicted a decline in oyster abundance as a result of copper and industrial pollutants. The oyster has now virtually disappeared from the area. A small population has been reported recently off Ward Point, Staten Island (MacMillan, personal communication). It has also been reported that bay scallops were once common to Raritan Bay.

Haskin (1962) and Campbell (1967) reported on the distribution and abundance of *Mercenaria mercenaria* in Raritan and Lower bays. Both investigations reported the paucity of juveniles (< 1" in length). There are apparently larger numbers of commercial-sized clams in the northern half (above Raritan Bay West Reach) of these bays. Paucity of juveniles was ascribed to pollution problems. Dean (1975) reported finding only occasional specimens of hard clams at six of his stations during his 1957 to 1960 survey.

All of the Lower Bay Complex has been closed to commercial harvesting since 1961 due to industrial and coliform pollution, as well as outbreaks of infectious hepatitis (MacMillan, personal communication). At present, harvesting of hard clams is limited to an area in Raritan Bay (see Fig. 24) under an experimental program. In this program, clams are depurated for 30 days in a plant on Staten Island (Great Kills) before release to the market. The most recent extensive survey of hard clam abundance was conducted by the New York State Department of Environmental Conservation in October of 1970 (Hendrickson, personal communication). The area surveyed and general patterns of abundance are shown in Figure 24. Few clams were found in the western portion, while the highest densities were found just south of the Raritan Bay West Reach.

Fishes

The waters of the Lower Bay Complex are a habitat for permanent resident species, as well as a seasonally temporary haven for species migrating to the Hudson River for spawning. Resident species include those which are found all year long and those which use the area for spawning. Croker (1965) identified 20 species of endemic planktonic fish eggs and larvae (Table 13) that occurred in Sandy Hook Bay. A fairly complete list of fish taxa caught in the Lower Bay Complex, consisting of 71 species, is shown in Table 14. Thirty-three of these taxa are caught regularly (see Abundance

Fig. 24: Map showing abundance of ***Mercenaria mercenaria*** in a 1970 New York State Department of Environmental Conservation survey. From Hendrickson (personal communication).

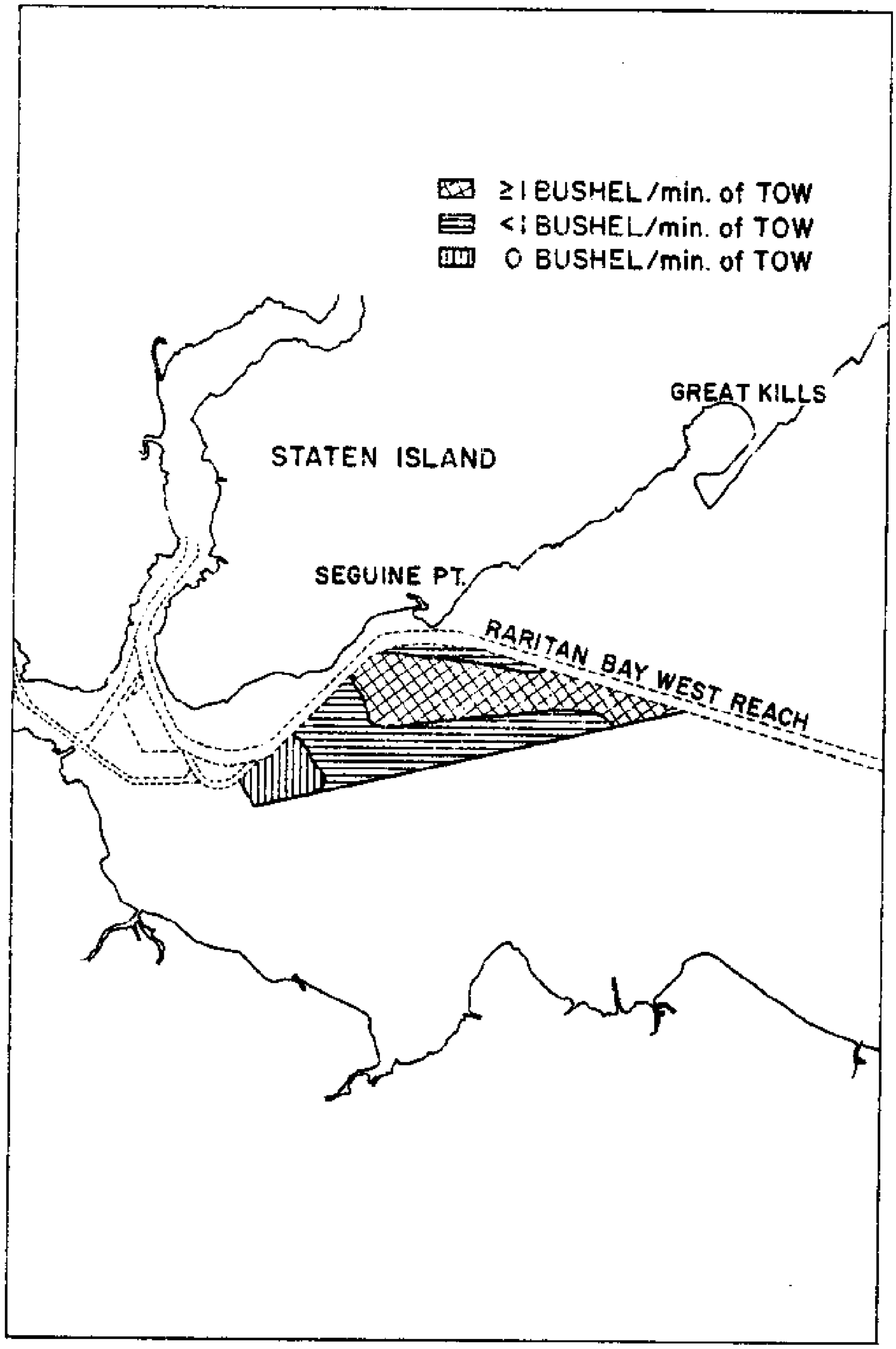


Table 13. Species of fish eggs and larvae and months of occurrence in Sandy Hook Bay (from Croker, 1965).

Species	Occurrence	
	Eggs	Larvae
Brevoortia tyrannus	May-June	Nov.-Dec.
Clupea harengus harengus		March-May
Anchoa mitchilli	May-June	June-Sept.
Anguilla rostrata		March-June
Fundulus heteroclitus	June-July	June
Enchelyopus cimbrius		June
Pollachius virens		April
Hippocampus erectus		June-April
Syngnathus fuscus		May-July
Micropogon undulatus		Nov.
Tautoga onitis	May-July	July
Gobiosoma sp.		Aug.
Prionotus sp.	May-June	
Myoxocephalus sp.		March-April
Ammodytes americanus		March-May
Peprilus triacanthus		July
Menidia menidia		May-July
Scophthalmus aquosus	May-June	June
Pseudopleuronectes americanus		April-June
Sphoeroides maculatus		June-July

Table 14. List of fish species reported for the Lower Bay Complex.

Taxa	Common name	Occurrence
Carcharhinidae		
Mustelus canis	smooth dogfish	(summer)
Squalidae		
Squalus acanthias	spiny dogfish	(uncommon)
Rajidae		
Raja erinacea	little skate	(uncommon)
Raja eglanteria	clearnose skate	(uncommon)
Dasyatidae		
Dasyatis centroura	roughtail stingray	(uncommon)
Acipenseridae		
Acipenser brevirostrum	shortnose sturgeon	(uncommon)
Acipenser oxyrhynchus	Atlantic sturgeon	(uncommon)
Anguillidae		
Anguilla rostrata	American eel	
Congridae		
Conger oceanicus	conger eel	(uncommon)
Clupeidae		
Alosa aestivalis	blueback herring	(all year)
Alosa mediocris	hickory shad	(uncommon)
Alosa pseudoharengus	alewife	(all year)
Alosa sapidissima	American shad	(fall-spring)
Brevoortia tyrannus	Atlantic menhaden	(all year)
Clupea harengus harengus	Atlantic herring	(fall-spring)
Engraulidae		
Anchoa hepsetus	striped anchovy	(uncommon)
Anchoa mitchilli	bay anchovy	(summer-fall)
Engraulis eurystole	silver anchovy	(fall)
Synodontidae		
Synodus foetens	inshore lizardfish	(uncommon)
Batrachoididae		
Opsanus tau	oyster toadfish	(uncommon)
Lophiidae		
Lophius americanus	goosefish	(uncommon)
Gadidae		
Enchelyopus cimbrius	fourbeard rockling	(larvae only)
Merluccius bilinearis	silver hake	(fall-spring)
Pollachius virens	pollock	(larvae only)
Urophycis chuss	red hake	(all year)
Urophycis regius	spotted hake	(all year)
Urophycis tenuis	white hake	(uncommon)
Atherinidae		
Menidia menidia	Atlantic silverside	(fall-spring)
Gasterosteidae		
Gasterosteus aculeatus	threespine stickleback	(uncommon)

Table 14- continued

Taxa	Common name	Occurrence
Syngnathidae		
Hippocampus erectus	lined seahorse	(late summer)
Syngnathus fuscus	northern pipefish	(late summer)
Cyprinodontidae		
Fundulus heteroclitus	mummichog	(larvae only)
Perichthyidae		
Morone americana	white perch	(uncommon)
Morone saxatilis	striped bass	(summer)
Serranidae		
Centropristis striata	black sea bass	(uncommon)
Pomatomidae		
Pomatomus saltatrix	bluefish	(summer-fall)
Carangidae		
Vomer septapinnis	Atlantic moonfish	(Sept.-Oct. only)
Selene vomer	lookdown	(uncommon)
Pomadasyidae		
Orthopristis chrysoptera	pigfish	(uncommon)
Sparidae		
Stenotomus chrysops	scup (porgy)	(summer)
Sciaenidae		
Bairdiella chrysura	silver perch	(fall only)
Cynoscion regalis	weakfish	(summer-fall)
Leiostomus xanthurus	spot	(fall)
Menticirrhus saxatilis	northern kingfish	(fall)
Micropogon undulatus	Atlantic croaker	(uncommon)
Chaetodontidae		
Chaetodon ocellatus	spotfin butterflyfish	(uncommon)
Labridae		
Tautoga onitis	tautog (blackfish)	(fall-spring)
Tautogolabrus adspersus	cunner	(fall)
Mugilidae		
Mugil curema	white mullet	(uncommon)
Uranoscopidae		
Astroscopus guttatus	northern stargazer	(uncommon)
Pholidae		
Pholis gunnellus	rock gunnel	(fall)
Ammodytidae		
Ammodytes americanus	American sand lance	(fall-winter)
Scombridae		
Scomber scombrus	Atlantic mackerel	(uncommon)
Stromateidae		
Peprilus triacanthus	butterfish	(all year)

Table 14- continued

Taxa	Common name	Occurrence
Gobiidae		
Gobiosoma sp.	goby	(larvae only)
Triglidae		
Prionotus carolinus	northern searobin	(summer)
Prionotus evolans	striped searobin	(summer-fall)
Cottidae		
Hemitripterus americanus	sea raven	(uncommon)
Myoxocephalus aenaeus	grubby	(summer-fall)
Myoxocephalus octodecemspinosus	longhorn sculpin	(fall-winter)
Myoxocephalus scorpius	shorthorn sculpin	(uncommon)
Bothidae		
Citharichthys arctifrons	Gulf Stream flounder	(uncommon)
Etropus microstomus	smallmouth flounder	(fall)
Paralichthys dentatus	summer flounder	(all year)
Scophthalmus aquosus	windowpane	(all year)
Pleuronectidae		
Pseudopleuronectes americanus	winter flounder	(all year
Balistidae		
Aluterus schoepfi	orange filefish	(uncommon)
Monocanthus hispidus	planehead filefish	(uncommon)
Diodontidae		
Chilomycterus schoepfi	striped burrfish	(uncommon)
Tetraodontidae		
Sphoeroides maculatus	northern puffer	(summer)

column) during some time of year and at more than one sampled station. Smith (1976) states that, despite the uses and abuses of the Hudson River estuary, there are more species in these waters now than when Henry Hudson arrived in 1609.

There have only been a handful of reports dealing with fishes in the Lower Bay Complex waters. Breder (1922) published the first extensive report on the fishes in Sandy Hook Bay. He followed these up with yearly studies (Breder, 1925, 1926, 1931) and later described the fish species in New York Harbor (Breder, 1938). These reports either lack quantitative detail, or are based on methods no longer used, so that comparisons of abundance with more recent reports can not be made. The presence of species recorded in Table 14 do not include information from Breder.

Only two recent reports deal with the distribution and abundance of fishes in the area. Wilk and Silverman (1976) conducted a summer study of fish distribution in Sandy Hook Bay. Wilk et al. (1977) present the most, and only recent, comprehensive study of fishes in the whole of the Lower Bay Complex. These two reports and data from work in progress by the present author form the basis for the list of species in Table 14. The following describes the seasonal occurrence and abundance patterns based on the studies by Croker (1965), Wilk and Silverman (1976) and Wilk et al. (1977).

<u>Croker (1965) Study</u>

Croker (1965) noted a gradual increase in the number of species of eggs and larvae through the spring to a peak in the summer, followed by a decline in the fall and winter. Seven species: *Anguilla rostrata*, *Clupea harengus harengus*, *Ammodytes americanus*, *Pseudopleuronectes americanus*, *Anchoa mitchilli*, *Syngnathus fuscus*, and *Menidia menidia* comprised 98% of all larvae collected. The larvae of *P. americanus* were most ubiquitous and exhibited a marked diel periodicity in abundance in surface waters.

According to Wilk et al. (1977), seasonal samples from stations in Sandy Hook Bay (see Table 15--Areas *I*, *C*, *P*, *Q*, *R*, and *S*) indicate higher numbers of the same species during the fall and winter months. The total number of species in Sandy Hook Bay appeared to be highest in early fall, when several semi-tropical species were also recorded in warmer bay waters. The study by Wilk and Silverman (1976) that was conducted between July and October in Sandy Hook Bay indicates a similar trend.

<u>Wilk and Silverman (1976) Study</u>

Wilk and Silverman (1976) divided Sandy Hook Bay into blocks 1' longitude by 1' latitude (e.g., see Fig. 25) which were sampled bi-weekly in 1970 with a 9.1 m footrope otter trawl towed for 10 min at 5.6 $km \cdot h^{-1}$. Data were grouped into eight sample periods of seven two-day and one one-day cruises. Presentation of quantitative data was performed in two ways: 1) maps showing distribution (abundance) of the more notable species within the blocks, but averaged over the entire study period or 2) tabulations indicating number of fishes and weight per species per sampling cruise. Unfortunately, these latter data are not subdivided into sampling blocks.

Catches in the northern half of Sandy Hook Bay (blocks 1-9) contained a total of 35 species recorded during the study; those in the southern half, 22 species. Only seven species occurred in more than 25% of each collection. The total catch, by both weight and number, averaged for the period July to October, in the northern half of the Bay exceeded that of the southern half (Fig. 25a,b). The greater abundance and diversity of species in the northern blocks are apparently related to the deeper and cooler water found there and the proximity to ocean waters (Wilk and Silverman, 1976).

Four species--*Pseudopleuronectes americanus*, *Prionotus evolans*, *Scophthalmus aquosus*, and *Prionotus carolinus*--

Fig. 25: The average catch (no.)(a) and weight (kg)(b) of all fish per 10-min tow in Sandy Hook Bay. After Wilk and Silverman (1976).

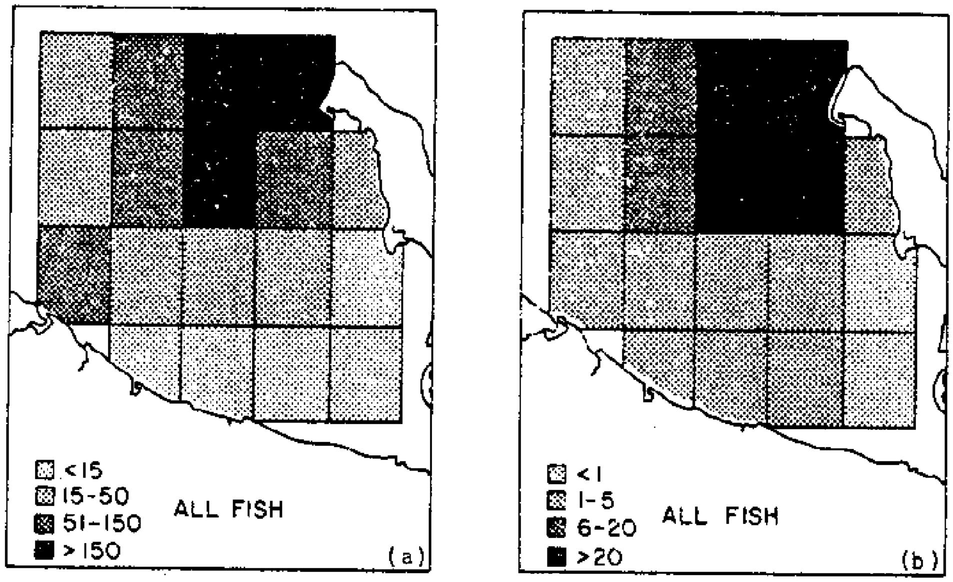
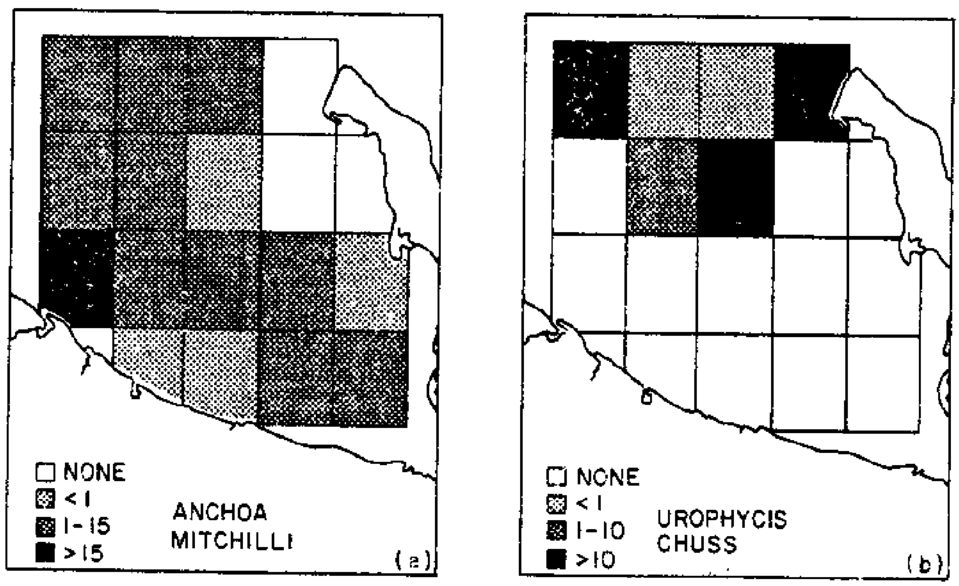


Fig. 26: The average catch (no.) of anchovy (a) and red hake (b) per 10-min tow in Sandy Hook Bay. After Wilk and Silverman (1976).



accounted for about 68% by number and 66% by weight of the total catch during the survey. The 10 most abundance species comprised 95% by number and about 85% by weight of the total catch. The average abundance distribution for the 10 most common species is shown in Fig. 26a,b, Fig. 27a-d, and Fig. 28a-d.

Wilk et al. (1977) Study

Wilk et al. (1977) present the only quantitative data for fish distribution throughout the Lower Bay Complex. These data are strictly tabulations, species number and weight by station number. The study represents data from 700 stations, encompassing the Lower Bay Complex and offshore locations in the New York Bight, that were sampled between June 1974 and June 1975. Again, the Lower Bay Complex was subdivided into blocks 1' longitude by 1' latitude (Fig. 29). A number of these blocks was randomly selected at the beginning of the survey and these blocks were visited at approximately monthly intervals. How many blocks they selected is not stated, nor is a map presented showing which blocks were selected. It should be noted that many of the station coordinates reported fall on exact 1' longitude or 1' latitude lines so that it is difficult to assess which block the station sample represented. Further, no indication is given of whether station coordinates represent the beginning or end of the tow, or in which direction it was taken. To determine which bay station numbers fall in which blocks, station coordinates were plotted by the present author and grouped subjectively into the nearest appropriate block. A listing of station numbers, sampling dates, depth, number of species, and total catch by number and weight is compiled and summarized in Appendix Table 8. The grouping of stations into distinct areas (i.e., blocks) indicated that Wilk et al. (1977) apparently sampled 19 blocks repeatedly (see Fig. 29); however, the clustering showed that not all areas were sampled monthly.

The majority of the stations was sampled by an otter trawl with a 9.1 m footrope, while others (indicated with an asterisk in Appendix Table 8) were sampled with a 24.4 m footrope Yankee #36 trawl. Both trawls were fitted with 12.7 mm stretch mesh cod end liners. Each trawl was conducted for 15 minutes. At some stations in a given sampling date, both nets were used. Catches with the larger net almost always yielded a greater number of species per station, as well as number and weight per species, than the smaller net. All specimens of each species were usually measured, except when subsamples of very large catches were measured. In that case, an expansion factor (weight of total catch/weight of subsample) was applied.

The tabulated data presented by Wilk et al. (1977) were reworked and ordered to determine the monthly occurrence by number and weight at each station falling in Areas *A* to *S* (Fig. 29) and tabulated by species (Appendix Table 9) in the same order of species listed in Table 14. This data base was then resequenced to present the monthly occurrence of species by area, including information on number of fishes caught per species and the number of species caught each month in that area (Table 15). These data are further grouped by bay. Areas *A*, *B*, *C*, *E*, *F*, *G*, *H*, *J*, *and K* are located in the Lower Bay; Areas *D*, *L*, *M*, and *N* are in Raritan Bay, and Areas *I*, *O*, *P*, *Q*, *R*, and *S* are in Sandy Hook Bay.

Lower Bay stations exhibited a greater number of species and number of individuals per species during the fall months. The 10 most common species during the fall are: *Anchoa mitchilli*, *Alosa sapidissima*, *A. pseudoharengus*, *Cynoscion regalis*, *Engraulis eurystole*, *Peprilus triacanthus*, *Pseudopleuronectes americanus*, *Paralichthys dentatus*, *Urophycis chuss*, and *U. regius*.

During winter months, the 10 most common species in the Lower Bay were:

Fig. 27: The average catch (no.) of spotted hake (a), scup (b), weakfish (c), and butterfish (d) per 10-min tow in Sandy Hook Bay. After Wilk and Silverman (1976).

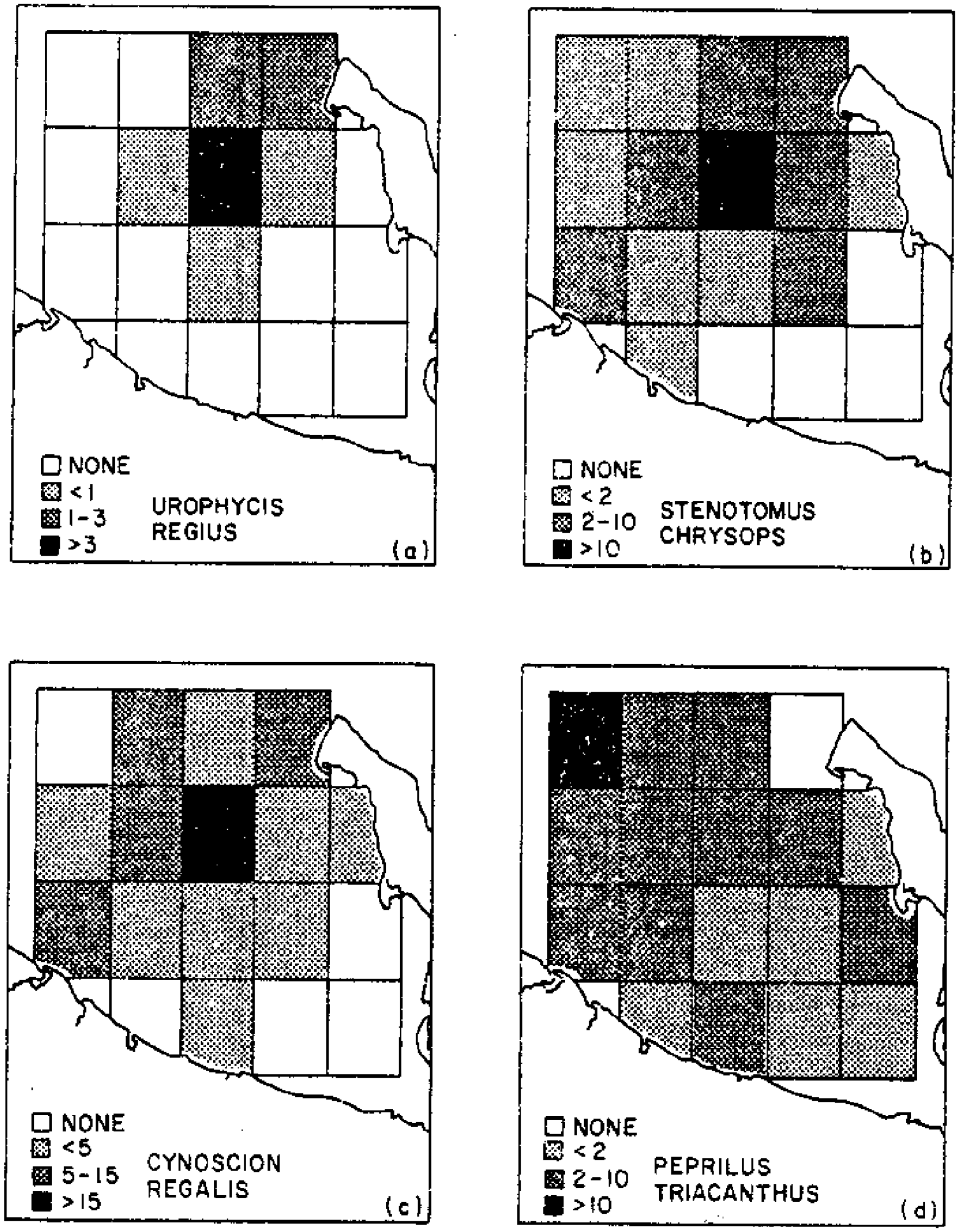


Fig. 28: The average catch (no.) of northern sea robin (a), striped sea robin (b), window pane (c), and winter flounder (d) per 10-min tow in Sandy Hook Bay. After Wilk and Silverman (1976).

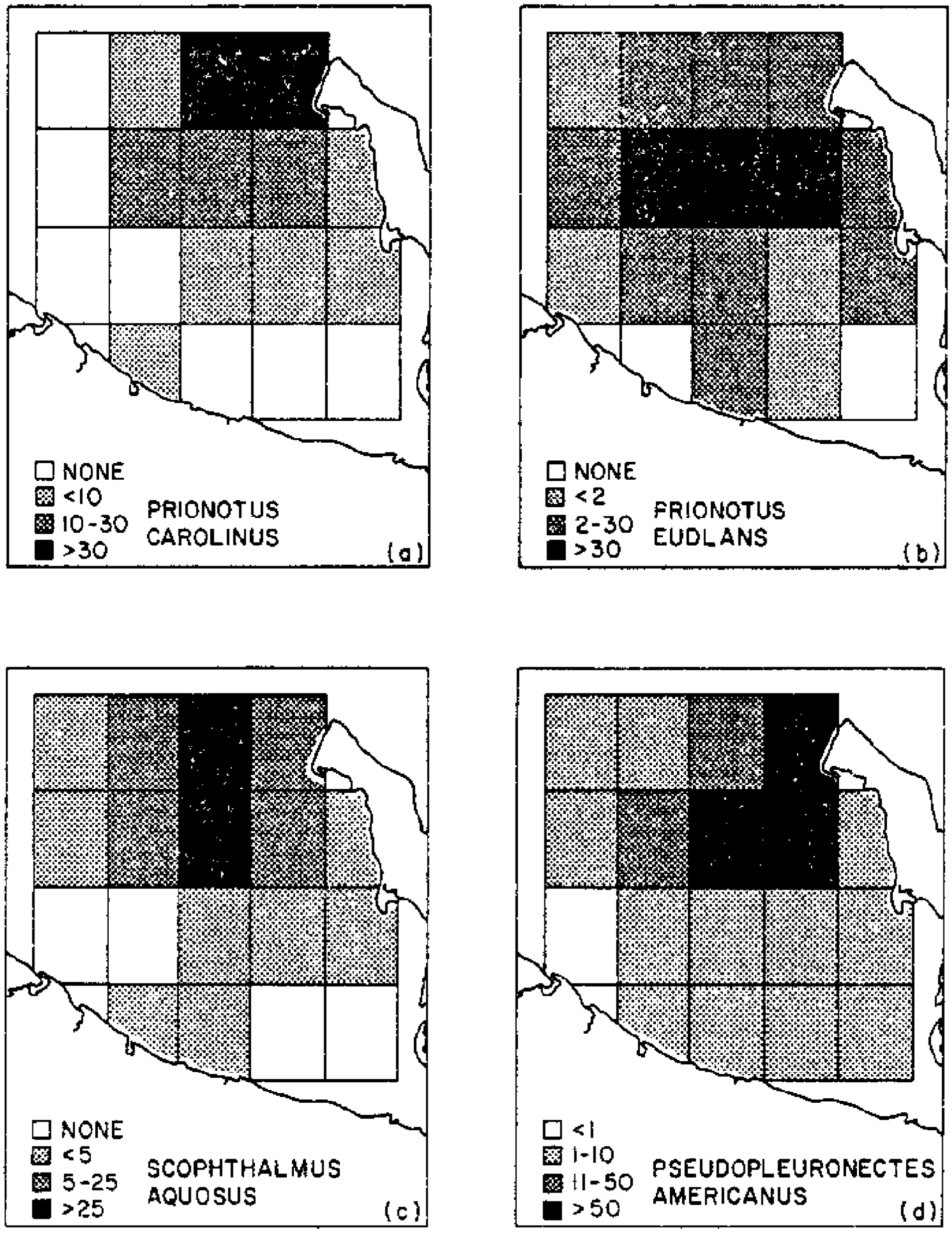


Fig. 29: Apparent blocks (shaded) sampled by Wilk et al. (1977) between June 1974 and June 1975. Numbered blocks (1-18) in Sandy Hook Bay are blocks sampled by Wilk and Silverman (1976) between July and October 1970.

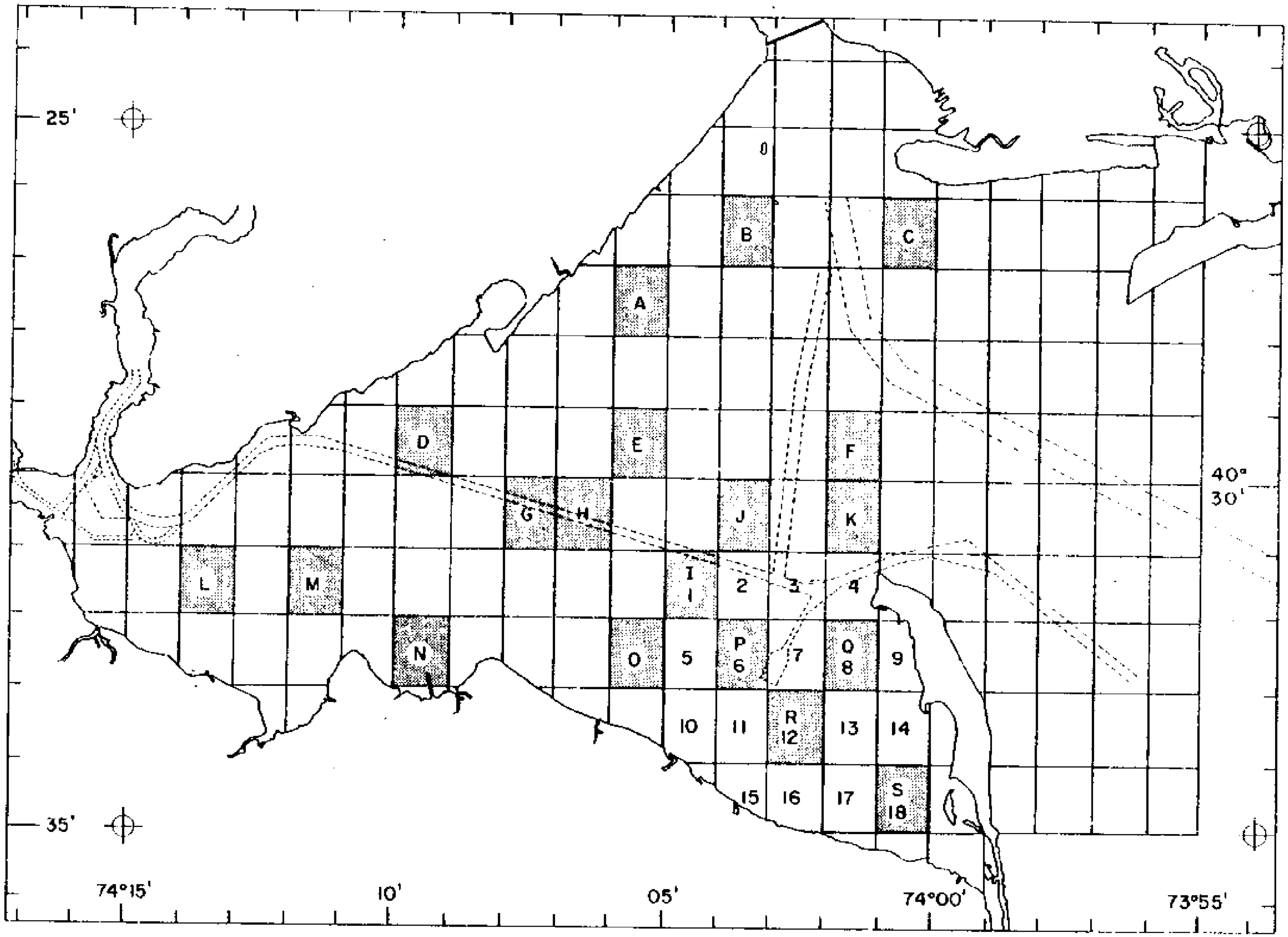


Table 15. Monthly occurrence of fish species in Lower, Raritan, and Sandy Hook bays reported by Wilk et al. (1977), sublisted with station areas. Numbers are total catch; each month totaled for # species; asterisk (*) indicates area not sampled that month. Note: No December or March cruises; ** means only reported occurrence.

LOWER BAY

Area A (West Bank)	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Mustelus canis		2									
Alosa aestivalis							1		43	10	
Alosa pseudoharengus							1		10	10	
Alosa sapidissima						6				8	
Brevoortia tyrannus										1	
Clupea harengus harengus							3		2		
Anchoa mitchilli				980		1					
Merluccius bilinearis							1			1	
Urophycis chuss		1									21
Urophycis regius						2				18	
Menidia menidia						1	1			14	12
Hippocampus erectus					1						
Morone saxatilis		1									
Stenotomus chrysops				1							
Cynoscion regalis				1							
Tautoga onitis					12	1				2	
Ammodytes americanus							21				
Peprilus triacanthus										2	2
Paralichthys dentatus		1								1	
Scophthalmus aquosus		1				2			1	5	
Pseudopleuronectes americanus		2		3		8			1		15
Total # species	0	6	0	4	2	7	6	*	5	11	4
Total # stations	1	1	1	1	1	1	1	*	1	1	1

Table 15 - continued

LOWER BAY											
Area B (West Bank)	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Mustelus canis		2	3			1					
Alosa aestivalis						3	2	1		2	
Alosa pseudoharengus						140	6	20			
Alosa sapidissima						10	5	1		2	
Brevoortia tyrannus	2							4		1	
Clupea harengus harengus								1		1	
Anchoa mitchilli	1		2	192					1		
Merluccius bilinearis						46	9	1	1	1	
Urophycis chuss	1	1			1	3	8			4	
Urophycis regius						14	2				
Menidia menidia					2	5				12	
Morone saxatilis		1									
Pomatomus saltatrix				2							
Vomer setapinnis				1							
Cynoscion regalis			1	100		4					
Menticirrhus saxatilis				1	1						
Ammodytes americanus					1						
Peprilus triacanthus			2								
Myoxocephalus aenaeus							2				
Etropus microstomus							1				
Paralichthys dentatus		1	7	4							
Scophthalmus aquosus	14	1	1		6	5					
Pseudopleuronectes americanus		2		4	1	2	1			2	
Monacanthus hispidus				1							
Total # species	4	6	6	8	6	11	9	6	2	8	*
Total # stations	1	1	1	1	1	1	1	2	1	1	*

Table 15 - continued

LOWER BAY											
Area C (East Bank)	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Alosa aestivalis							1			35	
Alosa sapidissima										1	
Brevoortia tyrannus										2	
Clupea harengus harengus										5	
Merluccius bilinearis						2					
Menidia menidia										6	
Tautoga onitis										1	
Ammodytes americanus							22	1			
Scophthalmus aquosus						1	1		1	6	
Pseudopleuronectes americanus						2	2				
Total # species	*	*	*	*	*	3	4	1	1	7	*
Total # stations	*	*	*	*	*	1	1	1	1	1	*

Table 15 - continued

RARITAN BAY											
Area D	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Alosa aestivalis								15	2	3	
Alosa pseudoharengus					1			1			
Alosa sapidissima						1					
Brevoortia tyrannus											2
Clupea harengus harengus								2	1		
Anchoa mitchilli		7	17	1,428							
Engraulis eurystole					50						
Merluccius bilinearis						3					
Urophycis chuss										2	
Urophycis regius						23					
Menidia menidia						1					12
Syngnathus fuscus						1					
Pomatomus saltatrix			1	1							
Stenotomus chrysops				1							
Cynoscion regalis				6							
Astroscopus guttatus					1						
Peprilus triacanthus				1	2						3
Myoxocephalus aenaeus						1					
Paralichthys dentatus				2		1					
Scophthalmus aquosus				1		2					
Pseudopleuronectes americanus	1			1	27	32					2
Total # species	1	1	2	8	5	9	*	3	2	2	4
Total # stations	1	1	1	1	1	1	*	1	1	1	1

Table 15 - continued

LOWER BAY											
Area E	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Alosa aestivalis					1	1		15	31		
Alosa pseudoharengus					9		3		17		
Alosa sapidissima					1		15				
Brevoortia tyrannus					15		2	1			
Clupea harengus harengus	1							6	1		
Anchoa mitchilli		1		659	2,046	8					
Engraulis eurystole				30,307	280						
Merluccius bilinearis						8				1	
Urophycis chuss										12	
Urophycis regius						1					
Menidia menidia					1	3					
Syngnathus fuscus					8						
Morone saxatilis					1						
Centropristis striata				1							
Pomatomus saltatrix		1			86						
Stenotomus chrysops				6							
Bairdiella chrysura					4						
Cynoscion regalis				18	42						
Leiostomus xanthurus					2						
Menticirrhus saxatilis				1							
*Chaetodon ocellatus***				1							
Tautoga onitis	1				1						
Pholis gunnellus				2							
Peprilus triacanthus			4		64						
Prionotus evolans					6						
Myoxocephalus aenaeus				1		1					
*Myoxocephalus scorpius***				1							
Etropus microstomus					25						
Paralichthys dentatus				22	20						
Scophthalmus aquosus					53	2					
Pseudopleuronectes americanus				20	15	13					
Total # species	2	2	1	12	20	8	3	3	3	2	*
Total # stations	1	1	2	2	2	1	1	1	1	1	*

Table 15 - continued

LOWER BAY											
Area F (Romer Shoal)	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Alosa aestivalis							19				
Alosa sapidissima							2				
Clupea harengus harengus							1	1	3		
Anchoa mitchilli		2									
Engraulis eurystole					10						
Merluccius bilinearis							1				
Menidia menidia											11
Stenotomus chrysops											1
Tautoga onitis						2					
Tautogolabrus adspersus						20					
Ammodytes americanus								16			
Peprilus triacanthus		1									
Prionotus carolinus			1								
Myoxocephalus aenaeus							1				
Paralichthys dentatus			3								2
Scophthalmus aquosus			1		1	1	1				4
Pseudopleuronectes americanus	1	1							2		
Total # species	1	3	3	*	2	3	6	2	2	*	4
Total # stations	1	1	1	*	1	1	1	1	1	*	1

Table 15 - continued

LOWER BAY											
Area G	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Mustelus canis											
Alosa aestivalis					29	85	67				
Alosa pseudoharengus					9	6	1,502				
Alosa sapidissima						94	152				
Brevoortia tyrannus					1	3	3				
Clupea harengus harengus							25				
Anchoa mitchilli				29	20,044	208					
Engraulis eurystole					5,200						
Merluccius bilinearis						7	31				
Urophycis chuss						1	13				
Urophycis regius						3	4				
Menidia menidia						344	2				
Syngnathus fuscus				1	4	10					
Morone saxatilis					1						
Pomatomus saltatrix					13	1					
Cynoscion regalis					12	4					
Tautoga onitis					3		2				
Astroscopus guttatus					2						
Pholis gunnellus					4	2	2				
Peprilus triacanthus				7	48						
Prionotus evolans					1						
Myoxocephalus aenaeus							5				
Myoxocephalus octodecemspinosus					1	32	4				
*Citharichthys arctifrons***				1							
Etropus microstomus					23	8					
Paralichthys dentatus					5	6	1				
Scophthalmus aquosus					26	71	14				
Pseudopleuronectes americanus				1	126	133	49				
Total # species	*	*	*	5	19	18	16	*	*	*	*
Total # stations	*	*	*	1	3	2	3	*	*	*	*

Table 15 - continued

LOWER BAY											
Area [illegible]	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Mustelus canis		7									
Alosa aestivalis						6	34		7	13	
Alosa pseudoharengus					4	34	201		2	38	
Alosa sapidissima							62			3	
Brevoortia tyrannus						6	246			1	
Clupea harengus harengus							2				
Anchoa hepsetus										2	
Anchoa mitchilli		840				8					
Engraulis eurystole					504						
*Synodus foetens***					1						
Merluccius bilinearis						10	5			22	
Urophycis chuss		2				1			1	364	
Menidia menidia										1	
Syngnathus fuscus										3	
*Morone americana***						1					
Pomatomus saltatrix		8	1		4						
Stenotomus chrysops		2									
Cynoscion regalis		9	1		6					9	
Tautoga onitis			1								
Astroscopus guttatus					1						
Pholis gunnellus					11					5	
Peprilus triacanthus		3								1	
Prionotus carolinus		1								1	
Myoxocephalus aenaeus		1								26	
Etropus microstomus					1						
Paralichthys dentatus		8	1		3	1				1	
Scophthalmus aquosus					1	9				11	
Pseudopleuronectes americanus		21			7	14			1	59	
Monacanthus hispidus			1								
Total # species	*	11	5	*	11	10	6	*	4	17	*
Total # stations	*	2	1	*	1	1	2	*	1	3	*

Table 15 - continued

SANDY HOOK BAY											
Area *I*	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Squalis acanthias	3										
Conger oceanicus						1					
Alosa aestivalis	1,172					367	2			9	
*Alosa mediocris***	2										
Alosa pseudoharengus	328					24	23			15	
Alosa sapidissima	7					29	55				
Brevoortia tyrannus	40				6	1	32			4	
Clupea harengus harengus	74										
Anchoa mitchilli	3,232			1,920		30					
Engraulis eurystole				152	312					1	
Merluccius bilinearis	69					55	15			7	
Urophycis chuss	42					1	6			135	
Urophycis regius						1	7				
Menidia menidia						8				1	
Hippocampus erectus				1							
Syngnathus fuscus										2	
Morone saxatilis	1									1	
Pomatomus saltatrix	5			79	8						
Vomer setapinnis				4	1						
Stenotomus chrysops	1					42					
Bairdiella chrysura				1							
Cynoscion regalis				369	6	29					
Leiostomus xanthurus				14		1					
Micropogon undulatus				1							
Tautoga onitis	1									3	
*Scomber scombrus***	1										
Peprilus triacanthus	91			49	20	1					
Prionotus evolans	1			1	1					1	
Myoxocephalus aenaeus				2			3				
Etropus microstomus					1	11					
Paralichthys dentatus	12			9	1						
Scophthalmus aquosus	10			1	2	112	29			6	
Pseudopleuronectes americanus	42			8	2	131	44			4	
Total # species	20	*	*	15	11	17	10	*	*	13	*
Total # stations	4	*	*	3	1	2	2	*	*	2	*

Table 15 - continued

LOWER BAY											
Area J	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Mustelus canis		12									
Alosa aestivalis	300					1	22			1	
Alosa pseudoharengus	40						3		1	2	
Alosa sapidissima	7					1	6				
Brevoortia tyrannus	4							2			
Anchoa mitchilli	104		1			26					
Engraulis eurystole					12						
Merluccius bilinearis									3	8	
Urophycis chuss						2			1	23	
Menidia menidia						2				5	
Morone saxatilis	8										
Pomatomus saltatrix	3	1	1								
Stenotomus chrysops	1										
Cynoscion regalis	1	3			1	2					
Tautoga onitis										3	
Tautogolabrus adspersus					1						
Peprilus triacanthus	11					2					
Prionotus carolinus									1		
Myoxocephalus aenaeus	1					2					
Myoxocephalus octodecemspinosus									2		
Paralichthys dentatus	4										
Scophthalmus aquosus	3								3	3	
Pseudopleuronectes americanus	11				4	7			3	2	
Total # species	14	3	2	*	4	9	3	1	7	8	*
Total # stations	2	1	1	*	1	1	1	1	2	1	*

Table 15 - continued

LOWER BAY											
Area *K* (Flynns Knoll)	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Mustelus canis		5				1	1	1		3	
Alosa pseudoharengus							23	1			
Alosa sapidissima							5			2	
Clupea harengus harengus							5	2			
Anchoa mitchilli	1			1		4	1				
Engraulis eurystole					64						
Merluccius bilinearis						1					
Urophycis chuss								1			
Urophycis regius						1					
Menidia menidia						7				28	
Hippocampus erectus					1						
Centropristis striata				4							
Pomatomus saltatrix		2				1					
Stenotomus chrysops				76							2
Cynoscion regalis		5									
Menticirrhus saxatilis				1							
Ammodytes americanus					15	1		29			
Myoxocephalus octodecemspinosus								1			
Paralichthys dentatus				2							2
Scophthalmus aquosus				2	3	1				1	1
Pseudopleuronectes americanus	1	1		2			1				
Total # species	2	4	0	7	4	8	6	6	*	4	3
Total # stations	1	1	1	1	1	1	1	1	*	1	1

Table 15 - continued

RARITAN BAY											
Area L	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Alosa aestivalis						9	1	1	70	2	1
Alosa pseudoharengus						8	3	1	1	3	
Alosa sapidissima										1	
Brevoortia tyrannus						3			1		1
Clupea harengus harengus							1	9			
Anchoa mitchilli			13	228		4					
Engraulis eurystole					23						
Merluccius bilinearis								1		6	
Urophycis chuss										39	
Hippocampus erectus										1	
Cynoscion regalis			1	2							
Menticirrhus saxatilis				3							
Peprilus triacanthus			2	8							
Scophthalmus aquosus								1		1	
Pseudopleuronectes americanus				3	16					3	
Total # species	0	*	3	5	2	4	2	4	3	8	2
Total # stations	1	*	1	1	1	1	1	1	1	1	1

Table 15 - continued

RARITAN BAY											
Area M	Months										
	1974						1974				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Alosa aestivalis						3			97		
Alosa pseudoharengus						7	21	13	4	3	
Alosa sapidissima						2	4			6	
Brevoortia tyrannus						1	1				7
Clupea harengus harengus							1				1
Anchoa mitchilli						31					
Engraulis eurystole					16						
Merluccius bilinearis							2			33	
Urophycis chuss										116	4
Urophycis regius						1				1	1
Urophycis tenuis											1
Menidia menidia						1					
*Gasterosteus aculeatus***							1				
Syngnathus fuscus										1	
Cynoscion regalis					2						
Peprilus triacanthus											3
Scophthalmus aquosus						1					
Pseudopleuronectes americanus					7	39	13		1	3	
Total # species	*	*	*	*	3	9	7	1	3	7	6
Total # stations	*	*	*	*	1	1	1	1	1	1	1

Table 15 - continued

RARITAN BAY											
Area N	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Alosa aestivalis						9					1
Alosa pseudoharengus					2	4				1	
Alosa sapidissima						1				2	
Brevoortia tyrannus						3					1
Anchoa mitchilli				17		20					
Engraulis eurystole					2						
Merluccius bilinearis										124	
Urophycis chuss										24	
Urophycis regius										2	
Urophycis tenuis											20
Syngnathus fuscus					1						
Pomatomus saltatrix				1							
Cynoscion regalis		1	4		1						
Menticirrhus saxatilis				9							
Peprilus triacanthus				3							10
Paralichthys dentatus		1									
Scophthalmus aquosus						2				2	
Pseudopleuronectes americanus	3				57	6				8	5
Total # species	1	2	1	4	5	7	*	*	*	7	5
Total # stations	1	1	1	1	1	1	*	*	*	1	1

Table 15 - continued

SANDY HOOK BAY											
Area *O*	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Mustelus canis		31									
Alosa aestivalis						1					1
Alosa pseudoharengus						1	9				
Alosa sapidissima						7	13				
Brevoortia tyrannus	2						2				4
Clupea harengus harengus							1				
Anchoa mitchilli		1		44		22					
Engraulis eurystole					480						
Urophycis chuss		2									
Urophycis regius		1			6						3
Urophycis tenuis											33
Menidia menidia						2					2
Morone saxatilis		1									
Centropristis striata											1
Pomatomus saltatrix		1		4							
Vomer setapinnis				1							
Stenotomus chrysops				1							
Cynoscion regalis		13		13	3	1					
Peprilus triacanthus				3							
Myoxocephalus aenaeus		1									
Etropus microstomus						2					
Paralichthys dentatus		10	1	6							2
Scophthalmus aquosus		1				3					2
Pseudopleuronectes americanus		21	1	2	2	5					9
Total # species	1	11	2	8	4	9	4	*	*	*	9
Total # stations	1	3	1	1	1	1	1	*	*	*	1

Table 15 - continued

SANDY HOOK BAY											
Area P	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
*Raja erinacea***		106									
Conger oceanicus											1
Alosa aestivalis						138	26	31	2		1
Alosa pseudoharengus	3						19	111	1	2	
Alosa sapidissima						13	80	12		1	
Brevoortia tyrannus						11	7	15			1
Clupea harengus harengus							3	24			
Anchoa mitchilli			31			58					
*Lophius americanus***						1					
Merluccius bilinearis						28			1	10	
Urophycis chuss						5		1		25	
Urophycis regius						6					1
Urophycis tenuis											2
Menidia menidia						17	3			1	78
Syngnathus fuscus						5					
Centropristis striata					1						
Stenotomus chrysops					1						1
Bairdiella chrysura					5	3					
Cynoscion regalis		2	1		61	75					
Leiostomus xanthurus					3						
Micropogon undulatus					1						
Tautoga onitis		1				1				1	
Astroscopus guttatus					1						
Peprilus triacanthus			1		4						8
Prionotus evolans					2	1					
Etropus microstomus					1	54					
Paralichthys dentatus		12			3	2					2
Scophthalmus aquosus		2			37	72		1		9	2
Pseudopleuronectes americanus		25			70	112				8	20
Total # species	*	6	3	*	13	18	6	7	3	8	11
Total # stations	*	1	1	*	2	2	1	1	1	1	1

Table 15 - continued

SANDY HOOK BAY											
Area Q	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Conger oceanicus									1		
Alosa aestivalis							41				
Alosa pseudoharengus						28	20		5		
Alosa sapidissima											
Brevoortia tyrannus	1					2					
Clupea harengus harengus							1				
Anchoa hepsetus			1								
Anchoa mitchilli			98								
Merluccius bilinearis						1			7	12	
Urophycis chuss						4			14	34	
Urophycis regius									1		
Menidia menidia										1	
Syngnathus fuscus									1		
Pomatomus saltatrix		1	6								
Stenotomus chrysops	1										
Cynoscion regalis			5			7					
Peprilus triacanthus			3								
Prionotus evolans						1					
Paralichthys dentatus		2							3		
Scophthalmus aquosus						12			2	22	
Pseudopleuronectes americanus	25		3			49				9	
Total # species	3	2	6	*	*	8	3	*	8	5	*
Total # stations	1	1	1	*	*	1	1	*	2	1	*

Table 15 - continued

SANDY HOOK BAY											
Area E	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Mustelus canis		1									
Alosa sapidissima						1	50				
Brevoortia tyrannus	4										
Anchoa mitchilli	1	164	144			4					
Engraulis eurystole			2								
Merluccius bilinearis						10				6	
Urophycis chuss										106	
Urophycis regius						20					
Menidia menidia						1					
Pomatomus saltatrix		10		4							
Stenotomus chrysops		15									
Cynoscion regalis		7		38	1	5					
Leiostomus xanthurus				1							
*Mugil curema***				1							
Peprilus triacanthus	10	4	1	4							
Prionotus carolinus		1									
Prionotus evolans		44		5	1						
Etropus microstomus					1	4					
Paralichthys dentatus	2	12		1	1						
Scophthalmus aquosus	1				3	41				8	
Pseudopleuronectes americanus	2	16		19	35	49				7	
Total # species	6	10	3	8	6	9	1	*	*	4	*
Total # stations	1	2	1	2	1	1	1	*	*	1	*

Table 15 - continued

SANDY HOOK BAY											
Area *S*	Months										
	1974						1975				
Species	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Apr	May	Jun
Alosa aestivalis							10			10	
Alosa pseudoharengus						1	21			6	
Alosa sapidissima							25			2	
Brevoortia tyrannus		1	1				1				
Clupea harengus harengus							10		1		
Anchoa mitchilli			35			2					
Engraulis eurystole					3						
Merluccius bilinearis						1				2	
Urophycis chuss										50	
Urophycis regius									1		
Menidia menidia					6		3			5	
Hippocampus erectus					1						
Pomatomus saltatrix			2								
Cynoscion regalis		1	1								
Tautoga onitis			1								
Prionotus evolans		1									
Paralichthys dentatus		5									
Scophthalmus aquosus						7				1	
Pseudopleuronectes americanus					10	35	3			9	
Total # species	*	4	5	*	4	5	7	*	2	8	*
Total # stations	*	1	1	*	1	1	1	*	1	1	*

Alosa pseudoharengus, *A. aestivalis*, *A. sapidissima*, *Brevoortia tyrannus*, *Clupea harengus harengus*, *Merluccius bilinearis*, *Urophycis chuss*, *U. regius*, *Ammodytes americanus*, and *Pseudopleuronectes americanus*. The winter flounder *P. americanus* was mostly found in Area *G* of the Lower Bay, during the January survey.

The spring and summer months in the Lower Bay can be generally characterized as the periods of fewest number of species and fewest number of individuals per species. The eight most common species encountered are: *Alosa aestivalis*, *A. pseudoharengus*, *Urophycis chuss*, *U. regius*, *Menidia menidia*, *Paralichthys dentatus*, *Scophthalmus aquosus*, and *Pseudopleuronectes americanus*.

Raritan Bay stations generally yielded fewer numbers of species and individuals per species. Similar patterns of seasonal abundance of the species described above for the Lower Bay were noted in Raritan Bay. Area *L* in Raritan Bay exhibited the fewest number and species of fishes in the study.

Sandy Hook Bay stations sampled by Wilk et al. (1977) were as productive as most areas in the Lower Bay. The numbers of species and individuals per species in northern blocks (numbered 1-9 in Fig. 29) of the Bay were higher than in southern blocks, similar to the pattern described by Wilk and Silverman (1976). Again, the patterns of seasonal abundance were similar to that noted in the Lower Bay. Sandy Hook Bay appears to be an important haven for some semi-tropical species, including *Vomer setapinnis*, *Selene vomer*, *Chaetodon ocellatus*, and *Hippocampus erectus*.

ASSESSING THE BIOLOGICAL EFFECTS OF SAND MINING

Introduction

The effects of sand mining in the Lower Bay Complex must be addressed from physical, chemical, geological, and biological viewpoints. It has already been noted that several physical and chemical effects can be predicted for the creation of mining holes in the Bay bottom (Swartz and Brinkhuis, 1978; Wong and Wilson, 1979). In selecting mining sites, one must first locate sources of suitable material; then, for each such site, address a range of potential physical, biological, etc. effects. It is difficult, indeed almost impossible, to determine which of these effects has the most significance. However, we must know what the biological community consists of at the candidate site since the first *biological effect* is outright removal of any benthic inhabitants. Thus, if a harvestable organism, or species, important to the survival of others, occurs in the area, it may not be desirable to exploit the sand resource at that location. On the other hand, if no important species, or low numbers of any organisms, occur at the site, other effects may be then addressed. For example, would mining the candidate site affect circulation patterns (it may also improve them), tidal current velocities, or create potential shore erosion problems?

As important as these effects may be, one must also consider the biological effects of suspended sediment plumes that will result from mining marine deposits. This effect could extend to other locations outside the mining site, where important species may occur. It has been well documented that suspended sediments affect a wide range of organisms. Each species has its own tolerance limit to certain concentrations of suspended sediment. The specific effects include the clogging of gills and interfering with respiratory gas exchanges as well as physical damage to biological membranes (the description of specific effects in various species will be dealt with later).

To evaluate these potential effects, we must be able to predict the range and extent of suspended sediment concentrations, and then relate the structure and pattern of the plume to known organism distribution patterns. Of course, if organism distribution at and near the candidate site is not known, one must conduct field surveys to determine organism abundance and distribution.

In the next sections, we will first describe a typical mining operation, then use a model to predict the structure and extent of suspended sediment plumes under a variety of conditions, and finally relate the predicted distribution of the suspended sediments to the known distribution of organisms falling within the plume area. The literature dealing with the effects of suspended sediments will then be examined for each species that may be important.

The Mining Scenario

Sand mining operations in the Lower Bay Complex might entail a number of locations and a variety of equipment. In interviews with several mining companies who have expressed interest in exploiting the Bay's sand resource, it has been determined that most operators intend to use a bucket-ladder dredge or clam-shell dredge (Sanko, personal communication). Hydraulic suction dredges will probably not be used, primarily because 1) they require water deeper than exists in potential mining sites and 2) the loading capacity per unit time of these dredges far exceeds the capacity to screen sands to obtain the desired material. Most of the deposits would probably have to be screened to obtain certain sand mixtures as per Department of Transportation (DOT) specifications. The extent of surface deposits showing coarse grained material that could be used as is, with little or no screening (see Table 3), is small and it is not certain that the coarser material persists with depth in the deposit.

It would be most economical to process mined sand at or near the site of removal. Two areas for proposed mining have been recommended by the New York State Department of Conservation, U.S. Environmental Protection Agency, and New York State Office of General Services. One area is on the East Bank; the other in the vicinity of Old Orchard Shoal (see Fig. 23). These areas are currently being surveyed for the presence and density of benthic invertebrate taxa, as well as fishes, by the author. The East Bank site encompasses surficial sediment Deposits I, III, and IV, while the Old Orchard Shoal site sediment deposits are described as Lower Bay Sands and Deposit XIV (see Fig. 11 and Table 3). All of these surface deposits are in the fine to medium sand size range. Bokuniewicz and Fray (1979) indicate that these deposits probably extend to a depth of approximately 10 m.

In a typical mining scenario, a clam-shell or bucket-ladder dredge would load material into a number of 1,000 to 1,200 yd^3 barges. These barges are normally loaded to 3/4 capacity, or in metric equivalent, to 500 to 700 m^3 of material. Assuming a mean density of 1.5 for a sand/water mixture with a fine to medium grain size (Berner, 1972), the material in one barge load will weigh 750 to 1,050 metric tons of which approximately 60% is sand. The material loaded into the dredge barge may then be pumped into an adjacent barge, over appropriate screens. Undesirably sized material will be washed overboard. Interviews with mining companies, conducted by Sanko (personal communication), indicate that a maximum probable processing rate is of the order 136 metric tons (150 tons) per hour. Best estimates indicate the screening operation requires 5.68×10^5 liters sea water per hour to process 135 metric tons of sediment (quoted at 150 tons/hr, 2,500 gal/ton; 1 ton = 0.907 metric tons; 1 gal = 3.7854 liters). It is estimated that in a *worst case* situation, the screening operation will dispose of 35% of the hourly intake

Table 16. Criteria for acceptability of New York Harbor (from Kastens et al., 1978).

Mortar Sand

N.Y. State Department of Transportation Specification 703-03 states:

When dry, mortar sand shall meet the following gradation requirements:

Sieve Size	% Passing by Mass
#4 16.00 mm	100
#8 2.83 mm	95-100
#50 .30 mm	10-40
#100 .149 mm	0-15

In addition, aggregate must meet standards for organic impurities.

Grout Sand

N.Y. State Department of Transportation Specification 703-04 states:

When dry, grout sand shall meet the following gradation requirements:

Sieve Size	% Passing by Mass
#16 1.19 mm	100
#100 .149 mm	0-10
#230 .062 mm	0-6

Since we did not use a #16 sieve, in the following table sand is considered acceptable if greater than 99% passes the #18 (1 mm) sieve. In addition, aggregate must meet standards for organic impurities.

Cushion Sand

N.Y. State Department of Transportation Specification 703-06 states:

Material for cushion sand used for concrete block slope paving shall, when dry, meet the following gradation requirements:

Sieve Size	% Passing by Mass	
	Minimum	Maximum
3/8 inch	100	
#4	90	100
#8	75	100
#16	50	85
#30	25	60
#50	10	30
#100	1	10
#200	3	3

Concrete sand must also meet requirements for organic impurities.

Table 16 - continued

Mineral Filler

N.Y. State Department of Transportation Specification 703-08 states:

Mineral filler used in bituminous concrete mixtures shall meet the following gradation requirements:

Sieve Size	% Passing by Mass
#30 .59 mm	100
#80 .177 mm	85-100
#200 .074 mm	65-100

Blasting Sand

There are 2 types of blasting sand: G-1 is fast cutting, while G-2 is slower on the first pass. Gradation requirements are as follows:

Sieve Size	% Retained by Mass	
	G-1	G-2
#12 1.68 mm	0	60-85
#16 1.19 mm	15-30	20-35
#20 .84 mm	20-30	0-10
#30 .59 mm	25-35	
#40 .42 mm	10-20	
pan	0-10	

Reference: Analysis of Ambrose Channel Sands by the N.Y. State Department of Public Works, Bureau of Materials. This report was furnished by J. Marotta of the N.Y. State Office of General Services.

Fill Sand for Roadways

A. Select Subgrade: N.Y. State Department of Transportation Specification 203-2.01 states:

Select subgrade shall consist of any suitable material having no particles greater than 6 inches in diameter.

B. Select Borrow and Select Fill

1. For underwater placement:

Sieve Size	% Passing
#200 .074 mm	10

2. For above water placement:

Sieve Size	% Passing
6 inches	100
#200 .074 mm	15

Table 16 - continued

Filter Sand

American Water Works Association Standard B100 for Filtering Materials states:

> "Filter Sand shall consist of hard durable grains of material less than 2.4 mm in greatest diameter."

Since we did not use a 2.4 mm sieve in our analysis, in the following table sand is marked acceptable for filter sand if less than 2% was retained on the 2 mm (#10) sieve. For determining the acceptability and uniformity of filtration sand, "effective grain size" and "uniformity" coefficients are used. The effective grain size is the 10th percentile measured in mm:

Effective Grain Size = Mm_{10}

The uniformity coefficient is the 40th percentile divided by the effective grain size:

$$U = \frac{Mm_{40}}{Mm_{10}}$$

as fine material. This estimate is based on reports of maximum % sediment mass less than 0.149 mm in size reported in samples from Kastens et al. (1978). The cut-off size of 0.149 mm is used because larger material would meet most of the DOT specifications for a variety of sand uses (see Table 16). In other words, 35% of 135 metric tons will be discharged per hour. This equates to 13.23 $kg \cdot s^{-1}$ of sediment discharge. The use of a clam-shell or bucket-ladder dredge will not result in any large amounts of suspended sediment while material is brought to the surface, so we need only concern ourselves with the mass discharge resulting from processing. Using these data, we can predict the extent and concentrations of suspended sediments in plumes downstream, in the tidal current, of the processing barge by applying the suspended sediment plume model prepared by Wilson (1979).

Prediction of Sediment Plumes

The model developed by Wilson (1979) is designed to describe the extent and structure of suspended sediment plumes produced by open-water pipeline disposal of dredged material in shallow waters. This model may also be used to model plumes resulting from a continuous source of suspended sediments, i.e., a screening operation of mined sediments that results in overboard disposal. The resulting plume will exist for the duration of one-half the tidal cycle, because, when the tidal flow reverses, the plume will disintegrate (Schubel et al., 1978; Wilson, 1979). Nomographs prepared by Wilson (1979) can be used to predict suspended sediment concentrations along the centerline of the plume. The predictions made by the model only relate to vertically averaged concentrations in a steady and spatially uniform ambient flow field. A complete description of the model is presented by Wilson (1979).

We will first examine a hypothetical case of a mining/screening operation performed in the vicinity of Old Orchard Shoal. As inputs to the model, we require the following information:

1. ω = diffusion velocity = 1 $cm \cdot s^{-1}$: estimated by Okubo (1962, 1971)

2. W = settling velocity of sediment = 1×10^{-2} $cm \cdot s^{-1}$: estimated by Schubel (personal communication)

3. D = average thickness of water column containing suspended sediment. In shallow water < 8 m deep, this is approximately 1/2 the water depth (Schubel et al., 1978). Water depth near Old Orchard Shoal is ≈ 7 m, so, D = 3.5 m

4. t = maximum plume age = (0.5)(tidal period) = (0.5)(12.42 h) [Swanson, 1976, for Lower Bay] = 6.21 h

5. γ = ratio of plume age to settling time = Wt/D
= $(1 \times 10^{-4}\ m \cdot s^{-1})(6.21\ h)(3600\ s \cdot h^{-1})/(3.5\ m)$ = 0.64

6. u = tidal current amplitude = (mean tidal current speed)$(2/\pi)$
= $(50\ cm \cdot s^{-1})(2/\pi)$ = 31.83 $cm \cdot s^{-1}$; current speed data from Doyle and Wilson (1978)

7. $\omega/u = 1(\text{cm}\cdot\text{s}^{-1})(31.83\ \text{cm}\cdot\text{s}^{-1}) = 0.03$

8. Q = water volume discharge rate = 150,000 $\text{gal}\cdot\text{h}^{-1} = 1.577 \times 10^{-1}\ \text{m}^3\cdot\text{s}^{-1}$, or $1.577 \times 10^2\ \text{l}\cdot\text{s}^{-1}$: see previous discussion in *Mining Scenario*

9. q = mass discharge rate at source = 13.23 $\text{kg}\cdot\text{s}^{-1}$, or $1.323 \times 10^7\ \text{mg}\cdot\text{s}^{-1}$: see previous discussion in *Mining Scenario*

10. C_o = concentration of suspended sediment at source = $q/Q = (1.323 \times 10^7\ \text{mg}\cdot\text{s}^{-1})/(1.577 \times 10^2\ \text{l}\cdot\text{s}^{-1}) = 8.39 \times 10^4\ \text{mg}\cdot\text{l}^{-1}$

11. x = distance measured along centerline of plume. The plume front is at a distance 1/2 the tidal period, or x^*ut. Converting u to $3.183 \times 10^{-1}\ \text{m}\cdot\text{s}^{-1}$ and t to 2.24×10^4 s, the front is 7.828×10^3 m, or 7.8 km downstream

12. x^* = non-dimensional, or normalized distance measured along the plume centerline. It is a function of x/ut. The point at which the sediment concentration falls to near zero (10^{-4}) is where ω/u (here = 0.03) crosses the abscissa in Wilson's Figure 1a, or 1.1

We now have enough information to apply the plume model, using the nomographs prepared by Wilson (1979). The nomographs available, without the extra expense of generating a separate solution for γ = 0.64, include only γ = 0.1, 1. We will calculate concentrations of suspended sediment at a number of distances, x^*, along the plume centerline for these two gamma values, and interpolate between them to arrive at concentrations for γ = 0.64.

First, we must determine the value of the normalized centerline concentration at $x^* = 1$, $G(1, \omega/u, \gamma)$, for $\omega/u = 3 \times 10^{-2}$ and $\gamma = 0.1$. This may be determined from Wilson's Figure 1d. For the first case, $G(1, \omega/u, 0.1) = 2.5 \times 10^{-2}$ while in the second case, $G(1, \omega/u, 1) = 9.8 \times 10^{-3}$.

The concentration, C, at any normalized distance x^* along the centerline may be described by:

$$C = (C_o)(Q)\ [G(x^*, \omega/u, \gamma)/G(1, \omega/u, \gamma)][G(1, \omega/u, \gamma)]\pi\omega^2 Dt$$

where $\pi\omega^2 Dt$ is used to nondimensionalize the flux of water, Q, and has the value $(\pi)(1 \times 10^{-4}\ \text{m}\cdot\text{s}^{-1})(3.5\ \text{m})*(6.21\ \text{h})(3600\ \text{s}\cdot\text{h}^{-1}) = 24.58$. For

$G(1, \omega/u, 0.1) = 2.5 \times 10^{-2}$,

$C_o = 8.39 \times 10^4\ \text{mg}\cdot\text{l}^{-1}$; and

$Q = 1.577 \times 10^{-1}$, $\text{m}^3\cdot\text{s}^{-1}$,

$C = 13.46\ [G(x^*, \omega/u, 0.1)/G(1, \omega/u, 0.1)]$

and for

$G(1, \omega/u, 1) = 9.8 \times 10^{-3}$

$C = 5.28\ [G(x^*, \omega/u, 1)/G(1, \omega/u, 1)]$

Using these values, we can proceed to evaluate $G(x^*, \omega/u, \gamma)/G(1, \omega/u, \gamma)$ for each value of x^* we are interested in by using the nomograph in Wilson's Figure 1a ($\gamma = 0.1$) and Figure 1b ($\gamma = 1$), and calculate C at each x^* along the centerline of the plume. These calculations are shown in Table 17.

To arrive at approximate concentration values for $\gamma = 0.64$ in a 7 m water column, we can linearly interpolate concentration values at $\gamma = 0.1$ and $\gamma = 1.0$. These values are presented in Table 19. To estimate the maximum width of the plume at each value of x^*, we can divide by 10 (Carter, personal communication). These values are also presented in Table 19. We can now draw a plume with the concentrations isopleths calculated and position this plume along the direction of tidal flow over a potential mining site. We selected a depth of 7 m and an ω/u of 0.03 corresponding to average depths and an ebb current amplitude of 0.5 $m \cdot s^{-1}$ over the Old Orchard Shoal deposits. Superposition of the plume over this area on the ebbing tide is shown in Figure 30. It makes some sense to create plumes only on ebbing tides, because on incoming tides a plume 7.87 km long might extend well into New York Harbor or western Raritan Bay. On the ebbing tide, suspended material would be transported in the direction out of the Lower Bay. The model assumes a current flow of uniform flow and direction. Figure 30 shows that the plume is diverted to the southeast, a condition not actually modelled. Current flow data from Doyle and Wilson (1978) indicate that the currents near Ambrose Channel flow southeast. The flow leaving Old Orchard Shoal is deflected by the shallow Romer Shoal, and most of this water exits via the Swash Channel. The depiction in Fig. 30 situates the latter half of the plume to the west of Romer Shoal, over the Swash Channel.

Of course, the model can not predict where the material will actually fall to the bottom. At the time of tide direction change, however, much of the material in suspension at each distance along the plume will quickly settle to the bottom. Remember, the model only predicts plumes resulting from suspension of sediments. About 99% of the mass discharged at the source falls to the bottom near the source (Schubel et al., 1978).

We can make calculations for plumes that may be created by mining on the East Bank site. Two variables change: the tidal current amplitude on ebbing tides is 0.7 $m \cdot s^{-1}$ and the average water depth is 5 m (D = 2.5) resulting in an ω/u = 0.02, and a γ = 0.80. The nomograph values for $G(x^*, \omega/u, \gamma)/G(1, \omega/u, \gamma)$ at γ = 0.1, 1 for the East Bank are shown in Table 18. We will again linearly interpolate between calculated concentrations at γ = 0.1, 1 values to approximate concentrations at γ = 0.8 (Table 19). Remember, we must reevaluate the normalizing term $\pi\omega^2 Dt$ because the depth has been changed to 5 m. Its value for the current case is 17.56. The structure and shape of the plume are shown in Figure 30.

The situations modelled thus far represent *worst cases* on ebbing tides. If we wish to examine the extent of plumes on flooding tides at lower current speeds, we can state without modelling that the plumes will be shorter and more dense within all areas of the plume. In modelling a processing plume on the East Bank, we assumed that 35% of the material mined would be disposed. Sediments in this area are usually medium sized. At most, probably only 15% of the mined material might be discharged back to the water. For the Old Orchard Shoal site, actual sediment discharge rates may also be lower.

Let us examine one more case on the East Bank, again on ebbing tides, at a reduced overboard discharge rate. The following parameters apply as a result of a reduced processing discharge (15% of the mass mined) on the East Bank:

q = 11.02 $kg \cdot s^{-1}$

Q = 1.577×10^{-1} $m^3 \cdot s^{-1}$

ω/u = 0.02

γ = 0.80

C_o = q/Q = 6.987×10^4 $mg \cdot l^{-1}$

Note that only q and C_o are affected. We can still use the values for γ = 0.1, 1, etc. as presented in Table 18. New calculations of C at each x^* along the centerline are shown in Table 20 and interpolated values of C for γ = 0.8 are shown in Table 21. The structure and shape of the new plume are shown in Figure 31.

Table 17. West Bank (Old Orchard Shoal) nomograph values of $G(x^*, \omega/u, \gamma)/G(1, \omega/u, \gamma)$ at distances x^* down the centerline of the plume (from Wilson, 1979; Fig. 1a and 1b) converted to average vertical concentrations, C, in a 7 m deep water column.

For $\gamma = 0.1$; $\omega/u = 0.03$; front distance $x = 7.83 \times 10^3$m; $G(1) = 2.5 \times 10^{-2}$; $C = (13.46)G(x^*)/G(1)$

$G(x^*)/G(1)$	x^*	Distance from source (m)	C (mg·l^{-1})
≈ 220	0.01	78	2,961
≈ 48	0.05	391	646
24	0.1	783	323
4.8	0.5	3,914	65
1	1.0	7,828	14
10^{-4}	1.1	8,611	≈ 0

For $\gamma = 1.0$; $\omega/u = 0.03$; front distance $x = 7.87 \times 10^3$; $G(1) = 9.8 \times 10^{-3}$; $C = (5.28)G(x^*)/G(1)$

$G(x^*)/G(1)$	x^*	Distance from source (m)	C (mg·l^{-1})
≈ 530	0.01	78	2,798
≈ 100	0.05	391	528
48	0.1	783	253
6.3	0.5	3,914	33
1	1.0	7,828	5
10^{-4}	1.1	8,611	≈ 0

Table 18. East Bank nomograph values of $G(x^*, \omega/u, \gamma)/G(1, \omega/u, \gamma)$ at distances x^* down the centerline of the plume (from Wilson, 1979; Fig. 1a and 1b), converted to concentrations, C, in a 5 m deep water column.

For $\gamma = 0.1$; $\omega/u = 0.02$; front distance $x = 1.1 \times 10^{-4}$ m;
$G(1) = 1.7 \times 10^{-2}$, $C = (12.75)G(x^*)/G(1)$

$G(x^*)/G(1)$	x^*	Distance from source (m)	C (mg·l^{-1})
≃ 220	0.01	110	2,805
≃ 48	0.05	550	612
24	0.1	1,100	306
4.8	0.5	5,500	61
1	1.0	11,000	13
10^{-4}	1.1	12,100	≃ 0
For $\gamma = 1.0$; $\omega/u = 0.02$; front distance = 1.1×10^{4} m; $G(1) = 6.8 \times 10^{-3}$; $C = (5.12)G(x^*)/G(1)$			
≃ 530	0.01	110	2,714
100	0.05	550	512
48	0.1	1,100	246
6.3	0.5	5,500	32
1	1.0	11,000	5
10^{-4}	1.1	12,100	≃ 0

Table 19. Interpolated, vertically averaged sediment concentrations (C) at various distances (x^*) down the plume centerline interpolated from Table 17 and Table 18.

For water 7 m deep, γ = 0.64 (Old Orchard Shoal)

x^*	Distance from source (m)	C ($mg \cdot l^{-1}$)	Max. plume width (m)
0.01	78	2,857	8
0.05	391	570	39
0.1	783	267	78
0.5	3,914	45	391
1.0	7,828	8	783
1.1	8,611	≃ 0	861

For water 5 m deep, γ = 0.80 (East Bank

0.01	110	2,732	11
0.05	550	532	55
0.1	1,100	258	110
0.5	5,500	38	550
1.0	11,000	7	1,100
1.1	12,100	≃ 0	1,210

Fig. 30: Projected excess suspended sediment concentrations (mg.l⁻¹) in plumes generated at Old Orchard Shoal and East Bank sites with a mass input of 13.23 kg.s⁻¹. Current vectors (from Doyle and Wilson, 1979) are shown for intermediate water depths.

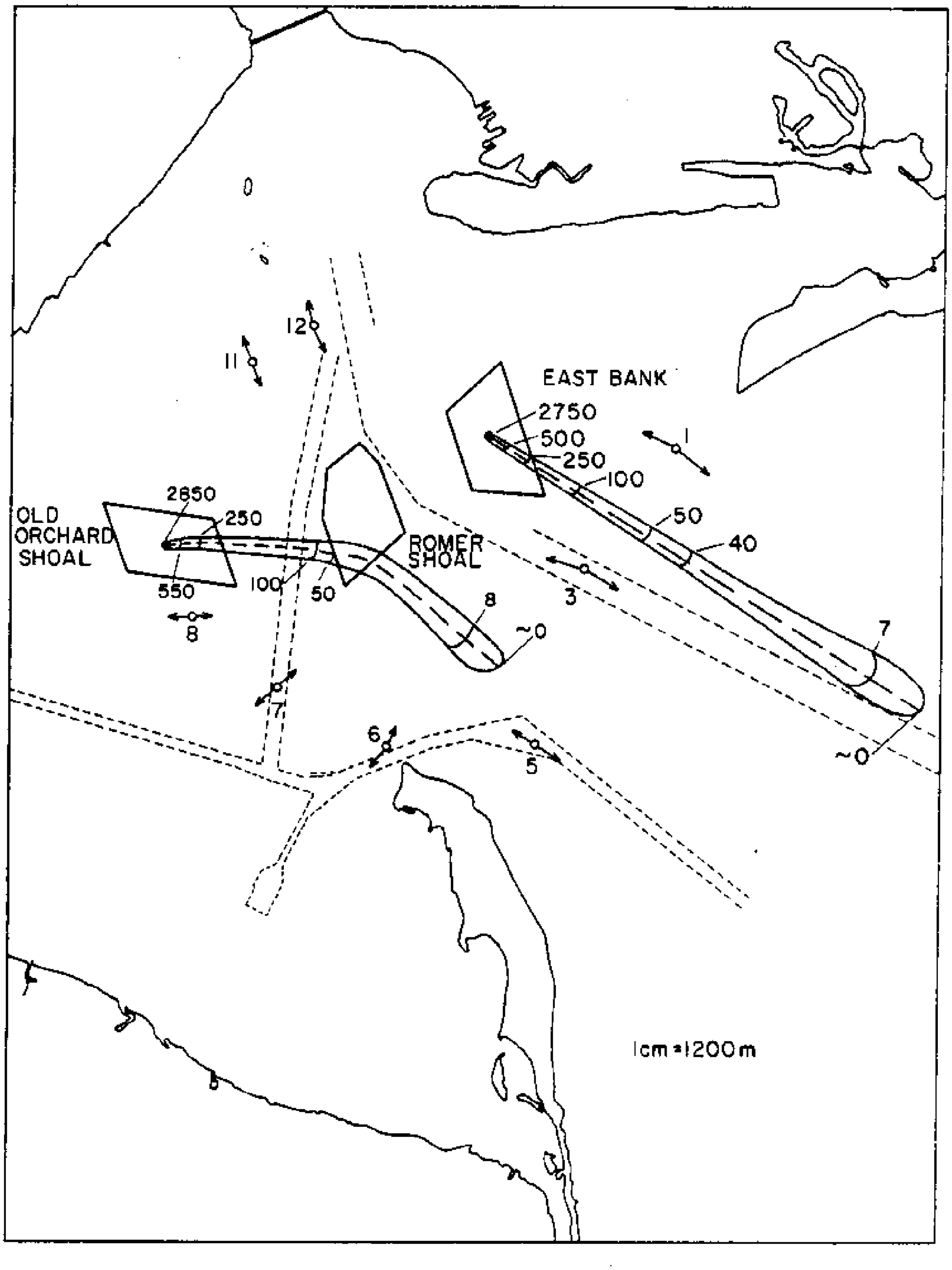


Fig. 31: Projected excess suspended sediment concentrations (mg l^{-1}) in a plume generated at the East Bank site with a mass input of 11.02 kg.s^{-1}. Current vectors (from Doyle and Wilson, 1979) are shown for intermediate water depths.

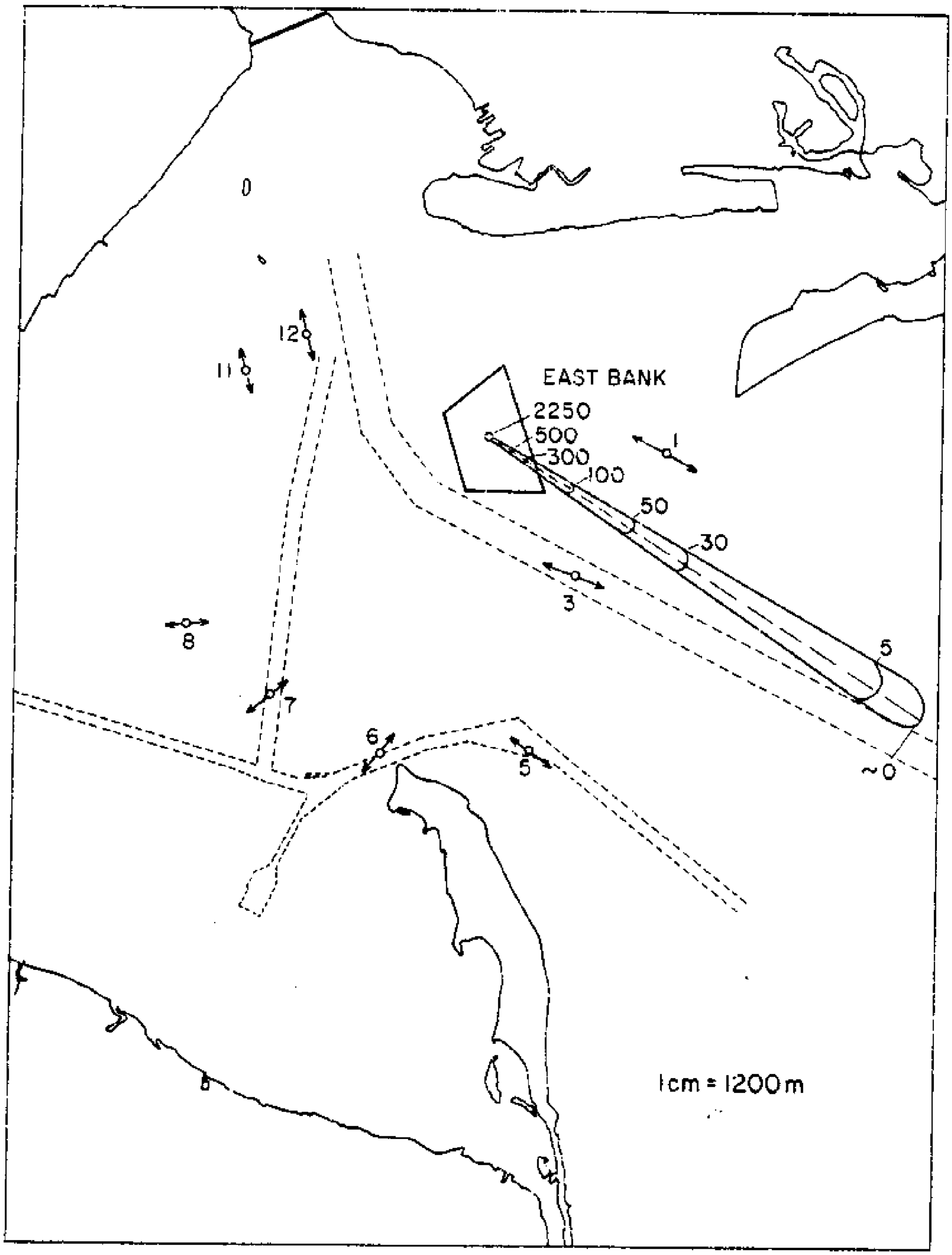


Table 20. East Bank nomograph concentration values (C) at distances x for a processing plume with a sediment discharge rate of 11.02 $kg \cdot s^{-1}$ and C_0 = 6.987 6.987 × 10^4 $mg \cdot l^{-1}$. All other conditions identical to those in Table 18.

For $\gamma = 0.1$; $C = (10.62) G(x^*)/G(1)$

Distance from source (m)	$C (mg \cdot l^{-1})$
110	2,336
550	510
1,100	255
5,500	51
11,000	7
12,100	≈ 0

For $\gamma = 1$; $C = (4.26) G(x^*)/G(1)$

Distance from source (m)	$C (mg \cdot l^{-1})$
100	2,258
550	426
1,100	204
5,500	27
11,000	4
12,100	≈ 0

Table 21. East Bank interpolated, vertically averaged sediment concentrations (C) at various distances down the plume centerline interpolated from Table 20.

For $\gamma = 0.8$

Distance from source (m)	$C (mg.l^{-1})$	Max. plume width (m)
110	2,274	11
550	577	55
1,100	296	110
5,500	32	550
11,000	5	1,100
12,100	≈ 0	1,210

If, in each of the preceding cases, we had wished to determine the distance along the plume centerline at which the excess suspended sediment concentration fell to a certain level, e.g., 50 $mg \cdot l^{-1}$, we could go back to the nomographs for γ = 0.1, 1 and the appropriate ω/u. Enter the nomograph in Wilson's Figure 1d for each γ with the value of ω/u. Proceed up the curve for the value of γ and obtain the concentration $[G(1, \omega/u, \gamma)]$ at unit distance. This is the value of the concentration when $x^* = 1$. To find the value of $G(1, \omega/u, \gamma)$ at that concentration in physical units, we must know the scale factor used to nondimensionalize the graph. It was $q/(\pi\omega^2 Dt)$. Thus, for conditions in Table 17 at $\gamma = 0.1$ the scale factor is

$$C = \frac{1.323 \times 10^7 \ mg \cdot s^{-2}}{\pi (1 \ cm^2 \cdot s^{-2})(350 \ cm)(6.21 \ h)(3600 \ s \cdot h^{-1})}$$
$$= 1.346 \ mg \cdot cm^{-3}$$

at $x = 1$, $G(1, \omega/u, \gamma)$ equals the concentration at unit distance (2.5 × 10^{-2} at $\gamma = 0.1$) times the scale factor, resulting in a concentration of 134.6 $mg \cdot l^{-1}$. To find the distance at which specific concentration occurs, e.g., 50 $mg \cdot l^{-1}$, we enter the ordinate of Wilson's Figure 1a ($\gamma = 0.1$) at the value of the ratio of 50/134.6 (= 3.7 × 10^{-1}) move across the curve for the appropriate ω/u and then down to the abscissa to find the normalized value of x^*. Once again, we must determine the scale factor of x, which was $x = ut$. In the first example, this value is (31.83 $cm \cdot s^{-1}$)(6.21 h)(3600 $s \cdot h^{-1}$) or 7.12 km. Multiply this scale factor times the abscissa value of x^* (= 0.99) to get 7.05 km. Thus, for $\gamma = 0.1$; $\omega/u = 0.03$, a 50 $mg \cdot l^{-1}$ concentration would occur 7.05 km downstream.

Tables 22, 23, and 24 show, for each of the circumstances presented in Tables 17, 18, 20, respectively, the expected distances concentrations of 50, 100, and 500 $mg \cdot l^{-1}$ at γ = 0.1, 1. At the bottom of each table is the linearly interpolate value for the appropriate γ in each case. The isopleths for 50, 100, and 500 $mg \cdot l^{-1}$ are also shown in each of the Figures, 30 and 31.

The preceding cases were used to demonstrate the extent, shape, and

Table 22. The distance at which 50, 100, and 500 $mg \cdot l^{-1}$ isopleths occur, and the width of the plume, on the Old Orchard Shoal for $\gamma = 0.1$, 1 and interpolated for $\gamma = 0.64$. (a) $\gamma = 0.1$; (b) $\gamma = 1$; $\omega/u = 0.03$ and $q = 13.23\ kg \cdot s^{-1}$; $x_1 = 7.12$ km.

	50		100		500	
Concentration (C)	a	b	a	b	a	b
$G(1, \omega/u, \gamma)/C$	0.37	9.49	0.74	19.00	3.70	94.90
x^*	0.99	0.40	0.98	0.23	0.60	0.05
Distance from source (m)	7,049	2,848	6,974	1,637	4,270	355

Interpolating for $\gamma = 0.64$

	50	100	500
x (m)	4,360	3,558	1,764
Plume width (m)	436	356	176

Table 23. The distance at which 50, 100, and 500 $mg \cdot l^{-1}$ isopleths occur, and the width of the plume, on the East Bank for $\gamma = 0.1$, 1 and interpolated for $\gamma = 0.80$. (a) $\gamma = 0.1$; (b) $\gamma = 1$; $\omega/u = 0.2$ and $q = 13.23\ kg \cdot s^{-1}$; $x_1 = 9.963$ km.

	50		100		500	
Concentration (C)	a	b	a	b	a	b
$G(1, \omega/u, \gamma)/C$	3.91	9.80	7.81	19.60	39.10	98.00
x^*	0.61	0.40	0.33	0.23	0.06	0.05
Distance from source (m)	6,077	3,985	3,288	2,291	.598	498

Interpolating for $\gamma = 0.80$:

	50	100	500
x (m)	4,403	2,490	518
Plume width (m)	440	249	52

Table 24. The distance at which 50, 100, and 500 $mg \cdot l^{-1}$ isopleths occur, and the width of the plume, on the East bank, for γ = 01, 1 and interpolated for γ = 0.80. (a) γ = 01.1; (b) γ = 1; ω/u = 0.02 and q = 11.02 $kg \cdot s^{-1}$; x_1 = 9.963 km.

	50		100		500	
Concentration (C)	a	b	a	b	a	b
$G(1, \omega/u, \gamma)/C$	4.69	11.68	9.37	23.36	46.90	116.80
x^*	0.50	0.38	0.23	0.22	0.05	0.05
Distance from source (m)	4,981	3,786	2,291	2,192	498	498

Interpolating for γ = 0.80:

	50	100	500
x (m)	4,025	2,212	498
Plume width (m)	403	221	50

ure of *excess* suspended sediment resulting from the processing of sediments at or near the mining site. We selected a number of variables from the literature regarding tidal current velocities and directions, plume age, water depth, sediment settling velocity, etc. These selected values are probably realistic, and we explored a range of these variables to see how they influence the structure and shape of the plume.

Since the tidal current velocities in the Lower Bay Complex are high, all plumes are long and narrow. Schubel et al. (1978) described plumes in shallower embayments with lower tidal current velocities as being relatively short and wide. In shallow waters with low current velocities, wind driven circulation becomes more important in determining the structure and shape of the plume. In the Lower Bay Complex near the proposed mining sites, wind stress is not expected to be the major factor affecting the structure and direction of the plume because of the high current speeds.

The one variable that is most suspect, or least accurate, is the estimated source term, q. The variable q is the most important one in determining actual concentrations of sediments at distances in the plume. We have relied on processing rates estimated by individuals in the industry, and then concluded that in *worst cases* the amount of material disposed is 15 to 35% of the sediment harvested. In certain locations, this discharge may be lower because sediments are not so fine. There are no hard data available on actual processing and discharge rates of mined marine deposits with the sediment character of the Lower Bay Complex. In fact, the processing rates quoted are principally for land-based operations, and these estimates are probably higher than those attainable at sea. Nonetheless, by assuming *worst cases* we can be certain that we have covered at least the most drastic circumstances.

Further, it is important to note that the model predictions along the plume centerline are vertically averaged values, and the assumption is made that the water column is homogeneous. Data collected by Swartz and Brinkhuis (1978) indicate that the water column chemistry in the two proposed sites is, in effect, homogeneous. Doyle and Wilson (1978) indicate that current speeds at the surface and intermediate depths and near the bottom are similar but the direction is not.

High tidal current velocities can cause resuspension of bottom sediments. Likewise, an irregular bottom may create vertical shear stresses, resulting in greater resuspension of sediments near the bottom. The model can not predict the extent of resuspension; it can predict only how far sediment discharged at the surface will be borne by tidal currents before it settles out. In other words, we can state how much sediment is at the mid depth of the water column, where it may affect fishes and other swimming creatures, but we can not accurately state what concentrations are near the bottom, where benthic infauna and epifauna are affected. However, assumption of *worst cases* probably covers the additional amounts of suspended sediment due to resuspension near the bottom.

<u>Ambient Suspended Sediment Concentrations</u>

As was noted in the previous section, sediment plume concentrations modelled were excess concentrations, or above ambient concentrations. There is a paucity of suspended sediment data for the Lower Bay area. Only Parker et al. (1976a), and Duedall et al. (1978) provide some data regarding seasonal levels as well as one tidal cycle study near the proposed mining sites. Typical suspended sediment concentrations during November 1973 to June 1974 are shown in Table 25. The East Bank Station (B) is located about 1 km south of the respective mining area while the West Bank Station (F) is located about 3 km due east of the tip of Sandy Hook, half way to the Ambrose

Channel along the Sandy Hook-Rockaway Pt. Transect. Figure 32 depicts surface and 1 m above bottom suspended sediment concentrations. It may be noted that bottom concentrations are higher, probably due to resuspension (Kao, 1975). The values are typical of estuarine waters along the east coast (Schubel, 1974; Bond and Meade, 1966). Higher values, up to 10,000 mg have been reported in Chesapeake Bay during severe storms (Schubel, 1974; Meade, 1969).

Table 25. Suspended solids concentrations (mg.$^{-1}$) at two stations in the Lower Bay during November 1973 to June 1974. East Bank Station is Sta. B and West Bank Station is Sta. F from Parker et al. (1976a). Data are averages of 3 readings taken near surface, mid-water, and 2 m above bottom. S = slack, F = flood, E = ebb.

Date	East Bank	West Bank
5-XI-73	6.4(E)	3.5(E)
		6.5(F)
		6.3(S)
		5.9(E)
22-I-74	12.5(F)	14.0(E)
	13.1(E)	14.3(F)
	14.2(F)	
20-IV-74	10.6(F)	12.9(S)
	12.7(E)	16.3(E)
	14.3(S)	15.2(F)
	13.3(F)	
5-VI-74	10.6(F)	21.1(F)
	13.6(E)	15.6(S)
	38.5(S)	21.8(E)
	24.3(F)	25.8(S)
		26.6(F)

Organisms Present Near Mining Sites

It was noted in *Prediction of Sediment Plumes* that processing (screening and washing) of mined material may result in localized areas of high suspended sediment concentrations. Much of the material in suspension is relatively coarse and settles out quite rapidly. The suspended sediment plume model predicted that excess suspended sediment will extend in a long, narrow band along the direction of tidal flow. The length of the plumes is determined by the maximum distance a parcel of water, originating at the discharge point at time = 0, will travel in one half of the tidal cycle. The width of the plumes was narrow because of the large tidal flow component. Predictions were only made for ebbing tides since it is unlikely a processing operation would be conducted on flooding tides, when sediment would be carried into the Lower and Upper bays. Further, it should be pointed out that the source of sediment was modelled as continuous for the duration of one half the tidal cycle.

The direction, extent, and structure of the suspended sediment plumes now have been characterized. The next step is to determine which organisms are potentially under the influence of these plumes . Let's first examine the East Bank site.

The only reported data on organism distribution and abundance on or near the East Bank are those from Woodward-Clyde (1975a,b), Steimle and Stone (1973), and Brinkhuis (1977-1979). A composite list of species and maximum abundances in the East Bank area are shown in Table 26.

The species listed in Table 26 are not present at all times during the year. Seasonal patterns of invertebrate abundance on the East Bank has only been reported by Steimle and Stone (1973 - see Appendix Table 7). Examination of monthly totals of organisms per square meter indicates that

Fig. 32: Background suspended sediment concentrations (mg.l⁻¹) in the water column between 1 and 4 meters (x) and one meter above the bottom (o) over a tidal cycle on 24 April 1974 at Station H from Parker et al. (1976a).

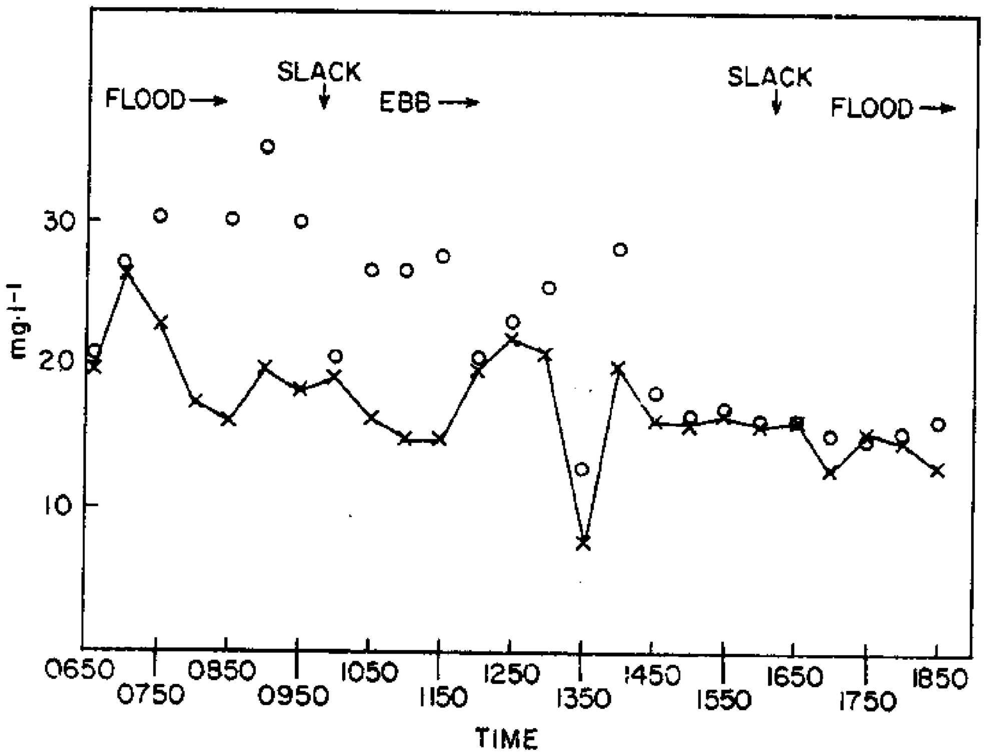


Table 26. Maximum abundances of fauna (#·m^{-2}) found in densities ≥ 100·m^{-2} in East Bank areas that may be affected by mining and suspended sediment plumes. Fish densities are on a relative scale of 1 to 5 (1 = most abundant). Based on reports by Woodward-Clyde (1975a - Sta. 2 not included - see text), Steimle and Stone (1973 - Transect A), and Brinkhuis (1977-1979). An asterisk (*) indicates literature available on suspended solids effects on that organism or a closely related species.

	Invertebrates	Maximum Abundance
*	*Mytilus edulis*	111,000
	Harmothoe extenuata	1,955
	Nematoda spp.	1,400
	Cirratulidae	1,020
	Oligochaetae	785
	Harmothoe imbricata	785
	Paraphoxus spinosus	785
	Ovalipes ocellatus	670
	Goniadella gracilis	650
*	*Nereis succinea*	610
*	*Spio filicornis*	600
*	*Cancer irroratus*	580
	Spisula solidissima	385
*	*Polydora ligni*	340
	Tharyx acutus	335
*	*Spio setosa*	320
	Echinarachnius parma	320
	Lepidonotus squamata	270
	Protohaustorius deichmannae	240
	Unciola serrata	215
*	*Jassa falcata*	190
	Unciola irrorata	175
	Crangon septemspinosa	175
	Acanthohaustorius millsi	175
*	*Metridium senile*	175
*	*Tellina agilis*	160
*	*Crepidula fornicata*	145
*	*Crepidula plana*	145
	Trichophoxus epistomus	130
	Parahaustorius longimerus	130

	Fishes	Maximum Abundance
*	*Anchoa mitchilli*	1
	Stenatomus chrysops	1
*	*Scophthalmus aquosus*	1
	Pseudopleuronectes americanus	1
	Tautoga onitis	2
*	*Ammodytes americanus*	2
	Peprilus triacanthus	2
*	*Alosa aestivalis*	3
	Engraulis eurystole	4
	Merluccius bilinearis	4
*	*Brevoortia tyrannus*	5
*	*Menidia menidia*	5

maximum numbers occur during the late spring, summer, and early fall months. The lowest numbers are found between November and April. The blue mussel, *Mytilus edulis*, apparently dominates abundance. However, studies underway by this author indicate that very few *Mytilus* are found on the East Bank within, or near, the proposed mining site.

The abundance of fishes on the East Bank has not been reported in the literature. There is a lack of quantitative and seasonal data in this area. The qualitative ranking of fishes in Table 26 is based only on preliminary data from this author's observations during 1979 and 1980 (and ongoing) studies. The most common species appear to be the bay anchovy, *Anchoa mitchilli*. However, abundances of fishes and numbers of species on the East Bank are generally low throughout the year. The seasonal fish surveys presently being conducted by this author will provide a more quantitative base of knowledge on fish diversity and abundance.

The distribution and abundance of fauna in the vicinity of the proposed West Bank mining site has been characterized by several quantitative studies. Walford (1971) and Dean (1975) described the diversity and abundance of invertebrates. However, no data are available on seasonal distribution patterns. Wilk et al. (1977) conducted studies on temporal variations in fish species and abundance (Areas E and J - see Fig. 29).

Table 27 indicates the maximum abundances of invertebrate species reported by Walford (1971) and Dean (1975) to be present in numbers greater than $100 \cdot m^{-2}$ at the Old Orchard Shoal site. The community on the West Bank appears dominated by the small bivalve, *Gemma gemma*, and the soft-shell clam, *Mya arenaria*. The diversity and composition of this community is quite different from the characteristics of the East Bank. These data indicate lower abundances and diversities

Table 27. Maximum abundances ($\# \cdot m^{-2}$) of fauna found in densities $\geq 100 \cdot m^{-2}$ in West Bank areas that may be affected by mining and suspended sediment plumes. Fish densities are on a relative scale of 1 to 5 (1 = most abundant). Based on reports by Dean (1975), Walford (1971), and Wilk et al. (1977). An asterisk (*) indicates literature available on suspended solids effects on that organism or a closely related species.

	Invertebrates	Maximum Abundance
*	*Gemma gemma*	62,000
*	*Mya arenaria*	21,760
*	*Mytilus edulis*	4,090
	Spisula solidissima	1,373
	Sabellaria vulgaris	780
*	*Tellina agilis*	510
*	*Mulinia lateralis*	370
*	*Polydora ligni*	358
*	*Balanus improvisus*	260
*	*Corophium* sp.	230
	Eumida sanguinea	155
	Spio setosa	150
	Ampelisca sp.	150
	Lumbrineris tenuis	130
	Harmothoe extenuata	113
	Fishes	
*	*Alosa aestivalis*	1
*	*Anchoa mitchilli*	1
	Paralichthys dentatus	2
	Peprilus triacanthus	2
	Pomatomus saltatrix	2
	Pseudopleuronectes americanus	2
	Alosa pseudoharengus	3
*	*Cynoscion regalis*	3
*	*Scophthalmus aquosus*	3
	Tautoga onitis	3
	Alosa sapidissima	4
*	*Brevoortia tyrannus*	4
	Urophycis chuss	4
*	*Clupea harengus harengus*	5
*	*Prionotus carolinus*	5

are present on the West Bank. The seasonal faunal surveys being conducted by this author will provide greater detail on patterns of invertebrate abundance. Preliminary data indicate that many of the species reported by Walford (1971) and Dean (1975) are present today but the community does not appear to be dominated by bivalves. Instead, polychaete worms and gammurid amphipods are the most common invertebrate species.

Table 27 also indicates the relative abundances of fishes on the West Bank, based on data from monthly surveys conducted by Wilk et al. (1977). The species of fishes caught here are essentially the same ones reported on the East Bank (see Table 25). Although comparing the qualitative rankings of fish on the East and West Banks does not distinguish actual abundances, greater numbers of fish are found on the West Bank. Fewest species and numbers are caught during the spring and late summer months. Preliminary results from the author's surveys during 1979 and 1980 support the findings of Wilk et al. (1977).

General Effects of Mining Operations

A discussion of the biological effects (*sensu strictu*) of sand mining and processing in the Lower Bay of New York Harbor cannot be limited to the effects on organisms inhabiting the area. Sediments discharged into the water during and after a screening operation are affected by physical and chemical properties of the water column and bottom, as well as by organisms themselves. Before discussing the impacts on organisms, we will examine how discharged sediments are affected by these other parameters to illustrate the complexity of interactions between them.

Slotta and Williamson (1974) reviewed the general features of impacts associated with estuarine dreding and spoiling. These same features would apply to sand mining operations. The impacts include:

1) altered circulation patterns
2) physical removal of organisms
3) burial or organisms
4) nutrient release
5) oxygen demand and sulfides
6) heavy metals
7) toxic hydrocarbons
8) turbidity and suspended solids

We will consider the effects of turbidity and suspended solids (8) separately in the section *Effects of Suspended Particulates on Organisms*.

Altered circulation

Mining of bottom sediments results in irregularly shaped holes. Several such holes already exist in the Lower Bay (Swartz and Brinkhuis, 1978). Wong and Wilson (1979) found that these holes altered current flows, depending on their size and location. Further study by computer simulations of altered bathymetry indicated that large holes mined in the vicinity of Romer Shoal and Flynns Knoll (see Fig. 1) intensified current velocities and increased tidal amplitudes in the Lower Bay near Staten Island. Kinsman et al. (1979) found that the locations of certain holes may concentrate wave rays along certain shore points of Staten Island. Again, the most critical areas appeared to be Romer Shoal and Flynns Knoll. These combined forces could act to increase local shore erosion rates along Staten Island's eastern shore. Further, Swartz and Brinkhuis (1978) found that certain holes may become anoxic during the late spring-summer. The authors indicated that the isolated nature of these holes did not permit adequate circulation to compensate for biological and chemical oxygen demand of the water column and underlying sediments. This phenomenon was only observe above West Bank holes, and not above East Bank holes. The waters on the East Bank apparently were well mixed and exchanged with the clearer waters of the Bight Apex.

Holes could probably be mined on the

West Bank without water column and circulation impacts if care was taken in choosing mining sites with regard to location and size. Such holes should have exchange (connection) with neighboring channels or other holes. They should not be located on Romer Shoal or Flynns Knoll. Of course, all circulation impacts could be minimized if mined holes were backfilled with dredge spoils, as has been proposed by numerous agencies, e.g. New York Office of General Services and U.S. Army Corps of Engineers.

Physical removal

The most apparent biological impact of mining pertains to the removal of benthic biota. The biota would probably be killed during mining operations, although there are no data available to suggest susceptibility of certain species or kill factors in general. Sessile forms would be most affected but there is some evidence that mining/dredging attracts feeding motile forms near disrupted sediments. The significance of this latter effect is not known.

Mining may expose sediments of a different texture, grain size, and porosity. This might affect recolonization from adjacent populations that survive the operations. Harrison et al. (1964), Saila et al. (1972), and Slotta et al. (1973) all detected immediate increases in infaunal populations after dredging, and a fairly rapid recolonization did occur. However, adjacent areas were characterized by high organism density and diversity. Density and diversity in the Lower Bay Complex are generally low. This would certainly affect repopulation rates in the Lower Bay. The U.S. Army Corps of Engineers is presently sponsoring a study in the Lower Bay, part of which will examine recolonization of dredged sediments placed in mined holes. That study should provide data which will permit better determination of local recolonization rates.

One further point to be considered is what has happened to biota density and diversity in the existing holes that were mined approximately 10 years ago. Studies by this author found that these holes on the West Bank filled in with 70-90 cm of highly organic sediment. Very few organisms were found. Little or no organic material accumulated in East Bank holes, and organism abundance was somewhat greater (see Tables 11 and 12). The organic material probably accumulated due to restricted circulation and exchange. This material is apparently unsuitable for most species, either due to the fine grain nature of the sediments (Swartz and Brinkhuis, 1978) or associated toxic effects of material associated with the organic matter and low oxygen levels. Except for a thin surface layer (< 5 mm), the sediments in West Bank holes are anoxic most of the year. Again, if a plan to backfill holes with dredge spoils capped by a clean sandy layer were implemented, these effects would be considerably reduced.

Burial

Burial of organisms is a factor critical only downstream of the plume generated by screening operations. As indicated previously, most of the material discharged will settle near the discharge point, along a narrow band. The ability of biota to survive burial in these areas depends primarily on their behavior and morphology. Burrowing polychaetes and bivalves have been shown to survive burial by up to 21 cm of sediments (Saila et al., 1973).

Between 95 and 99% of the sediments discharged into the water near a processing barge will rapidly settle to the bottom (Schubel et al., 1978). Most of the rapidly settling material will consist of the undesirable fine grain sands. This material will probably fall to the bottom as a density current rather than individual particles (Gordon, 1974), and will be deposited within a few hundred meters of the processing operation. When this material falls on hard sandy substrates, there will not be much of a density surge, or wave of sediment flowing out near the bottom. Gordon (1974) hypothesized that such density surges will only occur if there are much silt and clay in the discharged material. Typically, sediments in the proposed mining sites contain less than 2% silt, plus clay by mass (Kastens et al., 1978). Of course, these observations are only valid in considering a flat bottom. Ridges or sand waves may cause some material to be injected back into the water column, but this effect is probably minimal with fine sand sized material. Bokuniewicz and Brinkhuis are presently examining the behavior of sediments discharged into previously mined holes, some of which consist of hard bottom sandy sediments and others that have accumulated silt and clay material since they were mined. Many of these holes have an irregular bathymetry, and the effect of this bathymetry on settling material is also being examined.

Fine grained sediments settling to the bottom near the discharge point will be subject to several other influences. The material will be poorly sorted and will have a relatively high porosity. It will therefore, be more susceptible to resuspension and lateral transport by bottom currents. Gordon (1974) indicated that only about 1% of the material will be transported laterally by the density surge beyond 100 to 200 m of the impact area. On the other hand, Biggs (1970) found that as much as 12% of the material deposited on an underwater spoil material in Chesapeake Bay had "disappeared" 150 days after deposition. The lost material was probably transported by the bottom current, whose velocities are similar to those found in the Lower Bay waters. Nittrouer and Sternberg (1975) determined that spoil mounds of fine grained sediments in Puget Sound shrank in size within four months of deposition. Only 16% of the originally deposited material remained. The authors felt that this was principally due to bottom currents of 50 $cm \cdot s^{-1}$ similar to those found in the Lower Bay. Other reasons for the "disappearance" of the spoil mound include loss during disposal and water loss during consolidation, after settling on the bottom.

It should be pointed out, however, that these previous studies have all dealt with the disposal of sediments containing large silt and clay fractions. It is conceivable that in mining sand deposits in the Lower Bay, overburdens containing greater quantities of silt and clay may have to be disposed of in processing. Although this situation was not examined in the modelling scenario, there is enough evidence in the literature to predict what may happen to such fine material. Gordon (1974) and Schubel et al. (1978) observed that much of the fine material rapidly settles near the discharge. Masch and Espey (1967) found that when dredge wash water contained 80% or more silt and clay by weight, the sediment tended to flocculate into density layers. Such highly concentrated silt and clay overburdens are not to be expected in the Lower Bay (Kastens et al., 1978).

The mining scenario described previously indicated that a typical barge (700 m^3 capacity) would reject 35% as unsuitable fine grain sediments. If we assume that <u>all</u> (worst case) of this material settles within a 250 meter radius of the discharge, we can calculate that the 245 m^3 discharged would spread in a layer approximately 0.62 cm thick. Although such discharges may be piled somewhat higher near the source of the discharge, the sediments will have a high water content, and would likely spread even thinner and further by sediment resuspension due to tidal currents and wave action.

On the other hand, sessile species are probably killed by burial of any magnitude. Saila et al. (1972) reported acute kills from burial of various benthic organisms. However, Slotta et al. (1973) indicated that benthic infauna readjusted to former abundances within a few weeks after dumping of dredge spoil. It has been suggested that rapid recoveries in disturbed sediments is attributed to a resistant biological population (Slotta et al., 1973). This finding, however, was in an area of relatively high abundance of many species. It is not known if such rapid recolonization would occur in the generally impoverished Lower Bay. Again, the research being conducted under the auspices of the U.S. Army Corps of Engineers will provide some indications of recolonization rates.

Nutrient release

During mining/screening operations, significant concentrations of nutrients, primarily various chemical forms of nitrogen and phosphorus, will be released to the water column. For example, Cronin et al. (1970) reported increases near discharges from 50 to 1,000 times ambient levels. No increase in phytoplankton was observed in this Chesapeake Bay study. Windom (1973) also reported large nutrient increases in his study of five estuaries on the southeastern coast of the United States. In contrast to Cronin's study, he found significant increases in algal growth in experiments where dredged sediments were incubated in bottles containing receiving waters. Stimulation of algal growth was also observed at dredging sites. Schubel et al. (1978), on the other hand, did not detect significant increases in nitrogen or phosphate concentrations in sediment discharge plumes in Apalachicola Bay (Florida). They did not, however, examine phytoplankton growth characteristics.

Water column nitrogen and phosphorus concentrations in the waters of the Lower Bay Complex are among the highest reported. Further, phytoplankton productivity is the highest reported in the literature (Garside et al., 1976). Ammonia-nitrogen supports the large populations of phytoplankton and phytoflagellates (Mahoney and McLachlan, 1977). The majority of ammonia is derived from sewage inputs (O'Connors and Duedall, 1975). Garside et al. (1976) and Mahoney and McLachlan (1977) indicate that dense blooms of plankton in Lower Bay waters become light limited rather than nutrient limited. Suspended particulates will further reduce water column light intensities. Therefore, it is unlikely that nutrient release from mined sediments will result in a further increase in phytoplankton production. Further, Schubel et al. (1978) found that sources of nutrients from sediment discharges are rapidly diluted. There are no reported effects of elevated nutrient concentrations on other organisms.

Oxygen demand and sulfides

Mining/screening of sediments may result in the release of organic and inorganic materials that can increase oxygen demand in the receiving waters. The majority of this demand is ascribed to chemical reactions. For example, various iron sulfides are readily oxidized. Numerous authors have noted that iron and manganese were scavenged by suspended matter and freshly formed hydrous oxides. Schubel et al. (1978) did not detect any decrease in dissolved iron and manganese water column concentrations during pipeline discharges. Although considerable amounts of reduced particulate matter with a high potential oxygen demand might be introduced to the water during mining/screening operations, only a small proportion will be reactive during the time scale of the operation and the settling of particulate material. Between 95 and 99% of the material discharged is deposited close to the discharge in a time scale of tens to hundreds of seconds (Schubel et al., 1978). Therefore, the water column oxygen decrease is less than might be expected from either chemical reaction calculations or organic carbon analysis. Once discharged material has settled, its oxygen demand is initially dependent on expulsion of interstitial water during compaction processes and then is diffusion limited (Schubel et al., 1978). Schubel et al. (1978) noted oxygen sags of 0.4 mg $O_2 \cdot g^{-1}$ (from chemical reaction calculations) to 1.1 mg $O_2 \cdot g^{-1}$ sediment (from core incubations). Oxygen depression in surface water ranged from 0.2 to 6.0 $mg \cdot \ell^{-1}$ in shallow waters 0.6 to 2.1 m deep. The largest depressions were generally noted in the shallowest waters.

Swartz and Brinkhuis (1978) found low oxygen concentrations in waters above West Bank mined holes in the Lower Bay during the summer months. Values approached 3 mg $O_2 . \ell^{-1}$. During the remainder of the year, and above East Bank holes, oxygen concentrations were near saturation. The study indicated that sediment sulfide concentrations in undisturbed East Bank hole sediments were low (approx. 50 μg sulfide $.g^{-1}$ sediment) but were high in organically rich West Bank hole sediments (up to 868 μg sulfide $.g^{-1}$ sediment). Low bottom water oxygen concentrations were strongly correlated to measured chemical oxygen demand. Surface and midwater oxygen lows were related to high biological demand.

It is likely that mining/screening of Lower Bay sediments will create an oxygen depression. To a large extent, such depressions could be minimized by conducting these operations during cooler months of the year. This will decrease both biological and chemical oxygen demand at a time when water column oxygen concentrations approach or exceed saturation. It is believed, though, that during the time scale of a tidal cycle, most of the chemical interactions will occur during the injection of water into mined sediments for processing purposes. After sediments are directly in contact with the water column and while they are suspended in the plume, little further chemical interaction will occur. Chemical oxidation and other reactions occur quite rapidly in relation to the age of a fully developed plume.

<u>Heavy metals</u>

While the mined sediment is in contact with surface waters during processing and descent to the bottom, it may undergo a number of chemical interactions. Coastal marine sediments, especially in harbors, are normally reducing a few centimeters below the sediment surface. Many muddy sediments also contain reduced chemical complexes, e.g., metal sulfides. Material removed by a bucket-ladder or clam-shell dredge will remain "intact" during transport to the loading barge. However, when it is processed, this chemical integrity will be altered by mixing with large amounts of oxygenated sea water. Reduced chemical forms will be oxidized, thereby potentially releasing "trapped" metal ions (Gambrell et al., 1976; Khalid et al., 1978). This oxidation process also "consumes" oxygen from the water, resulting in an oxygen sag in the discharged water (Schubel et al., 1978). Sediments in the Lower Bay are reduced but are relatively low in sulfide concentrations (Swartz and Brinkhuis, 1978) that may trap metals.

Metal concentrations in Lower Bay sediments near the proposed mining sites are lower than other areas within the Lower Bay Complex (Grieg and McGrath, 1977). The highest metal contaminant levels are found in Western Raritan Bay and Sandy Hook Bay. Using an arithmetic mean of all metal (cadmium, chromium, copper, nickel, lead, and zinc) concentrations, they found that sediments east of the Ambrose Channel had the lowest concentrations (< 9.0 ppm). Mean concentrations near the proposed West Bank mining site approached 67 ppm. Cadmium, chromium, and copper concentrations were generally low. The authors noted that highest concentrations occurred in the winter. Concentrations of most metals in sediments of Raritan and Sandy Hook Bays were an order of magnitude greater. Grieg and McGrath (1977) indicate that the patterns of sediment metal concentrations correspond almost exactly to the faunal distribution of McGrath (1974) and the sediment patterns described by DeFalco (1967).

It is likely that some metal species will be released to the water column during mining/screening operations. It is unknown, without direct measurement, how significant this increase might be. Most studies to date on dredged material disposal have shown little or no release, primarily because material sinks to the bottom in a rapid jet, minimizing interaction with the water column. On the other hand, screening will inject large amounts of water into the sediments. Release of metals under such circumstances has not been extensively studied in polluted sediments (Schubel et al., 1978). Further, Waldhauer et al. (1978) and Seeliger and Edwards (1977) indicate already high lead and copper concentrations in some waters and algae of the Lower Bay Complex. No data have been reported on organism metal concentrations in the Lower Bay Complex. It is doubtful that a release of metals from processed sediments could be detected above ambient (also highly variable) water column concentrations reported by Waldhauer et al. (1978). Schubel et al. (1978) found increases in manganese, copper, and chromium near the discharge, and this was associated with particle concentrations near or exceeding 10^3 $mg \cdot \ell^{-1}$. Conversely, iron concentrations were low. No well defined plume could be found at any of the three sites studied in Gulf of Mexico waters. However, the presence of low (usually below detection limit) interstitial water concentrations of zinc, copper, chromium, cadmium, and lead precluded any substantial release of these metals.

<u>Toxic hydrocarbons</u>

No studies have thus far been reported on hydrocarbon concentrations in Lower Bay Complex sediments. Hydrocarbons would include oils and numerous pesticides. Searl et al. (1977) did, however, examine nonvolatile hydrocarbon concentrations in surface waters of the Lower Bay complex. These nonvolatiles are comprised only of oils with carbon chains of > 14 carbons. They found concentrations near the Ambrose Channel to be a factor of 10 higher than offshore. Highest concentrations were found near Manhattan and eastern Raritan Bay.

Brinkhuis (unpublished data) collected three sediment cores in one of the previously mined pits that has since accumulated organic matter. Since many hydrocarbons, including polyvinyl chloride biphenyls (PCBs), are frequently associated with fine and organic particulate matter (Chytalo, 1979), it might be expected that these pits would reflect maximum expected concentrations of hydrocarbons. Several layers in these cores were analyzed for the PCB Aroclor 1254. Concentrations were found to range from 0 to 0.57 parts per million (ppm). These are apparently not particularly high concentrations. Further upstream in the Hudson, near Manhattan, PCB concentrations in sediments are reported to be about 3 ppm (Bopp et al., 1979). No other data have been reported for the area.

<u>Effects of Suspended Particulates on Organisms</u>

Several recent reviews, e.g. Sherk and Cronin (1970), Morton (1976, 1977), Moore (1977) and Stern and Stickle (1978), have pointed to the complexity of suspended sediment effects on marine biota. These effects may be simplistically divided into direct and indirect effects. Direct effects include smothering, clogging of respiratory structures, filtering apparatus and the gut, and abrasion of tissues. Indirect effects include temperature, salinity and oxygen effects at the metabolic level (Haefner, 1969; 1970). The latter are more difficult to ascertain. Since particles suspended by dredging/mining operations eventually settle, effects also include population redistribution. Many species inhabit particular grain size ranges of sediment. Further, different life stages have different susceptibilities. Much of the literature is extremely qualitative, often based on field observations relating distribution of a species to turbid or clear waters. In some instances, experimental data is given.

Problems arise in the interpretation of quantified suspended sediment effects. As Moore (1977) indicates in the most comprehensive treatment of suspended sediment effects, these difficulties arise from: 1) use of artificial sediments (e.g., Kaolin clay, Fuller's earth and glass shards, 2) effectiveness of the experimental system in maintaining uniform suspended sediment loads and 3) lack of awareness, or incorporation, of indirect effects (e.g. reduced oxygen) into experimental design. In only a few cases have natural silts or sands been used. It is the latter's use that most often results in the caveat that toxicity effects may be mostly responsible for mortality.

We will first review what is known about the effects of suspended particulates on different taxa of invertebrates, followed by effects on fish species, found near sediment plumes generated at the two proposed mining sites.

Zooplankton include organisms that spend their entire life history as plankton as well as larval stages of invertebrates and fishes. There is no quantitative or qualitative distribution data for zooplankton relative to the proposed mining sites. In most estuaries, zooplankton is dominated by crustacea and larval stages of invertebrates. Most of these organisms are filter feeders. Sherk et al. (1974) observed a significant reduction of food when the copepods *Eurytemora affinis* and *Acartia tonsa* were exposed to mixtures of seawater and Fuller's earth, fine sand and natural Patuxent River silt. Sullivan and Hancock (1973) postulated that suspended sediment reduces efficiency of feeding appendages. Toxic interactions with contaminated material adhering to the organisms are also suspected (Morton, 1976).

Literature concerning suspended sediment effects on invertebrates is more expensive, however, much is qualitative. Table 28 summarizes the literature concerning effects on species that are found in the Lower Bay as a whole. Species labelled by asterisks occur within areas affected by sediment plumes at the two proposed mining sites (see also Tables 26 and 27). Most of this material was derived from the comprehensive review of Moore (1977). Tables 29 and 30 include other invertebrates described in the review of Peddicord et al. (1975).

We noted in Tables 19 and 21 that the highest concentrations of excess suspended sediments range from 2.9 and 2.3 $g \cdot l^{-1}$ at the East Bank and Old Orchard Shoal mining sites. These concentrations were predicted within 110 m from the source, down the centerline of the plume. Plume widths near the source ranged from 8 to 11 m, assuming a narrow point source (pipeline). It was also noted previously that most of the suspended material will rapidly settle in the area near the source. Therefore, this is where the greatest impact in terms of suspended sediment effects and burial will occur. Within 550 m downstream, concentrations fall to about 0.5 $g.l^{-1}$, and the plume has a width of only about 55 m.

Although most of the information listed in Table 28 is qualitative, most of the species appear tolerant of turbid conditions. It is quite probable that many of the species found in the Lower Bay are there because they have survived many years of onslaught from a combination of pollutants and occasionally turbid waters after major storms and periods of high runoff flow from the Hudson and Raritan Rivers. The exceptions are *Spio* sp. (Wolff, 1973), *Crepidula fornicata* (Johnson, 1972), *Tellina* sp. (Moore, 1977). Peddicord et al. (1975) data (Tables 29 and 30) indicate that many of the invertebrates they studied were quite resistant to turbidity. Quite low mortalities were reported at

Table 28. Invertebrates present in the Lower Bay Complex for which qualitative literature exists on suspended sediment effects. The species listed are all from Table 6. An asterisk (*) indicates the species present in areas potentially affected by sediment mining/processing plumes. Where no specific species is listed, literature exists only for the genus or a closely related species.

Anthozoa	
Sagartia modesta	Mistakidis (1951) reported *S. troglodytes* less common in turbid situations.
Metridium senile	Milne (1940) reported it less common on buoys in turbid waters.
Polychaeta	
Nereis sp.	Purchon (1937) and Wolff (1973) indicate *Nereis diversicolor* certainly not deterred by turbid waters.
Capitella capitata	Emerson (1974) found mortality of trochophores and metatrochs 50% in 96h exposures to 100:1, 10:1, 4:1, and 2:1 seawater sediment mixtures.
Ophelia bicornis	Moore (1977) indicates species inhabits surf zone.
* *Polydora* sp.	Barnard (1958) indicates *P. ligni* and *P. limicola* penetrates most turbid waters.
	Leung (1972) says *P. ciliata* is turbidity tolerant.
* *Spio* sp.	Wolff (1973) indicates *S. martinensis* intolerant of turbid conditions.
Paraonis sp.	Wolff (1973) indicates *P. fulgens* intolerant of turbid conditions.
Chaetopterus variopedatus	Moore (1977) indicates that species may be vulnerable due to clogging of mucus net filtering apparatus.
Sabella sp.	Dales (1957) indicated these fan worms found near mouths of rivers with high loads of fine detritus.
	Allen and Todd (1900) found *S. pavonina* most abundant in high salinity and turbid estuaries.
Hydroides sp.	Crippen and Reish (1969) indicate *H. norvegica* found in wide range of turbidity in Los Angeles Harbor.
Crustacea	
* *Balanus* sp.	Moyse and Knight-Jones (1967) suggested that turbidity indirectly affects larval release in *B. balanoides*. Silt reduces light, thereby reducing plankton blooms that normally trigger release.
	Purchon (1937) indicates *B. improvisus* tolerates silt pollution better than most barnacles.
Elasmopus sp.	Barnard and Reish (1959) report *E. rapax* less common in turbid water.
	McNulty (1961) noted *E. pectenicrus* occurred in turbid waters.
* *Jassa falcata*	Barnard and Reish (1959) report species common in turbid harbors.

Table 28 (continued)

* *Ampelisca* sp.	Mills (1967) indicates turbidity might be responsible for initiating feeding in tube dwelling amphipod *A. abdita* and *A. vadorum*.
* *Corophium* sp.	Meadows and Reid (1966) indicate *C. volutator* juveniles swim more in turbid water.
	Purchon (1937), Barnard and Reish (1959) and others indicate many tubiculous amphipods, particularly *Corophium* sp. found as fouling organisms in highly turbid areas.
Leptocheirus sp.	Pfitzenmeyer (1970) indicates *L. plumulosus* co-dominated areas in Chesapeake Bay spoil deposits and turbid waters.
	Goodhart (1939) describes *L. pilosus* as using suspended mud to build tubes.
Stenothoe sp.	Moore (1977) indicated that Chardy (1970) reported *S. dollfusi* absent from turbid areas.
Neomysis sp.	Moore (1977) indicated a positive role of turbid suspensions (0.1 $g.l^{3}$) on fat content and nourishment of *N. integer*.
* *Crangon* sp.	Moore (1977) indicates shrimp *L. crangon* fatter in turbid waters where feeding is not restricted to nighttime.
	Newton (1973) reports observations by Gray that adult *Crangon* survived immersion for 14 days in 3 $g.l^{-1}$ clay suspensions.
	Blackmar and Wilson (1973) report *L. crangon* survived 72 h in red mud concentrations up to 33 $g.l^{-1}$). (See also Tables 29 and 30)
* *Homarus americanus*	Sherk (1971) found species very resistant to turbid conditions.
	Saila et al. (1968) found no effects of turbidity on lobsters.
Pagurus sp.	Wolff and Sandee (1971) suggest high turbidity inhibited occurrence of *P. bernhardus*. (See also Table 30)
* *Cancer maenus*	Arudpragasam and Naylor (1964) indicate additions of suspended particulates elicit short-term, reversible respiration increases.
	Bacescu (1972) maintained that silt hinders respiration in crabs.
Gastropoda	
Littorina sp.	Fretter and Graham (1962) state that *L. littoralis* avoids turbid waters.
* *Crepidula fornicata*	Johnson (1971) found that turbidity decreases shell growth. Filtration decreased with increasing concentrations of Kaolin and Fullers earth, especially between 0.14 and 0.30 $g.l^{-1}$. Above 0.6 $g.l^{-1}$, no reduction in basal filtration rate occurred. He feels turbidity restricts its presence.

Table 28 (continued)

Busycon sp.	Clayton (1974) noted that whelks have long siphons and are adapted to local turbidity caused by its own stirring of mud and sandy bottom.
Nassarius sp.	Kay and Switzer (1974) found *Nassarius* restricted to clear lagoon waters in the Central Pacific.
	Peddicord et al. (1975) found *N. obsoletus* to be unaffected by 100 $g.l^{-1}$ Kaolin after 5 days (see Table 30).
Bivalvia	
* *Yoldia limatula*	Levinton and Bambach (1969) reported that bioturbated layers may cause high juvenile mortalities by fouling feeding apparatus. Adults apparently stabilize themselves in deeper layers.
	Rhoads (1963) reports that *Yoldia* is responsible for much of the sediment reworking in Long Island Sound. Adult organisms not affected by ensuing turbidity.
Crassostrea virginica	Loosanoff (1961) reported concentrations of 0.1 $g.l^{-1}$ reduced pumping rate. Silt affected egg development at 0.25 $g.l^{-1}$ and larval development at 0.75 $g.l^{-1}$.
	Loosanoff and Tommers (1948) found pumping rate decreased at 0.1 $g.l^{-1}$ silt and beyond.
	Hsiao (1950) indicated more turbid water increases irregularity in respiratory/feeding movements of shells. They died if settled silt covered them for more than 2 days.
	Davis (1960) indicated larval growth impaired at 0.75 $g.l^{-1}$ silt and died at 3.0 $g.l^{-1}$. (See also Loosanoff, 1961).
	Chiba and Oshima (1957) found pumping rates was not affected by concentrations of 0.5 to 1.0 $g.l^{-1}$ in *Ostrea gigas*.
Mercenaria mercenaria	Rice and Smith (1958) reported short-term effects on food removal efficiency.
	Davis (1960) reported normal egg development in silt concentrations up to 0.75 $g.l^{-1}$.
	Davis and Hidu (1969) indicate larvae pack stomach with small ingested particles of Kaolin and Fullers earth and die.
* *Mulinia lateralis*	Levinton and Bambach (1969) indicated high juvenile mortality in bioturbated layers. Adults stabilize in deeper layers.
	Saila et al. (1972) indicated *Mulinaria* reached through 21 cm of sediment.
* *Tellina* sp.	Moore (1977) cites Barnett as communicating that body weight and size decreases in turbid waters.
Macoma bathica	Purchon (1937) stated the species may be restricted to clearer waters.
	Moore (1977) and Saila et al. (1972) indicate that these deposit feeding tellinacea as a group

Table 28 (continued)

	appear turbidity tolerant.
* *Gemma gemma*	Shulenberger (1970) reported that catastrophic burial of *Gemma* by up to 230 mm sand and 57 mm silt is survived for periods up to 6 days. (See also Sellmer, 1967).
* *Mya arenaria*	Purchor (1937) indicates survival for limited times in high turbidity (11 days at 1.25 $g.l^{-1}$ mud and 15 days at 1.52 $g.l^{-1}$ chalk). Also present in normally turbid waters.
	Bousfield and Leim (1960) indicate presence in highly turbid waters.
Cephalopoda	
Loligo sp.	Hoese (1973) indicates closely related in-shore species *Loliguncula brevis* prefers intermediate turbidities (70-90% light transmission) while offshore (Georgia, USA) species *Doryteuthis plei* limited to waters with at least 90% light transmission.
Echinodermata	
Asterias sp.	Moore (1977) indicates *A. rubens* inhabits turbid waters.
	Zafiricu (1972) suggested turbidity may affect detection ability of prey in *A. rubens*.
Ectoprocta	
Alcyonidium sp.	Moore (1973d, 1977) indicates this bryzoan species largely confined to turbid waters.
Amathia sp.	Knight-Jones and Jones (1955) indicated *A. lendigera* appears to inhabit turbid waters.
Electra sp.	Moore (1973) indicates *E. pilosa* ubiquitous in turbid waters.

Table 29. Critical concentrations of Kaolin ($g.l^{-1}$) for 10 (LC 10), 20 (LC 20) and 50 (LC 50) percent mortality of some invertebrates exposed for 200 h (10 days). From Peddicord et al. (1975). Closest Lower Bay relative in parentheses.

SPECIES	LC 10	LC 20	LC 50
Mytilus californianus (*Mytilus edulis*)	26	42	96
Crangon nigromaculata (*Crangon septemspinosa*)	16	28	50
Palaemon macrodactylus (None)	24	77	(not reached)
Cancer magister (*Cancer irroratus*)	10	18	32
Anisogammarus confervicolus (*Gammarus* sp.)	17	35	55
Neanthes succinea (Same)	9	22	48

Table 30. Comparison of the mortalities at 10) g.l^{-1} Kaolin of relatively insensitive invertebrate species. From Peddicord et al. (1975). Closest Lower Bay relative in parentheses.

SPECIES	EXPOSURE TIME (Da.)	% MORTALITY
Strongylocentrotus purpuratus	9	0
(*Arbacia punctulata*)		
Crangon franciscorum	5	25
(*Crangon septemspinosa*)		
Pagurus hirsutiusculus	12	0
(*Pagurus pollicaris*)		
Sphaeroma pentodon	12	0
(*Cyathura polita*)		
Nassarius obsoletus	5	0
(same)		
Tapes japonica	10	0
(none)		
Mytilus edulis (2.5 cm)	5	10
Mytilus edulis (10.0 cm)	5	0
Mytilus edulis (10.0 cm)	11	10
(same)		
Mogula manhattensis	12	9
(same)		
Styela montereyensis	12	10
(*Mogula* sp.)		

suspended sediment concentrations ranging from 9 to 100 $g.l^{-1}$, far greater than those projected by the plume model. There appears to be some evidence that prolonged exposure for a week or so increases mortality, provided the stimulus is continuous. Mining operations in the Lower Bay will probably not be continuous for that length of time. As suggested earlier, operations should probably be conducted on ebbing tides so that material is flushed out of the bay system as much as possible. The plume disappears at the change of tidal flow and the ensuing period of inactivity might provide recuperation time. This is purely conjectural, since no studies have been conducted on mortality versus intermittent exposures to suspended sediments.

As noted earlier, larval stages and juveniles would be most affected by suspended sediment levels and toxic interactions. Accordingly, it would make sense to restrict turbidity increases when larval and juvenile abundances are minimal. Stickney (1973) suggests that impacts are reduced if turbidity increases are intermittent. Cronin (1970) indicates that the periods of least total damage from dredging and disposal are in February-March and September-October in Upper Chesapeake Bay. Table 5 notes that copepod zooplankton dominate in the early winter and summer while meroplankton of other invertebrates dominate in the spring and summer. Further, Pfitzenmeyer (1970) indicates winter/early spring as least determinal to benthic populations. Therefore, Cronin's recommendation might also apply to mining/screening operations in the Lower Bay.

Several studies on the effects of suspended sediments on fish have been reported in the literature (Rogers, 1969; Ritchie, 1970; Sherk et al., 1974; Neumann et al., 1975; O'Connor et al., 1976). One interesting effect noted by Stickney (1973) is that fish are attracted to areas where dredging/mining operations are conducted. This is primarily because of the exposure of benthic in fauna, or food. After dredging/spoiling operations have ceased, new populations of invertebrates become established in over a two year period. Initially, these populations may be of a different composition than before. As a result, the fish that tend to dominate the area are those whose food source is still available (Pfitzenmeyer, 1970; Stickney, 1973).

The most comprehensive study of suspended sediment effects on fish that are also found in the Lower Bay is that by Sherk et al. (1974). Table 31 indicates the sensitivities of several fishes. Tolerant species, including *Trinectes maculatus* (hogchoker) and *Rissola marginata* (cusk eel) have not been found locally at the proposed mining sites. However, *Scophthalmus aquosus* (windowpane) and *Ammodytes americanus* (sand lance) are comparable species in appearance and habit. All of these species either burrow into the sediment or live at the sediment surface for much of their time. One would expect that species with this type of existence tolerate some degree of suspended sediments. Note that the concentrations producing only 10% mortality after 24 h exposure (LC_{10}) were in excess of 10 $g.l^{-1}$.

Sensitive species (Table 31) include *Anchoa mitchilli* (bay anchovy) and *Brevoortia tyrannus* (menhaden), two typical estuarine species. Bay anchovies occur relatively frequently in the Lower Bay (see Tables 26, 27), especially during the fall months. Menhaden are less common overall, but are most abundant in the fall and early winter months. A 10% mortality after 24 h exposure occurred in suspended sediment concentrations between 1 and 9.9 $g.l^{-1}$.

Highly sensitive species (Table 31) include juveniles of menhaden and bluefish (*Pomatomus saltatrix*), and adult silversides (*Menidia menidia*). Juvenile menhaden and bluefish are most common during

Table 31. Sensitivity of fish species to suspended mixtures of Fullers earth at 10% (LC 10) mortality. From Sherk et al. (1974). Asterisks indicate local species and/or closely related species found at proposed mining sites in the Lower Bay (in parenthesis).

Tolerant (24 h LC 10 > 10 $g.l^{-1}$)	
	Fundulus heteroclitus
	Fundulus majalis
	Leiostomus xanthurus
	Opsanus tau
*	*Trinectes maculatus (Scophthalmus aquosus)*
*	*Rissola marginata (Ammodytes americanus)*
Sensitive (24 h LC 10 1 to 9.9 $g.l^{-1}$	
	Monrone americana
	Monrone saxatilis
*	*Anchoa mitchilli*
*	*Brevoortia tyrannus*
*	*Micropogon undulatus (Prionotus carolinus)*
*	*Cynoscion regalis*
Highly Sensitive (24 h LC 10 < 0.9 $g.l^{-1}$)	
*	*Menidia menidia*
*	*Pomatomus saltatrix (juvenile)*
*	*Brevoortia tyrannus (juvenile)*
	Monrone americana (juvenile)

ie summer months. Silversides are common the spring and fall months (see Table 14). Sherk et al. (1974) indicate that juveniles of most species are more sensitive than adults. These highly sensitive species were affected by suspended Fuller's earth concentrations less than $0.9\ g.l^{-1}$.

O'Connor et al. (1976) indicate that lethal effects of suspended solids vary with the type of material used. All species tested (same as in Table 31) were less sensitive to natural sediment (Patuxent River, Maryland) suspensions than those of Fuller's earth. Data presented in Table 31 are for Fuller's earth. At most, sensitivity was a factor of 2 less. Rogers (1969) also indicated that the composition of solids induces different effects. Particle shape and angularity were more critical than particle size. However, O'Connor et al. (1976) indicate larger particles had less effect than small ones. Common symptoms in dead fish include hemorrhaging of blood vessels throughout the body surface and packing of the gills and gut with sediment. Further, Rogers (1969) noted that decreased oxygen tensions may be the primary factor responsible for death in test fish. Air bubbling suspensions increased apparent tolerance. Low oxygen effects may also partly explain increased mortality in juvenile fish since they have greater oxygen demands per flesh weight than adults (see e.g., Rogers, 1969). It is now commonly believed that the cause for mortality by suspended mixtures results from anoxia. Sublethal effects are also noted, for example gill damage, and blood chemistry changes (O'Connor et al., 1976; Ritchie, 1970).

It appears that fish species living in estuaries are not strongly affected by suspended sediment concentrations. Many species experience temporary increases in these concentrations due to storm and increased runoff. They also avoid areas with high levels of suspended sediment (Stickney, 1973). Certainly, levels produced by mining/screening operations near the source of suspended sediments may cause some mortality if these levels were maintained for a prolonged period. However, mining periodically would minimize this potential effect as would limiting activity to times of year when fewest numbers of fish are present (winter, early-spring).

SUMMARY

There is relatively little quantitative information on species distribution and abundance in the Lower Bay Complex of New York Harbor. The greatest lack of data exists in seasonal information on abundance and distribution. There is a need for faunal surveys in certain portions of these waters, especially near Staten Island, Romer Shoal, and the East Bank regions.

The Lower Bay region may be characterized as an impoverished one with respect to the number of species found in any one area at a particular time. The same may be said for numbers of organisms per unit area.

The Lower Bay may be characterized as perturbated by a diverse input of pollutants which may have acted in the past (and present) to reduce organism abundance and restrict their distribution.

The presence of several previously mined sand pits on the West Bank region of the Lower Bay may further restrict organism abundance. Since they were mined 7 to 12 years ago, the bottom sediments in these pits have not been recolonized. Instead, they have accumulated large amounts of decaying organic matter. This factor is probably caused by the isolated nature of these holes and a restricted circulation on the West Bank.

There appears to be an undectable impact of mining pits on organism abundance on the East Bank region of the Lower Bay. This is probably due to the generally low species diversity and abundance in the area.

The probable effects of sand mining operations on biota *per se* appear to be minimal. Predicted suspended sediment plumes are long and narrow, with only high concentrations within a few hundred meters of the source. Relatively few species would be killed during removal from the bottom due to the impoverished nature of the bottom biota. Those organisms now present in the region appear to be minimally impacted by suspended sediments. There are a few exceptions, namely juveniles of certain fish species. Potential impacts could be minimized by restricting operations to winter months (November to March).

The impact of sand mining on other factors, e.g. altered circulation patterns, tidal currents and tidal amplitudes, is less clear. Literature information indicates that the presence of mined pits in certain locations of the Lower Bay may amplify currents and tidal amplitudes. Choosing sites for mining should pay special attention to these effects.

Due to the lack of quantitative data on organisms in several regions of the Lower Bay, it is recommended that sites selected in those areas be surveyed for biota on a seasonal basis for a period of time prior to approval of the site for mining.

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APPENDICES

Appendix Table 1. Summary of Walford (1971) data on samples obtained by an 0.1 m^2 Smith-McIntyre grab. Original data converted to $\#/m^2$; *a* and *b* are replicates.

Taxa	Stations											
(31 taxa)	2	5		6		10	12	21		27	28	
		a	b	a	b			a	b		a	b
Hydractinia echinata											20	
Cerebratulus sp.					10	10		10				
Nematoda							60					10
Aricidea jeffreysii									30			
Cirratulidae			10	10	10		10					20
Glycera sp.	20	20	10		10			10	10	10	10	10
Lumbrineris sp.				10								
Nephtys incisa					10	10		10	20		10	
Nereis sp.		10								40	10	10
Orbiniidae					10	10						
Pectinaria gouldii										20		
Phyllodocia sp.											10	40
Polynoidae			10									
Sabellidae			10									
Sabellaria vulgaris		180	1,430							780	1,840	1,380
Spio setosa					10			10			40	110
Streblospio benedicti		50	30									130
Crepidula fornicata		30	100					10		20	20	10
Crepidula plana			210				20	20	10	40	450	30
Nassarius trivittatus	10		30	10						30	60	60
Epitonium sp.											10	10
Tellina agilis	10			90	100		20	40		40	40	60
Mercenaria mercenaria										10	10	
Spisula solidissima							40					

Appendix Table 1 - continued

Taxa	Stations											
	2	5		6		10	12	21		27	28	
		a	b	a	b			a	b		a	b
Balanus improvisus	150	20	30								200	90
Cyathura carinata					10							
Unciola serrata			70		10				10	10	170	160
Pagurus longicarpus			10							10		
Cancer irroratus											10	
Rhithropanopeus texana			30							20	20	
Total # species	4	6	13	4	9	3	5	7	5	12	17	15
Total #/m^2	190	310	1,980	120	180	30	150	110	80	980	2,930	2,130

Appendix Table 2. Qualitative and quantitative distribution of marine invertebrates recorded by Dean and Haskin (1964). x = species obtained from qualitative samples; Q = qualitative sample only; number of grabs taken is under station letter; tabulated values are #/m^2. (- = station not sampled or reported.)

19 June, 2 July, and 20 August (1957)	Stations																		
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
Species	(3 or more)								–	3	3	-	3	–	–	3	–	3	6
Sagartia sp.																21		x	3
Rhynchocoela inident.																		x	
Eteone alba																		3	
Eumida sanguinea																			x
Nereis succinea													9			159		12	48
Nereis sp. A																			x
Polydora ligni													3			24		x	x
Streblospio benedicti													150						x
Lacuna vincta													3						
Modiolus demissus																			x
Mytilus edulis													x						
Macoma sp.													15			9			13
Mya arenaria																6			55
Balanus improvisus										x						660		x	x
Cyathura polita																			13
Ampelisca sp.																3			
Limulus polyphemus													x						3
Total #/m^2									–			-	180	–	–	882	–	15	135
# species quantitative									–			–	5	–	–	7	–	2	6
Total # species	0	0	0	0	0	0	0	0	–	1	0	–	7	–	–	7	–	6	12

Appendix Table 2 - continued

28 July and 15 August (1958)

Species	Stations																		
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
	-	-	-	Q	Q	Q	Q	Q	6	6	6	6	Q	6	Q	3	3	3	3
Sagartia sp.															x	x			x
Turbellaria unident.						x		x								x			x
Eteone alba										x	x	x	x		x		x		x
Nereis succinea						x	x	x	x	x		x	x	3	x	10	10	15	25
Nereis sp. A					x														
Glycera americana									3										
Polydora ligni						x	x	x		x	x	3	x	3	x	10	x	10	x
Streblospio benedicti						x	x			x	x			x	x		x		x
Heteromastis filiformis									5										
Pectinaria gouldi																5			
Urosalpinx cinerea												x							
Macoma sp.									8		13	5		3	x				
Mya arenaria												x	x	120	x	60	20	25	225
Balanus improvisus				x	x	x	x	x	10	x	x	x	x		x	x	x	x	x
Cyathura polita							x									5			15
Ampelisca sp.									3										
Gammarus mucronatus								x				x	x						x
Crangon septemspinosa																5			
Callinectes sapidus																		x	x
Membranipora lacroixi													x		x				
Bugula turrita																x			
Total #/m²	-	-	-						29		13	8		129		95	30	50	265
# species quantitative	-	-	-						4		1	2		4		6	2	3	3
Total # species	-	-	-	1	2	5	5	5	6	5	5	8	7	5	9	10	6	5	11

Appendix Table 2 - continued

20 July (1959)	Stations																		
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
Species	5	Q	6	6	3	–	6	Q	6	6	3	–	3	–	–	3	3	3	6
Sagartia leucolena													x			x	x	x	28
Turbellaria unident.							5	x	x										
Eteone alba								x					x			x	x		3
Nereis succinea					5		8	x	x	x	x		x			5		x	3
Nereis sp. A																	x	x	15
Glycera dibranchiata																			3
Scoloplos fragilis																	5		
Polydora ligni					5		15	x		10	5		x				5	10	50
Spio setosa											5							10	8
Streplospio benedicti													x			10			35
Tharyx sp.																			8
Pectinaria gouldi											20					5			5
Lacuna vincta											5								
Nassarius obsoletus																			10
Acteon punctostriatus																			3
Macoma sp.									10	3	20								
Ensis directus																			3
Mulinia lateralis																	5	10	30
Mya arenaria										3	10		290			14,200	2,500	12,400	8,458
Balanus improvisus					15		140	x	5	75	10					x	x	5	20
Cyathura polita					150		15	x	x							15		5	8
Edotea triloba																x			3
Gammarus mucronatus																x			x
Rhithropanopeus harrissi					x		8												

Appendix Table 2 - continued

20 July (1959) - continued	Stations																		
Species	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
Limulus polyphemus																		5	
Membranipora lacroixi													x			x	x		
Molgula manhattensis											x					x	x		
Total #/m²					175	-	191		15	94	75	-	290	-	-	14,245	2,515	12,445	8,696
# species quantitative					4	-	6		2	5	7	-	1	-	-	6	4	7	19
Total # species	0	0	0	0	6	-	6	7	6	6	10	-	7	-	-	13	11	10	20

Appendix Table 2 - continued

10 August (1960)	Stations																		
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
Species	-	6	6	-	6	-	-	-	6	-	3	-	3	-	-	-	-	-	6
Hydroid unident.													x						
Sagartia leucolena																			10
Anemone unident.													x						
Turbellaria unident.													x						
Nereis succinea													5						
Polydora ligni													x						15
Polydora sp.					130														
Spio setosa																			3
Spio filicornis									15										
Streblospio benedicti																			5
Tharyx sp.																			3
Amphicteis gunneri					3														
Acteon punctostriatus																			3
Macoma sp.									8				25						5
Mya arenaria									3				55						1,238
Balanus improvisus					568								x						
Cyathura polita		20	140		75				3		5								28
Crangon septemspinosa									3										
Rhithropanopeus harrisii					5				15										

Appendix Table 2 - continued

10 August (1960) - continued									Stations										
Species	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
Bugula sp.																			3
Bowerbankia gracilis					5														
Total #/m²	-	20	140	-	786	-	-	-	47	-	5	-	85	-	-	-	-	-	1,313
# species quantitative	-	1	1	-	6	-	-	-	6	-	1	-	3	-	-	-	-	-	10
Total # species	-	1	1	-	6	-	-	-	6	-	1	-	8	-	-	-	-	-	10

Note: Some genera listed by Dean and Haskin have since been changed. - *Neanthes* = *Nereis*; *Cistenides* = *Pectinaria*; *Haploscoloplos* = *Scoloplos*; *Carcinogammarus* = *gammarus*.

Appendix Table 3. Distribution and abundance of the 30 most prevalent species encountered in Dean's Raritan Bay Macrobenthos Survey, 1957-1960. Numbers given are the density per square meter; P = present in qualitative samples or species identified but not counted. Dean's original Table 4 has been reworked to yield station totals of the number of individuals per square meter, the number of species in quantitative determinations and the total number of species. These totals include those listed for each station in Dean's Table 5 (see Appendix Table 4. Unidentified species not included.) Numbers in parentheses beside station numbers = number of grab samples obtained. Stations 1-33 were sampled by van Veen and the rest by Smith-McIntyre grabs. A Q beside the station number indicates quantitative sample by other means.

Taxa	No. Sta. Where Found in Quant. Samples	Total No. Sta. Where Found	1957 Stations (all Raritan Bay) 1(3)	2(3)	3(3)	4(3)	5(3)	6(3)	7 (3)	23 (3)	24 (3)	25 (3)
Microciona prolifera	4	60					P		P			P
Haliplanella luciae	9	59										
Lepidonotus squamatus	4	41										P
Eteone lactea	25?	83		3				P	3	3		P
Eumida sanguinea	25	86				P					P	P
Nereis succinea	76	145	P	6	3		6		9	30	6	P
Nereis virens	28	42										
Glycera americana	57	59										3
Glycera dibranchiata	39	47				P				P		
Scoloplos fragilis	44	48	3									3
Polydora ligni	86	134	75			9		3		P		
Spio setosa	47	50					3					3
Streblospio benedicti	31	65										
Heteromastus filiformis	53	53	7									
Pectinaria gouldii	55	56										6
Crepidula fornicata	16	48										
Nassarius obsoletus	90	100										P
Nassarius trivittatus	41	45										
Mercenaria mercenaria	40	64	6									6
Ensis directus	78	79	15						3			P
Mulinia lateralis	78	79	18								3	
Mya arenaria	157	180	30			6	3		6	9	210	P
Balanus improvisus	34	97				P	9	P	P	P		P
Ampelisca sp.	101	125	1800	174	21	6				3	120	13200+
Unciola serrata	44	56		P								3
Cyathura polita	51	54						3				30
Callinectes sapidus	2	53	P	P		P		P				P
Limulus polyphemus	3	74	P	P			P	P	P			
Conopeum reticulum	14	55						P				
Molgula manhattensis	17	53		P				P				3
Total #/m^2			1960	183	24	21	21	15	78	45	339	13257+
# Species quantitative			9	3	2	3	4	4	5	4	4	9
Total # Species			14	8	2	7	6	11	8	7	5	25

Appendix Table 3. (cont'd.)

Taxa	26(3)	27(3)	28(3)	29(3)	30(3)	31(3)	32(3)	33(3)	34(3)	35(3)	36(3)	37(3)	38(3)	39(3)	40(3)
	1957 Stations (All Raritan Bay)														
Microciona prolifera					P	P	P	P	P			P			
Haliplanella luciae						P		P	15	P	P	P	P	10	P
Lepidonotus squamatus	P					P		P	P	P					P
Eteone lactea	3											P			
Eumida sanguinea	9	45	P		P	P	P	P	5	15					
Nereis succinea	P	78	P		5	P	P	10	40	5	P	10	P	5	P
Nereis virens															
Glycera americana	3			7	10	5	15	5		5			5		5
Glycera dibranchiata										5		5	5	10	P
Scoloplos fragilis	3		3	4	P							5		P	P
Polydora ligni	9	P			P							5	P	25+	P
Spio setosa		12												5	10
Streblospio benedicti													P	10	P
Heteromastus filiformis				4	5	10									10
Pectinaria gouldii	6		3			25	25			5	25	5	5		40
Crepidula fornicata										45	5				
Nassarius obsoletus			6	14		20									
Nassarius trivittatus															
Mercenaria mercenaria			3	P	10		5				5	5	P		
Ensis directus															
Mulinia lateralis			12	84		250	5				5	20			
Mya arenaria	3		9	95	15	250	P		10	60	10	75	350	275	25
Balanus improvisus	P	321							445	215	10	30	5		
Ampelisca sp.	3		60	42+	20	30	700	80	15	60	5			5	30
Unciola serrata		519		3	P	3		45	50	350	10	5		5	
Cyathura polita	15	6		7			5	5		15	5			5	5
Callinectes sapidus		P				P	P	P			P			P	P
Limulus polyphemus			P	P								P		5	P
Conopeum reticulum							P								
Molgula manhattensis	P	P	P						P	30	P	5		P	
Total #/m^2	63	1044	99	275	65	593	765	165	615	880	80	180	385	360+	140
# Species quantitative	12	11	8	12	6	8	8	8	10	14	9	13	6	11	9
Total # species	21	18	17	15	13	18	16	21	15	17	13	18	11	14	19

Appendix Table 3. (cont'd.)

Taxa	1957 Stations (All Raritan Bay) 41(3)	42(3)	43(3)	45(6)	46(6)	47(6)	48(6)	49(6)	50(6)	51(6)	52(6)	53(6)	55(6)	56(6)	57(6)
Microciona prolifera				P					P						
Haliplanella luciae	P			P	P		P		P		P	18			P
Lepidonotus squamatus	5					P									
Eteone lactea												5			5
Eumida sanguinea	5				P			P			8	8			13
Nereis succinea	P	P	P	2	P	P	13	28	15	8	10	145	13	P	15
Nereis virens							3	P	3	3	8				
Glycera americana	5	10													
Glycera dibranchiata	5				3	15	3				3	5			
Scoloplos fragilis		10		2											
Polydora ligni	5									3	55	8	P	P	
Spio setosa									3						P
Streblospio benedicti												3			P
Heteromastus filiformis															
Pectinaria gouldii	5	5		15	15	30	23	5	8		5			23	3
Crepidula fornicata							P						P		5
Nassarius obsoletus	15	15		P	P			3					3	5	8
Nassarius trivittatus	5		P							3				8	
Mercenaria mercenaria	P	5	P	2											3
Ensis directus	5														
Mulinia lateralis			20			5		8	13	5	10	3	55		
Mya arenaria	25	P	5	2		3	43	45	93	100	175	28	48	P	
Balanus improvisus	P		P	P	P	P	P					325			90
Ampelisca sp.	90	10500	800	33	40	18	5	30	3	33		10	3	P	P
Unciola serrata						P									
Cyathura polita		15													
Callinectes sapidus					P	P	P						P		
Limulus polyphemus	P	P	P		P		P	P					P		
Conopeum reticulum															
Molgula manhattensis	10			P	3	P	13	P	P	5	3	170	P	P	20
Total #/m^2	190	10550	845	61	67	77	103	122	138	163	277	741	128	36	173
# Species quantitative	14	7	4	9	6	7	7	7	7	9	9	15	7	3	11
Total # species	19	13	13	15	17	15	14	15	11	9	10	16	12	10	17

Appendix Table 3. (cont'd.)

Taxa	1957 Stations (All Raritan Bay) 58(6)	59(6)	60(6)	61(6)	62(6)	63(6)	64(6)	65(6)	66(6)	67(6)	68(6)	69(6)	1958 Stations 101(6)	102(6)	103(6)
Microciona prolifera												P			
Haliplanella luciae	P						P	P	3				P		
Lepidonotus squamatus							P								
Eteone lactea															P
Eumida sanguinea	P					P	P					P	P		P
Nereis succinea	P	10	5	3	8	8	3	10		8	5	8	P	3	P
Nereis virens				8		3			8		5				
Glycera americana										3					
Glycera dibranchiata	8		P	P	3		P					P	5	8	8
Scoloplos fragilis				3	3										
Polydora ligni		P				P	P	P	3		3		5	3	P
Spio setosa			3										3	3	
Streblospio benedicti				3				5			P				
Heteromastus filiformis														3	
Pectinaria gouldii				10	10		20	40	13	5		30			
Crepidula fornicata															
Nassarius obsoletus	3	3	3						3			3		3	
Nassarius trivittatus									3		5	8			
Mercenaria mercenaria	5													5	
Ensis directus	3			3									P	5	
Mulinia lateralis		3	25	5	10		P	3	50	40	45	10			3
Mya arenaria		5	28	153	138	25	15	148	135	90	45	25	73	10	100
Balanus improvisus					P	P		18				3	P	P	28
Ampelisca sp.	P			5	5	5	P	3	P		3	28		3	
Unciola serrata												P	8	5	3
Cyathura polita								3						40	
Callinectes sapidus					P	P			P		P	P		P	
Limulus polyphemus			P		P	P		3	P		P	P		P	
Conopeum reticulum													3	P	3
Molgula manhattensis	P			P	P	P	18	P			P	P			
Total #/m^2	24	21	74	196	178	41	59	241	218	146	111	123	1408[1]	100	385
# Species quantitative	5	4	5	10	8	4	5	11	8	5	7	10	8	15	7
Total # species	12	5	7	15	13	13	15	17	12	5	12	19	17	21	15

[1] *Gemma gemma* = 1308/m^2

Appendix Table 3. (cont'd.)

Taxa	1958 Stations (All Raritan Bay) 104 (6)	105 (6)	106 (6)	107 (6)	108 (6)	109 (6)	110 (6)	111 (6)	112 (6)	113 (6)	114 (6)	115 (6)	116 (6)	117 (6)	118 (6)
Microciona prolifera	P		P		P	P	P	P		P	P	P	P	P	P
Haliplanella luciae		P	P												
Lepidonotus squamatus											P		3		
Eteone lactea					P			P			P	P	P	P	P
Eumida sanguinea	P		P					P		P		P	3	P	
Nereis succinea	10	3			P		P	P		5	P		5		P
Nereis virens															
Glycera americana			5	3			3			3	10	10		13	3
Glycera dibranchiata		3													
Scoloplos fragilis			3			3			5		3			10	
Polydora ligni	P	P	3	P	3	10	15	5	3	8	5	3	50+	5	25
Spio setosa				3											
Streblospio benedicti								P		P	5	P	5	P	
Heteromastus filiformis	3	5	10	3		3		5	3		3	3		8	3
Pectinaria gouldii							3				5	18			
Crepidula fornicata				P						P					
Nassarius obsoletus	5	3		10	13		15	10		10	35	28	18	25	15
Nassarius trivittatus					3	3		8	3			10			
Mercenaria mercenaria			P		P	P		3	3	3	3	8		8	
Ensis directus				3	8		1/4		3	8		13	8	20	
Mulinia lateralis	3	3		3		5				3		5		3	
Mya arenaria	145	85	255	110	40	23	20	18	43		178	175	15	35	23
Balanus improvisus	P			P	15	P				103	P		15	P	80
Ampelisca sp.	P	18+	5	13	3		8	3	10		5	30		75	5
Unciola serrata		P	P										18		
Cyathura polita				15	10							15	3		
Callinectes sapidus		P													
Limulus polyphemus		P			P				P						
Conopeum reticulum		P	P	P	P	P	P			P		P	3		P
Molgula manhattensis	P														
Total #/m^2	172	171+	284	166	98	58	69+	61	75	177	252	339	168+	223	163
# Species quantitative	7	9	7	10	9	8	8	10	9	12	10	15	18	13	9
Total # species	15	17	18	14	17	14	13	18	10	21	17	26	25	24	18

Appendix Table 3. (cont'd.)

Taxa	132(3)	133(3)	134(3)	135(3)	136(6)	137(3)	138(3)	139(6)	140(6)	141(6)	142(3)	143(3)	144(3)	145(3)	146(3)
	1958 Stations (All Raritan Bay)														
Microciona prolifera				P		P	P								
Haliplanella luciae				P	P	P	P		P	P					P
Lepidonotus squamatus				P	P	P	P	P							P
Eteone lactea				P	P	P	P	5	3	P		P			P
Eumida sanguinea			P	P	P	P	P	P	5	P					
Nereis succinea	5		P	P	5	P	P	3	3	P		10			35
Nereis virens														5	15
Glycera americana			5	15											
Glycera dibranchiata									15	3					
Scoloplos fragilis				5		5									
Polydora ligni	5		30	15	33+	10	40	75	58	P	5	P	10	P	15
Spio setosa	5		5		3			3	3	10	5	10	5		
Streblospio benedicti			P			P		10	P			P			
Heteromastus filiformis			5	5	3	5									
Pectinaria gouldii			15			5									
Crepidula fornicata					83	P		3	50	P					
Nassarius obsoletus	15		60	30	8	P		5	25	5		10			130
Nassarius trivittatus			20	5		15			8						
Mercenaria mercenaria			15	P			P	3							
Ensis directus				5	18	10		5	3	30			5		
Mulinia lateralis						5		8	5	5			5		
Mya arenaria	20	5	70	10	53	50	90	168	483	55	15	70	1120	755	70
Balanus improvisus	P				33	P	P	P	545	23	5	P	P	P	218
Ampelisca sp.				10	3	100	10	13	P			10			
Unciola serrata				P	30	P		53	28						10
Cyathura polita					8	P				3			10		
Callinectes sapidus			P		P	P				P	P	P	P		P
Limulus polyphemus				P	P	P	P			P		P	P		P
Conopeum reticulum			P	P	3	P	P	3	3	P					
Molgula manhattensis					P			P			P				P
Total #/m^2	50	10	225	105	336+	205	200	362	1261	137	45	100	1160	760	493
# Species quantitative	5	2	9	10	21	9	7	21	20	9	6	4	7	2	7
Total # species	7	3	14	22	34	36	20	30	25	19	9	10	10	7	18

Appendix Table 3. (cont'd.)

Taxa	147(3)	148(3)	149(3)	150(3)	151(3)	152(3)	153(3)	154(3)	155(3)	156(3)	157(3)	158(3)	159(3)	160(3)	161(3)
	1958 Stations (All Raritan Bay)														
Microciona prolifera			P					P			P		P	P	
Haliplanella luciae				P	5			P							
Lepidonotus squamatus															
Eteone lactea	P			P		P	P	P							
Eumida sanguinea				P			P								
Nereis succinea	P			P	5	10	P	5	5					5	5
Nereis virens	5	10	10	15					5	20	40	P	5		P
Glycera americana								5							
Glycera dibranchiata						10	10				5				
Scoloplos fragilis					10					P				5	
Polydora ligni	25	5		20	5	P	5	P	P	P	P		5	15	
Spio setosa									5	20	5				
Streblospio benedicti			P				P		P						
Heteromastus filiformis							5	5							
Pectinaria gouldii															
Crepidula fornicata															
Nassarius obsoletus				70	105	15	40	15	20	P			20	20	15
Nassarius trivittatus															
Mercenaria mercenaria															
Ensis directus	10	5	10		5	5			30	10	10			5	
Mulinia lateralis			10												5
Mya arenaria	265	570	320	225	665	80	45	160	80	840	1640	100	220	15	50
Balanus improvisus				225	P	P	P	P	P		P		P		
Ampelisca sp.							5	10		5	P		P		
Unciola serrata				5	5				P						
Cyathura polita					5										
Callinectes sapidus	P	P	P					P		P	P	P	P	P	
Limulus polyphemus	P	P	P	P				P			P				
Conopeum reticulum					5	P		P	P						
Molgula manhattensis	P			5	5		P								
Total #/m²	305	605	350	575	830	175	115	210	270	900	1715	100	255	65	75
# Species quantitative	4	6	4	9	13	10	7	8	10	6	7	1	5	6	4
Total # species	12	8	9	17	18	17	14	20	21	10	14	3	9	8	5

Appendix Table 3. (cont'd.)

Taxa	(Raritan Bay) 162(3)	164(3)	165(3)	166(6)	1958 Stations (Lower Bay) 167(Q)	168(Q)	169(Q)	170(Q)	171(6)	172(3)	173(6)	174(3)	175(3)	176(6)	177(3)
Microciona prolifera	P	P	5					P	P				P		P
Haliplanella luciae	P					P									
Lepidonotus squamatus	P				P	P		P	15	P	P	P	P	P	
Eteone lactea	P		P	13		P		P			3	20	P	3	P
Eumida sanguinea	P	P	P	P	P		P	P	5	P	3	10	P	3	
Nereis succinea	P	P	P		P	P	P	P	8	5	3	10	P	5	P
Nereis virens				P			P		15					P	
Glycera americana			5	18			P			40	5	20	30	3	
Glycera dibranchiata															
Scoloplos fragilis			5	8								5			
Polydora ligni	10	P	10	53	P	P	P	P	28	15	3	30+	P	5	P
Spio setosa	5			35							5	5			
Streblospio benedicti	P	5	P	305		P	P	P		P		10		P	P
Heteromastus filiformis			10	28					3				5		5
Pectinaria gouldii		5		20						5					5
Crepidula fornicata	P	P			P	P	P		5	P	P	5	P	P	
Nassarius obsoletus	15	20	25				P								P
Nassarius trivittatus			5	3			P		5	10		5	20	10	5
Mercenaria mercenaria	P		5												P
Ensis directus		5		38					3	10	8	25	15	28	
Mulinia lateralis		5		330					5				20		370
Mya arenaria	25	60	45	53	P				5		3	15	80	3	5
Balanus improvisus	P	P		P	P	P		P	P		P	P		3	
Ampelisca sp.	5	5	P									10	55	3	5
Unciola serrata								P	3		25	30	P	3	
Cyathura polita	20	5	45							5	13				P
Callinectes sapidus	P								18		3				P
Limulus polyphemus	P		P			P									P
Conopeum reticulum	P	P	5		P	P				P	3	P	P		
Molgula manhattensis									P	P				P	
Total #/m²	85	110	170	1835[1]	---	---	---	---	5032+[2]	135	114	290+	295	128	420
# Species quantitative	7	8	12	23	0	0	0	0	37	12	20	21	13	21	11
Total # species	26	22	22	29	16	23	20	22	44	27	29	31	28	33	20

[1] *Spisula solidissima* = 802/m²
Tellina agilis = 510/m²

[2] *Spisula solidissima* = 1373/m²
Mytilus edulis = 2960 +/m²

Appendix Table 3. (cont'd.)

Taxa	(Lower Bay) 1958 Stations		(Lower Bay)			1959 Stations (Raritan Bay)									
	178(3)	179(6)	210(6)	211(6)	212(6)	213(3)	214(3)	215(3)	216(3)	217(6)	218(6)	219(3)	220(6)	221(6)	222(6)
Microciona prolifera						P	P	P	P	P	3	P			
Haliplanella luciae						P		P		P	P	P			
Lepidonotus squamatus															
Eteone lactea				P		P	P	5	P	P	P	10		3	P
Eumida sanguinea				P			P	P				P			P
Nereis succinea		5		3		P	P		5	P	15	P		8	3
Nereis virens				3							P				
Glycera americana	10					5	P				3	5			
Glycera dibranchiata			13	27	20				15					10	18
Scoloplos fragilis					3			5			3				
Polydora ligni		10		10		P	P	P	P		P	P			P
Spio setosa		3						5					3		13
Streblospio benedicti		3			3	P	P	55	P	5	10	30			3
Heteromastus filiformis	25	5				25	155		5	5					
Pectinaria gouldii	25	5		3											
Crepidula fornicata	P	P		P										P	
Nassarius obsoletus			48	5				15	45		20	10		65	35
Nassarius trivittatus		10	5												
Mercenaria mercenaria	P	13	5	5		5					P				
Ensis directus		5											23	5	
Mulinia lateralis	35	8											3	8	
Mya arenaria		5	93	3	85	20	5	75	75	10	1120	1440	453	13	85
Balanus improvisus				P	P		5					5			
Ampelisca sp.	45	67	3	73	3	45	10	15	25		10	30	13	3	
Unciola serrata		15	8					P							
Cyathura polita				25		5	5		5			40			
Callinectes sapidus		P		P	P					P	P				
Limulus polyphemus	P	P	P		P	P	P	P						P	
Conopeum reticulum		3			3										P
Molgula manhattensis															
Total #/m^2	160	208	63701[1]	163	263	120	180	175	200	28	1184	1575	498	121	157
# Species quantitative	8	20	10	12	9	7	5	7	9	5	8	9	6	10	6
Total # species	12	25	11	17	12	19	12	13	13	15	16	14	6	13	14

1 Gemma gemma = 63,520/m^2

Appendix Table 3. (cont'd.)

Taxa	223(3)	224(6)	225(6)	226(6)	227(3)	228(3)	229(6)	230(3)	231(6)	232(6)	233(6)	234(6)	235(6)	236(Q)	237(6)
	1959 Stations (All Raritan Bay)														
Microciona prolifera	P									P		P	P	P	P
Haliplanella luciae				P						P				P	
Lepidonotus squamatus										P			P	P	P
Eteone lactea	P	P		P	P			P		P			P	P	P
Eumida sanguinea	P									P			P	P	P
Nereis succinea			3	P				P	P	P	P	P	P	P	P
Nereis virens		3	8	P	10		5	P							
Glycera americana										3	3	5	18		13
Glycera dibranchiata				3											3
Scoloplos fragilis			3							3		3	10		13
Polydora ligni	P			P	P			P	3	3	P	40	120	P	43
Spio setosa															5
Streblospio benedicti	P	3			P		3					40			5
Heteromastus filiformis										3	5	160	80		13
Pectinaria gouldii		3	3		P							8	3		
Crepidula fornicata				P				P				P	P		P
Nassarius obsoletus	35		5	10	20			5	P	8	18	8	33		75
Nassarius trivittatus										3		3	3		5
Mercenaria mercenaria								P		P	8	3		P	3
Ensis directus		23	20		10	20	20				10	80	13		73
Mulinia lateralis			3			5	10				3	120			53
Mya arenaria	1440	1400	252	420	1840	560	790	P	P		5	1400	83		3
Balanus improvisus	P		P		P			P	P	P	P		P		
Ampelisca sp.								P	3	3	13	200	640	P	153
[illegible] serrata														P	3
Cyathura polita						5									5
Callinectes sapidus										P					P
Limulus polyphemus	P		P		P	P			P	P	P	P			
Conopeum reticulum				P				P		P	P		P		
Molgula manhattensis															
Total #/m^2	1475	1435	297	436	1880	590	828	10	9	31	68	2201	1249	---	603
# Species quantitative	2	6	8	4	4	4	5	2	3	8	9	18	15	0	21
Total # species	9	7	12	13	11	5	5	13	9	21	18	24	30	21	33

Appendix Table 3. (cont'd.)

Taxa	Raritan Bay					1959 Stations					Lower Bay				
	238(3)	239(3)	240(6)	241(3)	242(3)	243(6)	244(6)	245(6)	246(3)	247(3)	248(3)	249(6)	250(6)	251(6)	252(6)
Microciona prolifera			P	P											
Haliplanella luciae			5	P		3	P								
Lepidonotus squamatus	P		P			P							P	P	
Eteone lactea	5	P	3	P		10	3	3	P	P			8	P	50
Eumida sanguinea	5		3	P		P	P						P	P	P
Nereis succinea	5	P	P	P	P	3			P				P		
Nereis virens									P	20			P	P	
Glycera americana	20	5		5							5	18	20	40	3
Glycera dibranchiata			5			3	3	10							5
Scoloplos fragilis					5										
Polydora ligni	250	50+	15+	P	20	50+	5		P		10	5	33	30	358
Spio setosa				5	5			3					20		
Streblospio benedicti	10				15								8	P	13
Heteromastus filiformis		5						3				3			
Pectinaria gouldii	10											8			
Crepidula fornicata	P		18		P		P						5	5	
Nassarius obsoletus	150	55	35	15	20	15	5	30		P					
Nassarius trivittatus							3						8		5
Mercenaria mercenaria	19	10	5	10								P	3	P	5
Ensis directus	5		8			18		63	50	5	5	3	33	15	18
Mulinia lateralis				35	30			23	115	5			5	5	
Mya arenaria	70	P	168	1440	1330	205	30	400	300	455	495	P	55	35	105
Balanus improvisus			8			P	3	3	35				3	P	
Ampelisca sp.	160	P	35	110	40	3		3				5			
Unciola serrata	15		3			13	5	5					53	5	3
Cyathura polita	5		3											15	3
Callinectes sapidus												P			
Limulus polyphemus				P	P		P	P	5			P	P		P
Conopeum reticulum				P		3	3						P	5	
Molgula manhattensis														45	
Total #/m²	735	135+	331+	1625	1445	342+	50	549	505	485	515	55	364	320	606
# Species quantitative	16	7	18	8	10	15	10	12	5	4	4	9	27	16	20
Total # species	19	13	25	17	15	23	15	13	10	6	4	14	38	29	26

Appendix Table 3. (cont'd.)

Taxa	Lower Bay						1959 Stations					Raritan Bay			
	253(3)	254(6)	255(3)	256(3)	257(6)	258(3)	259(3)	260(3)	261(3)	262(3)	263(3)	264(3)	265(3)	266(3)	267(6)
Microciona prolifera			P							5	P	5		P	
Haliplanella luciae							P	P	P	P	P				
Lepidonotus squamatus		P	P								P				
Eteone lactea	10	23	20						P	P	P		P		P
Eumida sanguinea	5	3	P		3						5	P	P	P	
Nereis succinea	P	3	5	P			P		P	5	5	P	P	5	P
Nereis virens				P			P								
Glycera americana		8	50								10				
Glycera dibranchiata	P														
Scoloplos fragilis		8		P										5	
Polydora ligni	105+	130	155+				5		P	30	5	P	P	25	P
Spio setosa	15	3	5												
Streblospio benedicti		P	5		3				P		10	P		P	P
Heteromastus filiformis			5								5	5			
Pectinaria gouldii		5	15												
Crepidula fornicata	P	P	P								P			P	
Nassarius obsoletus							5			10	P	25	5	10	
Nassarius trivittatus	20	8	45					5			P			P	3
Mercenaria mercenaria		10									5	P	P	P	P
Ensis directus		25	45		3	10	55		5		5	10	40		
Mulinia lateralis		18	10	70	20	60	100	20	175	40	35	90	30	5	
Mya arenaria	75	48	21760	1000	2150	3320	4000	45	1240	2475	12160	5920	335	35	5
Balanus improvisus	260	P	P				P			1475		P		5	P
Ampelisca sp.			35			5				5	110	105	30	40	
Unciola serrata	P	5	20							P					
Cyathura polita	5	5									20			5	
Callinectes sapidus						P			P						
Limulus polyphemus					P						P	P			
Conopeum reticulum	P	P	P						P					P	
Molgula manhattensis		P	5						P	5					
Total #/m^2	62580+[1]	341	22215+	1070	2187	3395	4175	70	1445	4050	12390	6170	460	140	11
# Species quantitative	13	23	21	2	7	5	6	3	6	9	15	9	8	9	3
Total # species	25	33	36	5	8	6	10	4	15	13	28	20	16	21	10

1 Gemma gemma = 62,000/m^2

Appendix Table 3. (cont'd.)

Taxa	1959 Stations (Raritan Bay) 283(3)	284(3)	308(3)	309(3)	310(3)	1960 Stations 311(3)	312(3)	313(3)	314(3)	315(3)	(Lower Bay) 316(3)	317(3)	318(3)
Microciona prolifera		P											
Haliplanella luciae		5											
Lepidonotus squamatus													
Eteone lactea		P											
Eumida sanguinea		P	55								25		10
Nereis succinea	5		25			5		20	5	10		20	5
Nereis virens	25	30				20							
Glycera americana			10								35		15
Glycera dibranchiata			30			5		5			20		
Scoloplos fragilis					5	10	10	25			50		65
Polydora ligni	5	P			5		65		25			10	55
Spio setosa			40			5	20					5	35
Streblospio benedicti		5											5
Heteromastus filiformis							5		65		100		40
Pectinaria gouldii	5	15						30	20	15			
Crepidula fornicata			20							5	5		5
Nassarius obsoletus	5	5	45		5	15		50	50	25	80		
Nassarius trivittatus					5						150		40
Mercenaria mercenaria					5				5	5	15		
Ensis directus			25	5		5	5		5	20		5	10
Mulinia lateralis	105	25					20						
Mya arenaria	5760	9880	4000	115	25	2625	1155	2540	755	110	1045	1305	
Balanus improvisus		P	P	P		15							
Ampelisca sp.			10450	10	65	195	300	685	4895	570	7985	30	150
Unciola serrata			1835	5			5				60		
Cyathura polita	10		30			5		85			5		5
Callinectes sapidus													
Limulus polyphemus		D											
Conopeum reticulum													
Molgula manhattensis			P	P			5						
Total #/m^2	5920	9995	17075	145	140	2940	1595	3440	5860	885	9875	1380	680
# Species quantitative	8	8	19	6	9	13	11	8	11	9	19	7	24
Total # species	8	14	22	9	9	13	11	8	11	9	19	7	24

Appendix Table 3. (cont'd.)

Taxa	1960 Stations		(Lower Bay)	
	319(3)	320(3)	321(3)	322(3)
Microciona prolifera				
Haliplanella luciae				
Lepidonotus squamatus		5		
Eteone lactea				
Eumida sanguinea		155	125	
Nereis succinea		10	10	10
Nereis virens				
Glycera americana		30	25	5
Glycera dibranchiata	10			
Scoloplos fragilis	80	15	25	90
Polydora ligni		315	150	50
Spio setosa	5	45	150	5
Streblospio benedicti			5	
Heteromastus filiformis	5	5	40	15
Pectinaria gouldii	20	15		
Crepidula fornicata			85	
Nassarius obsoletus	5			
Nassarius trivittatus		65		
Mercenaria mercenaria		10		
Ensis directus				
Mulinia lateralis				
Mya arenaria	20		10	10
Balanus improvisus				
Ampelisca sp.	5		35	45
Unciola serrata		5	15	
Cyathura polita		25	20	
Callinectes sapidus				
Limulus polyphemus				
Conopeum reticulum		P		
Molgula manhattensis				
Total #/m^2	175	4490[1]	1740[2]	870[3]
# Species quantitative	11	20	22	12
Total # species	11	23	25	13

[1] Mytilus edulis = 4,090/m^2

[2] Mytilus edulis = 670/m^2

[3] Mytilus edulis = 620/m^2

Table 4. Distribution and abundance of the less prevalent species encountered in the Dean's (1975) Raritan Bay Macrobenthos Survey, 1957-1960. In parentheses after each station number is the number of organisms per m^2 or their presence (P) in qualitative samples.

Species Found Principally in Raritan Bay

Species	Station Nos. & Densities
Cerianthus sp.	145(P)
Lepidonotus sublevis	235(P)
Eteone heteropoda	6(3), 213(P)
Podarke obscura	47(P), 61(P), 63(P), 69(P), 141(P), 240(P)
Drilonereis longa	152(5), 154(5), 155(10), 157(5), 212(3), 213(15), 237(3)
Scolelepis squamata	27(3)
Scoloplos armiger	26(3), 40(10), 46(3), 65(3), 106(3), 111(3), 235(3)
Pectinaria hyperborea	117(8), 237(18), 242(5), 246(P), 254(3), 257(5), 259(10), 261(15), 264(5), 266(5)
Pectinaria sp.	53(5), 138(10), 152(5), 155(30), 316(20), 318(5)
Sabella microphthalma	25(P), 26(P), 34(P), 48(P), 49(P), 50(P), 58(P), 65(P), 104(P), 105(P), 106(P), 110(P), 137(P), 138(P), 140(P), 146(P), 150(P), 154(P), 162(P), 164(P), 225(P), 236(P), 264(P), 308(5)
Protula tubularia	137(P)
Littorina littorea	28(P)
Eupleura caudata	115(5), 137(P), 139(5), 155(5), 164(P), 235(P), 239(5)
Busycon carica	164(P)
Retusa obtusa	148(10), 152(5), 212(3), 216(15), 316(40)
Pyramidella fusca	235(40), 308(20)
Odostomia trifida	222(P), 265(P)

Table 4 - continued

Species	Station Nos. & Densities
Odostomia sp.	265(5)
Doridella obscura	27(6), 101(P), 136(P), 139(5), 140(8), 150(P), 162(P), 164(P), 173(P), 217(P), 222(P), 243(P)
Modiolus demissus	64(P), 151(P)
Crassostrea virginica	152(P), 155(P), 168(P), 170(P), 221(P), 255(P)
Petricola pholadiformis	103(P), 116(P), 117(P), 136(P), 237(P)
Balanus eburneus	53(P), 62(P), 63(P), 64(P), 105(P), 146(P), 150(5), 152(P), 164(P), 222(P), 226(P), 227(P)
Stenothoe cypris	139(P), 146(P), 236(P), 240(P), 243(P)
Stenothoe sp.	147(P)
Carinogammarus mucronatus	47(P), 49(P), 53(3), 57(3), 61(P), 65(P), 101(P), 102(3) 103(P), 117(P), 132(P), 136(8), 137(P), 139(P), 140(3), 146(P), 150(P), 151(P), 153(P), 154(P), 165(P), 243(P), 253(P)
Carcinus maenas	27(3)
Eurypanopeus depressus	31(P)
Hexapanopeus angustifrons	111(P), 118(3), 262(P), 263(P)
Rhithropanopeus harrissi	263(P)
Bugula sp.	32(P), 33(P), 46(P), 49(P), 64(P), 66(P), 68(P), 69(P), 106(P), 111(P), 113(P), 116(P), 142(P), 217(P), 233(P)
Amathia vidovici	26(P), 27(P), 42(P)
	Species Common to Raritan and Lower Bays
Cliona sp.	25(P), 32(P), 101(P), 118(P), 136(3), 137(P), 162(P), 170(P), 174(P), 179(P), 217(P), 236(P), 240(3), 263(P), 266(P)
Hydractinia echinata	102(P), 252(P)

Appendix Table 4 - continued

Species	Station Nos. & Densities
Tubularia sp.	26(3), 102(3), 108(P), 109(P), 110(P), 113(P), 118(P), 136(P), 137(P), 139(P), 146(P), 147(P), 152(P), 162(P), 165(P), 171(P), 179(P), 211(3), 213(P), 233(P), 239(P), 242(P), 243(3), 255(P), 263(P), 266(P), 267(P), 308(P), 309(P)
Metridium senile	28(P), 167(P), 261(P), 265(P), 266(P)
Harmothoe extenuata	25(P), 30(P), 31(P), 33(P), 35(P), 106(P), 113(3), 136(3), 139(P), 168(P), 169(P), 170(P), 171(113), 172(P), 175(P), 176(P), 218(P), 230(P), 232(P), 234(P), 235(P), 236(P), 237(P), 240(P), 241(P), 250(8), 251(5), 252(3), 254(3), 255(P), 264(P), 266(P)
Harmothoe imbricata	169(P), 171(10), 176(P), 213(P), 232(P), 235(P), 237(P), 250(3), 255(P)
Paranaitis speciosa	115(P), 135(P), 165(P), 168(P), 170(P), 238(5), 250(P), 252(3)
Exogone dispar	137(P), 138(P), 173(P), 253(P)
Autolytus cornutus	33(P), 136(10), 138(40), 168(P), 171(3), 236(P), 252(5), 254(3)
Nephtys incisa	26(3), 29(7), 34(5), 43(20), 45(2), 58(5), 107(3), 109(8), 110(5), 111(3), 112(5), 113(3), 138(5), 159(5), 177(10), 220(3), 232(5), 233(3), 265(10), 319(15)
Spio filicornis	312(5), 318(5)
Spiochaetopterus oculatus	47(3), 49(P), 61(3), 253(5)
Tharyx sp.	29(4), 33(P), 40(5), 45(3), 46(3), 53(5), 61(P), 105(3), 149(P), 150(5), 151(5), 152(30), 154(5), 155(80), 165(5), 166(3), 171(3), 239(5), 250(3), 255(5), 257(3), 263(5)
Pherusa affinis	41(5), 171(3), 176(3)
Capitellid A	29(4), 115(3), 117(3), 135(5), 137(P), 139(5), 162(P), 166(208), 170(P), 171(5), 174(10), 175(25), 177(P), 213(P), 217(5), 218(P), 219(5), 235(3), 237(8), 238(10), 242(5), 243(3), 250(3), 252(5), 263(5), 264(P), 321(5)
Capitellid B	166(18), 217(P), 240(8), 250(5)
Sabellaria vulgaris	33(10), 34(15), 56(P), 58(P), 101(3), 103(P), 106(P), 115(P), 116(5), 136(5), 139(8), 140(5), 151(P), 155(P), 168(P), 170(P), 171(P), 172(5), 173(8), 174(5), 222(P), 236(P), 243(5), 244(10), 250(8), 251(90), 253(P), 318(5), 320(125), 321(30)

Appendix Table 4 - continued

Species	Station Nos. & Densities
Asabellides oculata	102(3), 104(3), 108(3), 157(P), 166(225), 171(5), 175(5), 176(15), 178(5), 224(3), 250(3), 264(5)
Polycirrus eximius	27(48), 33(P), 34(15), 35(5), 101(P), 116(P), 136(P), 137(P), 138(P), 139(8), 173(5), 174(P), 179(5), 210(3),
Crepidula plana	45(P), 46(P), 57(P), 136(P), 141(3), 155(P), 162(5), 166(P), 167(P), 168(P), 169(P), 170(P), 171(3), 173(5), 174(P), 176(P), 240(P), 244(P), 250(P), 318(5), 320(10),
Lunatia heros	1(P), 28(P), 42(P), 56(P), 113(P), 166(3), 167(P), 176(3), 235(P), 252(3), 254(3), 318(5)
Urosalpinx cinerea	25(P), 26(P), 31(P), 45(2), 46(P), 109(P), 113(P), 114(P), 116(3), 117(P), 118(P), 136(18), 137(P), 139(3), 140(5), 162(P), 167(P), 168(P), 169(P), 174(10), 175(P), 176(3), 230(P), 234(3), 235(P), 240(3), 251(P), 255(P), 320(5)
Busycon canaliculatum	31(P), 114(P), 164(P), 177(P), 233(P)
Retusa canaliculata	178(5), 179(3), 234(80), 235(80), 237(73), 249(5), 252(3), 258(5), 265(5), 267(3), 318(15)
Nucula proxima	55(3), 250(3)
Mytilus edulis	1(P), 2(P), 6(P), 25(P), 28(3), 30(P), 37(P), 43(P), 113(25), 155(P), 166(3), 167(P), 168(P), 169(P), 170(P), 171(2960+), 172(P), 176(P), 221(3), 236(P), 239(P), 242(P), 250(8), 251(5), 252(5), 253(5), 254(3), 255(P), 310(5), 318(70), 320(4090), 321(670), 322(620)
Gemma gemma	27(P), 101(1308), 103(240), 117(P), 179(15), 210(63,520), 212(140), 253(62,000)
Macoma balthica	6(6), 7(57), 38(15), 49(3), 51(3), 63(3), 65(5), 69(3), 105(48), 144(5), 151(5), 156(5), 216(10), 217(3), 221(3), 226(3), 308(25), 309(5), 310(20), 311(15), 314(15), 315(125), 316(85), 317(5), 322(10)
Edotea triloba	37(5), 101(P), 104(P), 106(P), 139(P), 140(P), 151(P), 153(5), 154(P), 155(P), 165(P), 166(P), 168(P), 243(3), 261(5), 262(P), 308(165)
Corophium sp.	33(P), 57(P), 115(P), 116(3), 118(P), 154(P), 174(P), 236(P), 321(230), 322(5)
Crangon septemspinosus	37(5), 46(P), 47(3), 48(P), 55(3), 65(P), 69(5), 104(3), 111(3), 115(P), 118(3), 133(5), 136(3), 142(5), 145(P), 152(10), 157(10), 167(P), 169(P), 179(5), 211(3), 234(5), 250(3), 251(5), 308(35), 309(5), 314(20), 316(20), 319(5), 320(10)

Appendix Table 4 - continued

Species	Station Nos. & Densities
Panopeus herbsti	25(P), 27(P), 28(P), 29(P), 34(P), 40(P), 41(5), 42(P), 43(P), 63(P), 102(P), 103(P), 108(P), 111(P), 113(3), 115(P), 116(P), 117(P), 135(P), 136(P), 137(P), 164(P), 213(P), 217(P), 231(P), 237(P), 238(P), 241(5), 243(P), 263(5), 264(P), 320(45), 321(25)
Bowerbankia gracilis	26(P), 27(P), 28(P), 32(5), 35(5), 43(P), 115(P), 136(3), 137(P), 138(5), 140(3), 147(P), 166(P), 168(P), 171(P), 172(5), 173(3), 174(P), 175(P), 176(P), 179(3), 226(P), 240(3), 251(5), 253(P), 254(P), 255(5), 263(P), 318(5), 320(P), 321(P)
	Species Found Principally in Lower Bay
Eulalia viridis	172(P)
Phyllodoce groenlandica	171(5), 172(P)
Nereis arenaceodentata	27(3), 171(23), 172(P), 173(P), 253(10)
Nephtys picta	166(25), 171(3), 176(3), 210(3?), 250(10), 252(8), 319(5?), 321(5?), 322(5?)
Diopatra cuprea	252(3), 254(3)
Lumbrineris tenuis	33(5), 115(13), 117(10), 118(3), 166(5), 173(5), 174(50), 175(15), 176(3), 177(5), 235(120), 237(33), 250(3), 253(5), 254(18), 255(10, 316(130), 318(115), 321(20)
Spiophanes bombyx	166(15)
Dodecaceria coralii	170(P)
Hydroides dianthus	33(5), 116(5), 170(P), 173( )
Polinices duplicatus	30(P), 43(P), 172(5), 177(10), 178(10), 236(P), 249(3), 251(5), 255(5), 308(5), 316(5), 321(5)
Mitrella lunata	171(158)
Adalaria proxima	171(45), 251(P)
Yoldia limatula	230(5), 231(3), 234(3), 249(5)

Appendix Table 4 - continued

Species	Station Nos. & Densities
Anomia simplex	251(P)
Tellina agilis	166(510), 171(205), 172(15), 175(15), 176(18), 179(20), 234(40), 250(45), 252(P), 254(3)
Spisula solidissima	116(3), 166(820), 171(1373), 172(15), 173(5), 175(5), 176(3)
Balanus crenatus	169(P), 171(53), 172(P)
Haustorius sp.	171(5)
Paraphoxus spinosus	253(65)
Stenothoe minuta	171(3)
Elasmopis laevis	33(P), 170(P), 175(P), 176(5), 235(P), 236(P), 237(P), 252(P), 254(P)
Microdeutopus gryllotalpa	168(P), 170(P), 171(10), 173(P), 174(5), 243(P), 318(5), 320(5), 321(30)
Jassa marmorata	171(20)
Pagurus longicarpus	251(10), 255(5)
Cancer irroratus	167(P), 171(18), 173(3)
Libinia sp.	167(P), 174(5), 178(P), 249(P), 250(P), 253(P)
Arbacia punctulata	171(P)
Asterias forbesi	167(P), 168(P), 169(P), 171(3), 225(P), 251(P), 322(P)
Electra hastingsae	176(3)
Membranipora tenuis	172(P)
Schizoporella unicornis	33(P), 116(3), 169(P), 170(P), 175(P), 176(P), 236(P), 250(P), 254(P), 255(P), 321(P)

Appendix Table 4 - continued

Species	Station Nos. & Densities
Cryptosula pallasiana	155(P), 168(P), 169(P), 172(P), 173(3), 174(P), 175(P), 176(P), 250(3), 251(P), 255(P), 318(5), 320(P), 321(P)
Alcyonidium polyoum	109(3), 116(P), 117(P), 169(P), 171(3), 172(P), 173(P), 174(P), 250(P), 251(P), 253(P), 255(P), 265(P)

Appendix Table 5 . Number of species found in quantitative samples at selected stations which were sampled in Raritan Bay and Lower Bay for three or four consecutive summers, 1957 to 1960. (From Dean, 1975).

		Raritan Bay																Lower Bay					
		Head								Halfway				Lower									
North	Station Number	55	133	261	309					34	137	241	315	32	115	235	316						
	Number Species	7	2	7	5					11	9	7	8	8	15	15	19						
Mid-Bay	Station Number	6	149	228	310	69	160	220	312	41	165	264	314	30	111	231	317	175	255	318	176	250	321
	Number Species	5	4	4	9	10	6	7	10	16	12	9	11	6	9	3	8	13	22	26	22	28	24
South	Station Number	64	151	226	311					39	104	215	313	27	101	210	308				178	249	322
	Number Species	5	13	4	14					12	7	7	8	12	9	10	18				8	9	12

Appendix Table 6. Benthic invertebrate data from Shipek grabs collected by Woodward-Clyde on the East Bank in June, 1975. Data was obtained from their Table C-1 and has been modified to express abundance/m^2 (Shipek area = 0.04 m^2). Notes: Table C-1 data were sum totals of 3 grabs (= 0.12 m^2); not all species reported in Table 4 of this report were obtained in Shipek grabs; 2 species (*Pisione remota* and *Micronephtys minuta*) reported in Table C-1 were not included because of uncertainty of taxonomic status.

	Number of organisms/m^2							
Station No.	1	2	3	4	5	6	7	8
Taxa								
Rhynchocoela spp.			58.3	8.3			8.3	
Nematoda spp.		25.0		8.3	1,366.7			
Oligochaeta spp.	8.3		16.7	75.0	141.7	783.3	558.3	658.3
Eumida sanguinea	8.3					50.0	83.3	
Paranaitis speciosa							8.3	
Harmothoe extenuata							33.3	
Glycera capitata		8.3			8.3	25.0		
Goniadelia gracilis		8.3		16.7	425.0	650.0	8.3	
Nephtys picta	50.0	8.3	8.3				33.3	
Nephtys sp.			16.7				8.3	
Autolytus cornutus							25.0	
Capitella capitata			8.3					
Polydora ligni							8.3	
Scolelepis squamata	8.3				8.3			
Spio filicornis	166.6	8.3		16.7		50.0	600.0	50.0
Spiophanes bombyx	91.7	25.0	50.0		8.3		250.0	
Magelona sp.		25.0					8.3	
Tharyx acutus	8.3				8.3	125.0	333.3	
Pherusa affinis	16.6						16.7	
Asabellides oculata	8.3						50.0	
Ampharetidae							25.0	
Cirratulidae							1,016.7	8.3
Glyceridae	8.3					25.0		

Appendix Table 6 - continued

	Number of organisms/m^2							
Station No.	1	2	3	4	5	6	7	8
Taxa								
Goniadidae		8.3	8.3		41.7			
Magelonidae			50.0					
Phyllodocidae	8.3						8.3	
Polynoidae	8.3						25.0	
Spionidae	66.7	25.0	16.7				216.7	25.0
Unidenti. Polychaeta	25.0	41.7	16.7	75.0	16.7	25.0	50.0	8.3
Leptocuma minor					25.0			8.3
Leptochelia filum		33.3		58.3				8.3
Cyathura polita							16.7	
Unciola serrata							216.7	
Unciola irrorata	8.3						150.0	
Unciola sp.				8.3	25.0		8.3	
Elasmopus laevis					8.3		8.3	
Gammarus annulatus	16.7	16.7	8.3	16.7	33.3		58.3	16.7
Bathyporeia quoddyensis			8.3	8.3				8.3
Protohaustorius deichmannae		8.3	116.6	33.3				
Parahaustorius longimerus			33.3	8.3				16.7
Acanthohaustorius millsi		50.0	8.3					16.7
Listriella sp.						50.0		
Paraphoxus spinosus		8.3	8.3				783.3	
Trichophoxus epistomus		8.3						
Haustoridae	8.3			8.3				
Pagurus sp.							25.0	
Libinia emarginata			16.7	8.3				
Ovalipes ocellatus		8.3			41.7	666.7	183.3	

Appendix Table 6 - continued

	Number of organisms/m^2							
Station No.	1	2	3	4	5	6	7	8
Taxa								
Lunatia heros						25.0		
Nucula proxima	50.0							
Mytilus edulis	25.0	41.7	8.3	316.7	5,550.0	110,708.3	58.3	25.0
Spisula solidissima	91.7	166.7	16.7		33.3	25.0	66.7	308.3
Tellina agilis	108.3	16.7		8.3		50.0	50.0	
# species/grab (1)	10	16	8	7	7	6	25	4
(2)	10	5	9	7	5	5	24	10
(3)	14	9	10	8	14	11	23	5
# organisms/m^2/grab (1)	575	825	275	200	17,450	165,100	3,350	2,125
(2)	400	250	625	350	1,100	60,150	5,700	1,075
(3)	1,400	550	525	1,475	4,675	114,525	5,950	275
Av. #/m^2	791.3	541.5	474.8	674.8	7,741.6	113,258.3	4,999.6	1,158.2
Total # species	20	20	19	16	16	14	33	13

Appendix Table 7. Benthic grab collection records from Steimle and Stone (1973) Transect *A* stations in 1966-1967. Each number of organisms found in a Petersen grab was multiplied by 16.0256 to convert to a /m² basis. Note: December cruise cancelled.

Station *A1*	Month										
Species	F	M	A	M	J	J	A	S	O	N	J
Mytilus edulis	16		4,423	3,926	15,897	92,869	30,144	2,580		16	NO SAMPLE COLLECTED
Harmothoe extenuata					80	497					
Cancer irroratus						577					
Protohaustorius deichmannae	224										
Nereis succinea	16						160				
Trichophoxus epistomus	128										
Harmothoe imbricata						64	64				
Nereis pelagica						96					
Tellina agilis	64					16					
Neopanope texana							64	16			
Lepidodonatus squamata							64				
Phyllodoce mucosa						48					
Parahaustorius holmesi	32										
Spio setosa						32					
Unciola irrorata			16								
Metridium senile					16						
Scolelepsis squamata	16										
Autolytus cornutus			16								
Ischyroceros anquipes					16						
Total	497	0	4,455	3,926	16,010	94,199	30,497	2,596	0	16	X

Average # of organisms/m² <u>15,200</u>   Total # taxa <u>19</u>

Appendix Table 7 - continued

Station *A2*	Month										
Species	F	M	A	M	J	J	A	S	O	N	J
Mytilus edulis			16	176	5,609	60,481	36,362	11,090	609		
Cancer irroratus						353	256	48	16		
Harmothoe extenuata					32	128	208	48			
Protohaustorius deichmannae				160							
Nereis succinea							64	64			
Elasmopus laevis									96		
Parahaustorius attenuatus				64							
Jassa falcata					16	16					
Unident. nermertean	16					16					
Heteromysis formosa									16		
Lunatia heros								16			
Tellina agilis							16				
Pherusa affinis							16				
Chiridotea tuftsi				16							
Lumbrineris sp.				16							
Nephtys bucera										16	
Parahaustorius holmesi		16									
Acanthohaustorius millsi				16							
Polycirrus phosphoreus						16					
Eumida sanguinea							16				
Cirratulus grandis								16			
Total	16	16	16	449	5,657	61,010	36,939	11,282	737	16	

Average # of organisms/m^2 10,500 Total # taxa 21

Appendix Table 7 - continued

Station 43											
		Month									
Species	F	M	A	M	J	J	A	S	O	N	J
Protohaustorium deich[illegible]	1[illegible]	32	96	80	192	240		32	32		
Mytilus edulis	32			16	32				112		
Spisula solidissima					32	48	385				
Tellina agilis				112		32	160	32			
Acanthohaustorius mil[illegible]			64	16			80				
Crepidula plana				144							
Lunatia heros						16		16	32		
Nephtys picta				32	16						
Leptocuma minor				32							
Elasmopus laevis				32							
Spio setosa				16		16					
Lumbrineris fragilis	1[illegible]										
Pagurus pollicaris				16							
Unident. nemertean				16							
Tharyx acutus					16						
Ovalipes ocellatus							16				
Chiridotea tuftsi							16				
Lyonsia hyalina							16				
Sigalion arenacola							16				
Cancer irroratus								16			
Spiophanes bombyx			16								
Parahaustorius attenuatus								16			
Parahaustorius holmesi										16	
Harmothoe extenuata				16							
Hemipodus sp.						16					
Total	35	32	176	529	288	369	689	112	176	16	0

[illegible] # organisms/m² 249 Total # taxa 25

Appendix Table 7 - continued

Station *A4*	Month										
Species	F	M	A	M	J	J	A	S	O	N	J
Mytilus edulis			240		16	16			240		
Spio setosa			320			64					
Protohaustorius deichmannae		128			80		80	32			
Echinarachnius parma		320									
Acanthohaustorius millsi				48	16		176				
Parahaustorius longimerus					128		96				
Tellina agilis		96			16	80					
Unciola irrorata						176					
Spisula solidissima				16	48		32				
Jassa falcata						96					
Lunatia heros						48			16		
Parahaustorius holmesi		32		32							
Crangon septemspinosa						32				16	
Chiridotea tuftsi						32					
Parahaustorius attenuatus							32				
Ophelia bicornis	32										
Glycera dibranchiata			16								
Lumbrineris fragilis		16									
Sthenelais limicola							16				
Nereis succinea								16			
Cancer irroratus						16					
Leptocuma minor						16					
Nepthys picta						16					
Harmothoe extenuatus						16					
Lumbrineris tenuis						16					
Total	32	593	577	96	304	625	433	48	256	16	0

Average # of organisms/m^2 271   Total # taxa 25

Appendix Table 7 - continued

Station A5	Month										
Species	F	M	A	M	J	J	A	S	O	N	J
Mytilus edulis					1,042	61,731	30,352	8,189		304	2,900
Harmothoe extenuata						1,955	769				48
Cancer irroratus						577	304	144			16
Nereis succinea						609	192	48			
Harmothoe imbricata						785	32				
Lepidonotus squamata						272	160				
Polydora ligni						337					
Neopanope texana						128	64	16			
Jassa falcata						192					
Metridium senile						176					
Crepidula fornicata						144					
Elasmopus laevis						16	16	96			
Spisula solidissima				16		80					
Parahaustorius holmesi				64							
Protohaustorius deichmannae				32	32						
Acanthohaustorius spinosus				64							
Parahaustorius longimeris				48							
Acanthohaustorius millsi				48							
Lunatia heros								16		16	
Crangon septemspinosa		16				16					
Unciola irrorata							32				
Eumida sanguinea						32					
Unident. nemertean						16					
Cirratulus imbricata							16				
Ovalipes ocellatus									16		

Appendix Table 7 - continued

Station A5 - continued	Month										
Species	F	M	A	M	J	J	A	S	O	N	J
Lumbrineris fragilis				16							
Asterias forbesi						16					
Mitrella lunata						16					
Tellina agilis						16					
Tharyx acutus						16					
Polydora sp.						16					
Unident. oligochaete						16					
Cirratulus sp.							16				
Glycera dibranchiata							16				
Nereis grayi									16		
Total	0	16	0	288	1,074	67,162	31,971	8,510	32	321	2,965

Average # of organisms/m^2 10,200 Total # taxa 35

Appendix Table 7 - continued

Station A6	Month										
Species	F	M	A	M	J	J	A	S	O	N	J
Crangon septemspinosa						176					
Tellina agilis					32	144					
Acanthohaustorius millsi					112				16		
Parahaustorius holmesi		64					48				
Protohaustorius deichmannae			32			48			16		
Cancer irroratus						64	16				
Nephtys picta									16		64
Diastylis polita						48					
Asabellides oculata						48					
Parahaustorius longimerus			48								
Mytilus edulis			16		16						
Leptocuma minor						16					
Neomysis americana						16					
Unident. nemertean						16					
Lumbrineris fragilis					16						
Ophelia bicornis	16										
Sigalion arenecola										16	
Spisula solidissima										16	
Hemipodus sp.							16				
Asterias forbesi											16
Scoloplos sp.					16						
Total	16	64	96	0	192	577	80	0	48	32	80

Average # of organisms/m^2 108 Total # taxa 21

Notes: Petersen grab samples 0.0625 m^2; 1 mm mesh screen was smallest used. Samples at each station are from single grabs.

Appendix Table 8. Station data reported by Wilk et al. (1977) but grouped by areas shown in Figure 29. Stations with * were surveyed by a #36 trawl (24.4 m footrope); all other stations sampled by net with 9.1 m footrope; - indicated weight < 0.5 kg.

Area	Station #	Date Sampled	Depth (m)	# Species	Total #	Total wt. (kg)
A Lower Bay	13	06-vi -74	5	0	0	0
	72	25-vii -74	6	1	1	-
	127	21-viii-74	4	0	0	0
	188	24-ix -74	5	4	985	6.4
	255	24-x -74	4	6	12	1.4
	307	19-xi -74	5	6	15	1.4
	362	03-i -75	5	6	28	0.9
	500	07-iv -79	5	5	57	1.4
	556	06-v -79	4	11	72	2.3
	636	09-vi -79	4	5	50	0.9
B Lower Bay East Bank	14	06-vi -74	12	5	22	3.6
	71	25-vii -74	11	7	10	2.7
	123	14-viii-74	6	6	16	7.7
	187	24-ix -74	6	9	306	6.8
	254	24-x -74	3	2	13	4.5
	306	19-xi -74	7	10	232	3.6
	361	03-i -75	5	9	36	0.9
	379	03-ii -75	6	6	28	0.5
	380	03-ii -75	5	0	0	0
	499	07-iv -75	9	2	2	-
	555	06-v -75	5	8	25	0.9
C Lower Bay East Bank	305	19-xi -74	5	3	5	0.5
	360	03-i -75	7	4	26	0.9
	378	03-ii -75	6	1	2	-
	498	07-iv -75	3	1	1	-
	554	06-v -75	4	7	56	2.7
D Raritan Bay	6	04-vi -74	6	1	1	
	75	25-vii -74	6	1	7	-
	130	21-viii-74	6	2	18	0.5

Appendix Table 8 - continued

Area	Station #	Date Sampled	Depth (m)	# Species	Total #	Total wt. (kg)
D Raritan Bay (continued)	189	24-ix -74	6	8	1,441	9.5
	249	23-x -74	6	5	81	2.7
	312	20-xi -74	5	9	65	3.6
	385	04-ii -75	6	3	18	0.5
	495	02-iv -75	5	2	2	0.5
	552	05-v -75	4	2	5	0.5
	633	03-vi -75	5	5	21	0.5
E Lower Bay Old Orchard Shoal	7	04-vi -74	6	2	2	1.4
	74	25-vii -74	7	2	2	-
	128	21-viii-74	3	2	71	0.5
	129	21-viii-74	6	0	0	0
	184	23-ix -74	8	8	610	3.6
	196*	23-ix -74	7	9	30,371	57.6
	240	22-x -74	6	7	289	0.5
	256*	22-x -74	8	18	2,392	32.2
	308	19-xi -74	6	8	37	2.7
	363	03-i -75	7	3	20	-
	381	03-ii -75	7	3	22	1.8
	493	02-iv -75	6	3	49	2.3
	551	05-v -75	7	2	13	1.4
F Lower Bay Romer Shoal	12	06-vi -74	6	1	1	-
	73	25-vii -74	6	2	3	-
	122	14-viii-74	5	3	5	2.3
	253	24-x -74	5	2	11	-
	304	19-xi -74	5	3	23	2.3
	359	03-i -75	7	6	27	1.8
	377	03-ii -75	5	2	17	0.5
	491	01-iv -75	5	2	5	1.8
	635	09-vi -75	5	4	16	0.5

Appendix Table 8 - continued

Area	Station #	Date Sampled	Depth (m)	# Species	Total #	Total wt. (kg)
G Lower Bay	183	23-ix -74	9	5	39	-
	239	22-x -74	9	5	4,714	2.7
	256*	22-x -74	7	12	5,339	22.2
	258*	22-x -74	5	15	15,499	32.7
	301	18-xi -74	8	9	71	1.8
	320*	18-xi -74	8	18	945	53.5
	373	31-i -75	9	6	92	1.4
	387*	31-i -75	8	12	416	9.1
	388*	31-i -75	8	10	1,372	17.7
H Lower Bay	68	24-vii -74	10	9	26	11.3
	79*	24-vii -74	9	9	876	29.0
	134	22-viii-74	9	5	5	3.6
	238	22-x -74	9	11	543	2.7
	300	18-xi -74	9	13	102	2.3
	368	06-i -75	9	3	26	0.5
	374	31-i -75	8	6	524	12.2
	494	02-iv -74	6	4	11	0.5
	550	05-v -75	8	5	14	1.8
	566*	05-v -75	9	11	211	17.7
	567*	05-v -75	8	13	456	76.2
I Sandy Hook Bay	2	03-vi -74	7	3	48	1.8
	3	03-vi -74	7	3	9	0.5
	17*	03-vi -74	7	18	2,859	106.6
	18*	03-vi -74	8	8	2,250	22.7
	182	23-ix -74	8	6	200	2.7
	194*	23-ix -74	7	8	1,865	11.8
	195*	23-ix -74	8	12	545	17.2
	237	22-x -74	8	12	357	4.1
	299	18-xi -74	8	11	134	5.4
	319*	18-xi -74	8	14	590	23.6
	372	31-i -75	9	3	35	0.5
	386*	31- -75	10	10	1,815	24.0

Appendix Table 8 - continued

Area	Station #	Date Sampled	Depth (m)	# Species	Total #	Total wt. (kg)
I Sandy Hook Bay (continued)	549	05-v -75	7	4	8	1.4
	565*	05-v -75	8	11	181	18.1
J Lower Bay	1	03-vi -74	8	4	5	4.5
	16*	03-vi -74	8	13	494	27.2
	65	24-vii -74	9	3	16	8.2
	133	22-viii-74	8	2	2	0.9
	241	22-x -74	8	4	18	0.5
	302	18-xi -74	7	9	45	0.5
	367	06-i -75	7	3	31	0.5
	382	03-ii -75	8	1	2	-
	489	01-iv -75	7	5	10	1.4
	490	01-iv -75	5	2	4	0.5
	561	08-v -75	7	8	47	9.5
K Lower Bay Flynns Knoll	11	06-vi -74	6	2	2	-
	66	24-vii -74	8	4	13	22.7
	121	14-viii-74	5	0	0	0
	186	24-ix -74	5	8	89	3.2
	251	24-x -74	5	4	83	0.5
	303	19-xi -74	5	7	16	4.5
	358	03-i -75	7	5	35	2.3
	376	03-ii -75	5	7	36	0.9
	553	06-v -75	5	4	34	-
	634	09-vi -75	5	4	7	0.9
L Raritan Bay	5	04-vi -74	5	0	0	0
	131	21-viii-74	6	3	16	1.4
	190	24-ix -74	5	5	238	1.4
	248	23-x -74	4	2	39	0.9
	313	20-xi -74	5	5	27	1.4
	370	09-i -75	3	2	4	0.5

Appendix Table 8 - continued

Area	Station #	Date Sampled	Depth (m)	Species	Total #	Total wt. (kg)
L Raritan Bay (continued)	383	04-ii -75	4	4	12	2.7
	497	02-iv -75	4	4	73	0.5
	557	06-v -75	4	7	55	4.1
	632	03-vi -75	3	2	2	-
M Raritan Bay	247	23-x -74	4	3	25	0.9
	314	20-xi -74	5	9	86	3.2
	371	09-i -75	3	8	68	2.3
	384	04-ii -75	6	1	13	-
	496	02-iv -75	5	3	102	0.9
	558	06-v -75	4	8	161	15.4
	631	03-vi -75	4	6	17	1.4
N Raritan Bay	4	03-vi -74	4	1	3	0.5
	76	25-vii -74	4	2	2	3.6
	132	21-viii-74	4	1	4	8.6
	191	24-ix -74	3	4	30	0.9
	246	23-x -74	3	6	64	4.5
	315	20-xi -74	4	7	45	1.4
	559	06-v -75	3	7	47	3.2
	630	03-vi -75	3	5	37	1.8
O Sandy Hook Bay	8	04-vi -74	5	1	2	-
	62	23-vii -74	6	4	18	1.4
	67	24-vii -74	9	5	21	11.3
	77*	24-vii -74	8	10	55	93.9
	135	22-viii-74	6	2	2	0.5
	193	25-ix -74	6	8	74	8.2
	245	23-x -74	5	3	485	0.5
	309	19-xi -74	5	11	54	0.9
	369	06-i- -75	7	4	25	0.5
	629	03-vi -75	5	9	57	2.3

Appendix Table 8 - continued

Area	Station #	Date Sampled	Depth (m)	# Species	Total #	Total wt. (kg)
P Sandy Hook Bay	70	24-vii -74	7	7	46	14.5
	126	15-viii-74	5	3	33	-
	242	23-x -74	6	13	141	15.0
	244	23-x -74	6	3	50	5.4
	310	19-xi -74	5	11	71	5.4
	318*	18-xi -74	8	18	533	33.1
	366	06-i -75	7	6	137	2.7
	375	03-ii -75	6	7	195	9.5
	488	01-iv -75	6	3	4	-
	560	06-v -75	5	9	58	10.4
	628	03-vi -75	7	10	116	3.2
Q Sandy Hook Bay	10	04-vi -74	6	3	27	3.2
	64	23-vii -74	7	2	3	1.4
	136	23-viii-74	7	6	116	7.3
	311	19-xi -74	8	9	105	6.4
	365	06-i -75	7	6	137	2.7
	486*	01-iv -75	7	6	21	3.2
	487*	01-iv -75	11	7	14	1.8
	562	08-v -75	7	5	78	14.5
R Sandy Hook Bay	9	04-vi -74	5	7	22	2.7
	63	23-vii -74	8	6	86	9.1
	78*	24-vii -74	7	7	205	44.0
	125	15-viii-74	5	2	3	-
	185	23-ix -74	8	6	22	8.2
	192	25-ix -74	5	9	198	3.6
	243	23-x -74	6	6	42	5.0
	316	20-xi -74	6	9	135	9.5
	563	08-v -75	5	4	127	17.7

Appendix Table 8 (continued)

Area	Station #	Date Sampled	Depth (m)	# Species	Total #	Total wt. (kg)
Sandy Hook Bay	69	24-vii -74	7	4	11	5.0
	124	15-viii-74	6	4	39	0.5
	250	24-x -74	5	5	21	0.9
	317	20-xi -74	6	5	46	5.9
	364	06-i -75	6	7	73	4.5
	492	02-iv -75	5	2	2	-
	564	08-v -75	5	8	85	7.3

Appendix Table 9. List of fish species reported by Wilk et al. (1977) in the Lower Bay Complex during 1974-75 survey. Data compiled by month and area found, including number of fish and weight in kg. An asterisk (*) indicates < 0.5 kg.

Mustelus canis	1974 Jul(A: 2;1.4 B: 2;1.4 H: 2;0.9, 5;3.6 J: 12;5.0 K: 5;3.6 O: 31;39.5 R: 1;1.4) Aug(B: 3;2.7) Nov(B: 1;0.9 K: 1;1.4)
Squalus acanthias	1974 Jun(I: 3;14.5)
Raja erinacea	1974 Jul(P: 106;50.8) Note: these totals > than station totals
Conger oceanicus	1974 Nov(I: 1;*) 1975 Apr(Q: 1;0.5) Jun(M: 1;* P: 1;0.5)
Alosa aestivalis	1974 Jun(I: 140;0.9, 1,032;6.8 J: 300;2.3) Oct(E: 1;* G: 29;0.5) Nov(B: 3;* E: 1;* G: 5;*, 80;15.1 H: 6;* I: 367;7.3 J: 1;* L: 9;* M: 3;* N: 9;* O: 1;* P: 138;5.9) 1975 Jan(A: 1;* B: 2;* C: 1;* F: 19;0.9 G: 67;0.5 H: 26;*, 8;* I: 2;0.5 J: 22;0.5 K: 1;* P: 26;0.5 Q: 41;0.5 S: 10;*) Feb(B: 1;* D: 15;* E: 15;0.5 K: 1;* P: 31;*) Apr(A: 43;0.5 D: 2;* E: 31;0.9 H: 7;* L: 70;0.5 M: 97;0.9 P: 2;*) May(A: 10;* B: 2;* C: 35;* D: 3;* H: 4;*, 9;1.8 I: 9;1.8 J: 1;* K: 3;* L: 2;* S: 10;*) Jun(D: 2;* L: 1;* N: 1;* O: 1;* P: 1;*)
Alosa mediocris	1974 Jun(I: 2;0.5)
Alosa pseudoharengus	1974 Jun(I: 328;42.6 J: 40;0.9) Oct(D: 1;* E: 9;0.5 G: 8;05, 1;* H: 4;* N: 2;*) Nov(B: 140;1.8 G: 2;*, 4;* H: 34;0.9 I: 24;0.9 L: 8;* M: 7;* N: 4;* O: 1;* Q: 28;1.4 S: 1;*) 1975 Jan(A: 1;* B: 6;* E: 3;* G: 18;0.5, 281;3.2, 1,203;10.0 H: 12;*, 189;9.5 I: 23;05, 1,634;15.9 J: 3;* K: 23;0.9 L: 3;* M: 21;0.5 O: 9;* P: 19;0.5 Q: 20;0.5 S: 21;0.5) Feb(B: 20;* D: 1;* K: 1;* L: 1;* M: 13;* P: 111;2.7) Apr(A: 10;* E: 17;0.9 H: 2;* J: 1;* L: 1;* M: 4;* P: 1;* Q: 3;0.9, 2;0.5) May(A: 10;* H: 22;1.4, 16;0.9 I: 15;0.9 J: 2;* L: 3;* M: 3;* N: 1;* P: 2;* S: 6;*)
Alosa sapidissima	1974 Jun(I: 1;*, 6;0.5 J: 7;*) Oct(E: 1;*) Nov(A: 6;* B: 10;* D: 1;* G: 24;0.5, 70;1.8 I: 6;*, 23;* J: 1;* M: 2;* N: 1;* O: 7;* P: 3;*, 10;* R: 1;*) 1975 Jan(B: 5;* E: 15;* F: 2;* G: 2;*, 117;1.4, 33;0.5 H: 6;*, 56;0.9 I: 7;*, 48;0.9 J: 6;* K: 5;* M: 4;* O: 13;* P: 80;0.9 R: 50;0.5 S: 25;0.5) Feb(B: 1;* P: 12;*) May(A: 8;* B: 2;* C: 1;* H: 2;*, 1;0.5 K: 2;* L: 1;* M: 2;* N: 6;* P: 1;* S: 2;*)

Appendix Table 9 - continued

Species	Records
Brevoortia tyrannus	1974 Jun(B: 2;0.5 I: 1;*, 1;*, 36;7.3, 2;0.5 J: 4;0.5 O: 2;* Q: 1;* R: 4;0.5) Jul(S: 1;*) Oct(E: 15;0.5 G: 1;* I: 2;*, 4;0.9 S: 1;*) Nov(G: 1;0.5, 2;* H: 6;0.5 I: 1;* L: 3;0.5 M: 1;* N: 3;* P: 11;3.2 Q: 2;0.5) 1975 Jan(E: 2;* G: 1;*, 2;* H: 246;1.4 I: 5;0.5, 27;0.5 M: 1;* O: 2;* P: 7;* S: 1;*) Feb(B: 4;* E: 1;* J: 2;* P: 15;0.5) Apr(L: 1;*) May(A: 1;* B: 1;* C: 2;* H: 1;* I: 4;0.9) Jun(D: 2;* L: 1;* M: 7;0.9 N: 1;1.4 O: 4;0.9 P: 1;*)
Clupea harengus harengus	1974 Jun(E: 1;* I: 4;0.5, 70;19.1) 1975 Jan(A: 3:0.9 F: 3;0.9 G: 2;0.5, 8;1.8, 15;3.6 H: 2;0.5 K: 5;1.4 L: 1;0.5 M: 1;0.5 O: 1;0.5 P: 3;0.9 Q: 1;0.5 S: 10;3.2) Feb(B: 1;* D: 2;* E: 6;1.4 F: 1;0.5 K: 2;0.5 L: 9;2.7 P: 24;6.4) Apr(A: 2;0.5 D: 1;* E: 1;0.5 F: 3;0.9 S: 1;*) May(B: 1;* C: 5;0.9) Jun(M: 1;*)
Anchoa hepsetus	1974 Aug(Q: 1;*) 1975 May(H: 2;*)
Anchoa mitchilli	1974 Jun(B: 1;* I: 2,080;9.1, 1,152;6.8 J: 104;0.5 K: 1;* R: 1;*) Jul(D: 7;* E: 1;* F: 2;* H: 1;*, 840;3.2 O: 1;*, 2;* R: 164;0.9) Aug(B: 2;* D: 17;* J: 1;* L: 13;* P: 31;* Q: 98;0.5 R: 144;* S: 35;*) Sep(A: 980;6.4 B: 192;1.4 D: 1,428;4.1 E: 67;0.5, 592; 2.3 G: 29;* I: 152;0.9, 1,768;7.7 K: 1;* L: 228;1.4 N: 17;* O: 44;*) Oct(E: 2,046;10.0 G: 4,680;1.4, 15,364;20.9) Nov(A: 1;* E: 8;* G: 208;0.5 H: 8;* I: 30;0.5 J: 26;* K: 4;* L: 4;* M: 31;* N: 20;* O: 22;* P: 28;*, 30;0.5 R: 4;* S: 2;*) Jan(K: 1;*) Apr(B: 1;*)
Engraulis eurystole	1974 Aug(R: 2;*) Sep(E: 30,307;41.7 I: 152;0.5) Oct(D: 50;* E: 280;* F: 10;* G: 5,200;11.3 H: 504;* I: 312;1.4 J: 12;* K: 64;* L: 23;* M: 16;* N: 2;* O: 480;* S: 3;*) 1975 May(I: 1;*)
Synodus foetens	1974 Oct(H: 1;*)
Lophius americanus	1974 Nov(P: 1;10.4)

Appendix Table 9 - continued

Merluccius bilinearis	1974	Jun(*I*: 69;3.2)
		Nov(*B*: 46;* *C*: 2;* *D*: 3;* *E*: 8;* *G*:2;*, 5;* *H*: 10;* *I*: 14;*, 41;* *K*: 1;* *P*: 1;*, 27;* *Q*: 1;* *R*: 10;* *S*: 1;*)
	1975	Jan(*A*: 1;* *B*: 9;0.5 *F*: 1;* *G*: 28;*, 3;* *H*: 5;* *I*: 15;0.5 *M*: 2;*)
		Feb(*B*: 1;* *L*: 1;*)
		Apr(*B*: 1;* *J*: 3;09 *P*: 1;* *Q*: 6;1.8, 1;4)
		May(*A*: 1;* *B*: 1;* *E*: 1;* *H*: 5;1.4, 17;3.6 *I*: 7;1.4 *J*: 8;2.3 *L*: 6;1.8 *M*: 33;6.8 *N*: 4;*, 121;29.5 *P*: 10;2.7 *Q*: 12;2.3 *R*: 6;2.3 *S*: 2;*)
Urophycis chuss	1974	Jun(*B*: 1;* *I*: 42;2.3)
		Jul(*A*: 1;* *B*: 1;* *H*: 1;*, 1;* *O*: 2;*)
		Oct(*B*: 1;*)
		Nov(*B*: 3;* *G*: 1;* *H*: 1;* *I*: 1;* *J*: 2;* *P*: 1;*, 4;* *Q*: 4;*)
	1975	Jan(*B*: 8;* *G*: 1;*, 7;*, 5;* *I*: 6;0.5)
		Feb(*K*: 1;* *P*: 1;*)
		Apr(*H*: 1;* *J*: 1;* *Q*: 9;0.5, 5;*)
		May(*B*: 4;* *D*: 2;* *E*: 12;1.4 *H*: 3;*, 147;9.1, 214;25.4 *I*: 2;*, 133;9.1 *J*: 23;5.0 *L*: 39;1.8 *M*: 116;7.7 *N*: 24;0.9 *P*: 25;1.8 *Q*: 34;5.4 *R*: 106;13.2 *S*: 50;5.0)
		Jun(*A*: 21;* *M*: 4;*)
Urophycis regius	1974	Jun(*I*: 3;* *R*: 2;*)
		Jul(*O*: 1;*)
		Nov(*A*: 2;* *B*: 14;* *D*: 23;* *E*: 1;* *G*:3;* *I*: 1;* *K*: 1;* *M*: 1;* *O*: 6;* *P*: 4;*, 2;* *R*: 20;*)
	1975	Jan(*B*: 2;* *G*: 4;* *I*: 7;0.5)
		Apr(*Q*: 1;* *S*: 1;*)
		May(*A*: 18;* *M*: 1;* *N*: 2;*)
		Jun(*M*: 1;* *O*: 3;* *P*: 1;*)
Urophycis tenuis	1975	Jun(*M*: 1;* *N*: 20;* *O*: 33;* *P*: 2;*)
Menidia menidia	1974	Oct(*B*: 2;* *E*: 1;*, 1;* *S*: 6;*)
		Nov(*A*: 1;* *B*: 5;* *D*: 1;* *E*: 3;* *G*: 24;*, 320;1.8 *I*: 1;*, 7;* *J*: 2;* *K*: 7;* *M*: 1;* *O*: 2;* *P*: 1;*, 16;* *R*: 1;*)
	1975	Jan(*A*: 1;* *G*: 2;* *P*: 3;* *S*: 3;*)
		May(*A*: 14;* *B*: 12;* *C*: 6;* *H*: 1;* *I*: 1;* *J*: 5;* *K*: 28;* *P*: 1;* *Q*: 1;* *S*: 5;*)
		Jun(*A*: 12;* *D*: 12;* *F*: 2;*, 9;* *O*: 2;* *P*: 78;*)
Gasterosteus aculeatus	1975	Jan(*M*: 1;*)
Hippocampus erectus	1974	Sep(*I*: 1;*)
		Oct(*A*: 1;* *K*:1;* *S*:1;*)
	1975	May(*L*: 1;*)

Appendix Table 9 - continued

Syngnathus fuscus	1974	Sep(*G*: 1;*)
		Oct(*E*: 8;* *G*: 2;*, 2;* *N*: 1;*)
		Nov(*D*: 1;* *G*: 10;* *P*: 5;*)
	1975	Apr(*Q*: 1;*, 1;*)
		May(*H*: 3;* *I*: 2;* *M*: 1;*)
Morone americana	1974	Nov(*H*: 1;*)
Morone saxatilis	1974	Jun(*I*: 1;2.7 *J*: 8;17.2)
		Jul(*A*: 1;0.9 *B*: 1;0.9 *O*: 1;1.8)
		Oct(*E*: 1;1.4 *G*: 1;5.4)
	1975	May(*I*: 1;*)
Centropristis striata	1974	Sep(*E*: 1;* *K*: 4;*)
		Oct(*P*: 1;*)
	1975	Jun(*O*: 1;*)
Pomatomus saltatrix	1974	Jun(*I*: 3;*, 2;5.0 *J*: 1;2.3, 2;*)
		Jul(*E*: 1;* *H*: 6;3.6, 2;0.5 *J*: 1;* *K*: 2;0.5
		O: 1;5.0, 10;4.1 *Q*: 1;* *R*: 10;2.3)
		Aug(*D*: 1;0.5 *H*: 1;0.5 *J*: 1;0.9 *Q*: 6;0.5 *S*: 2;*)
		Sep(*B*: 2;* *D*: 1;3.6 *I*: 13;1.4, 24;1.4, 42;5.9
		N: 1;0.5 *O*: 4;0.5 *R*: 2;*, 2;*)
		Oct(*E*: 1;*, 85;6.4 *G*: 1;*, 12;4.1 *H*: 4;0.5 *I*: 8;0.5)
		Nov(*G*: 1;3.6 *K*: 1;4.5)
Vomer setapinnis	1974	Sep(*B*: 1;* *I*: 2;*, 1;*, 1;* *O*: 1;*)
		Oct(*I*: 1;*)
Orthopristis chrysoptera	1974	Oct(*P*: 1;*)
Stenotomus chrysops	1974	Jun(*I*: 1;* *J*: 1;*, 1;* *Q*: 1;*)
		Jul(*H*: 1;*, 1;* *O*: 1;* *R*: 15;0.9)
		Sep(*A*: 1;* *D*: 1;* *E*: 2;*, 4;0.5 *K*: 76;0.5 *O*: 1;*)
		Oct(*P*: 1;*)
		Nov(*I*: 42;*)
	1975	Jun(*F*: 1;* *K*: 2;* *P*: 1;*)
Bairdiella chrysura	1974	Oct(*E*: 4;0.5 *I*: 1;* *N*: 1;* *P*: 5;*)
		Nov(*P*: 3;*)
Cynoscion regalis	1974	Jun(*J*: 1;2.3)
		Jul(*H*: 6;6.4, 3;14.5 *J*: 3;3.2 *K*: 5;18.6 *N*: 1;2.7
		O: 2;4.1, 11;42.2 *P*: 2;4.1 *R*: 7;17.7 *S*: 1;*)
		Aug(*B*: 1;* *H*: 1;1.4 *L*: 1;1.4 *N*: 4;8.6 *P*: 1;*
		Q: 5;5.9 *S*: 1;*)
		Sep(*A*: 1;* *B*: 100;1.4 *D*: 6;* *E*: 5;*, 13;*
		I: 18;*, 295;3.2, 56;0.5 *L*: 2;* *O*: 13;2.3
		R: 9;5.9, 29;0.5)
		Oct(*E*: 42;0.5 *G*: 1;*, 11;* *H*: 6,* *I*: 6;* *J*: 1;*
		M: 2;* *N*: 1;* *O*: 3;* *P*: 59;1.4, 2;* *R*: 1;*)
		Nov(*B*: 4;* *G*: 1;*, 3;* *I*: 10;*, 19;2.3 *J*: 2;*
		O: 1;* *P*: 3;*, 72;0.5 *Q*: 7;* *R*: 5;*)

Appendix Table 9 - continued

Leiostomus xanthurus	1974	Sep(I: 1;*, 5;0.5, 8;0.9 R: 1;*)
		Oct(E: 2;* P: 3;*)
		Nov(I: 1;*)
Menticirrhus saxatilis	1974	Sep(B: 1;* E: 1;*,6;* K: 1;* L: 3;* N: 9;0.5)
		Oct(B: 1;*)
Micropogon undulatus	1974	Sep(I: 1;*)
		Oct(P: 1;*)
Chaetodon ocellatus	1974	Sep(E: 1;*)
Tautoga onitis	1974	Jun(E: 1;1.4 I: 1;3.2)
		Jul(P: 1;*)
		Aug(H: 1;1.4 S: 1;*)
		Oct(A: 12;4.5 E: 1;0.5 G: 1;* 2;1.8)
		Nov(A: 1;* F: 2;0.9 P: 1;*)
	1975	Jan(G: 2;0.5)
		May(A: 2;0.5 C: 1;0.9 H: 9;11.8 I: 3;3.2 J: 3;1.4 P: 1;2.3)
Tautogolabrus adspersus	1974	Oct(J: 1;*)
		Nov(F: 20;1.4)
Mugil curema	1974	Sep(R: 1;*)
Astroscopus guttatus	1974	Oct(D: 1;* G: 1;*, 1;* H: 1;* P: 1;*)
Pholis gunnellus	1974	Sep(E: 2;*)
		Oct(G: 4;*)
		Nov(G: 2;*)
	1975	Jan(G: 2;*)
		May(H: 1;*, 4;*)
Ammodytes americanus	1974	Oct(B: 1;* K: 15;*)
		Nov(K: 1;*)
	1975	Jan(A: 21;* C: 22;*)
		Feb(C: 1;*) F: 16;* K: 29:8)
Scomber scombrus	1974	Jun(I: 1;*)
Peprilus triacanthus	1974	Jun(I: 46;1.8, 4;*, 37;1.4, 2;* J: 2;*, 9;0.5 R: 10;0.5)
		Jul(F: 1;* H: 3;* R: 4;*)
		Aug(B: 2;* E: 4;* L: 2;* P: 1;* Q: 3;0.5 R: 1;*)
		Sep(D: 1;* G: 7;* I: 14;0.5, 8;0.5, 27;0.9 L: 8;0.5 N: 3;* O: 3;* R: 1;*, 3;*)
		Oct(D: 2;* E: 2;*, 62;3.2 G: 29;1.4, 12;0.5, 7;0.5 H: 11;0.5 I: 20;1.8 P: 4;0.5
		Nov(I: 1;* J: 2;* P: 1;* Q: 1;*)
	1975	May(A: 2;* H: 1;*)
		Jun(A: 2;* D: 3;* M: 3;* N: 10;0.5 P: 8;0.5)

Appendix Table 9 - continued

Prionotus carolinus	1974	Jul(H: 1;* R: 1;*)
		Aug(F: 1;*)
	1975	Apr(J: 1;*)
		May(H: 1;*)
Prionotus evolans	1974	Jun(I: 1;*)
		Jul(R: 44;3.6 S: 1;*)
		Sep(I: 1;* R: 4;1.4, 1;*)
		Oct(E: 6;* G: 1;* I: 1;* P: 2;* R: 1;*)
		Nov(P: 1;* Q: 1;*)
	1975	May(I: 1;0.5)
Myoxocephalus aenaeus	1974	Jun(J: 1;*)
		Jul(H: 1;* O: 1;*)
		Sep(E: 1;* I: 2;*)
		Nov(D: 1;* E: 1;* J: 2;*)
	1975	Jan(B: 2;* F: 1;* G: 5;* I: 3;*)
		May(H: 26;*)
Myoxocephalus octodecemspinosus	1974	Oct(G: 1;*)
		Nov(G: 32;0.5)
		Jan(G: 4;*)
		Feb(K: 1;0.5)
		Apr(J: 2;0.5)
Myoxocephalus scorpius	1974	Sep(E: 1;*)
Citharichthys arctifrons	1974	Sep(G: 1;*)
Etropus microstomus	1974	Oct(E: 25;* G: 20;*, 3;* H: 1;* I: 1;*
		P: 1;* R: 1;*)
		Nov(G: 8;* I: 11;* O: 2;* P: 54;* R: 4;*)
	1975	Jan(B: 1;*)
Paralichthys dentatus	1974	Jun(I: 9;10.0, 3;3.2 J: 4;3.2 R: 2;0.9)
		Jul(A: 1;* B: 1;* K: 8;5.9 N: 1;0.9
		O: 1;0.5, 5;3.2, 4;5.0 P: 12;8.2 Q: 2;1.4
		R: 12;2.7 S: 5;4.1)
		Aug(B: 7;5.0 F: 3;2.3 H: 1:0.5 O: 1;0.5)
		Sep(B: 4;2.7 D: 2;1.8 E: 1;0.9, 21;14.5
		I: 2;1.4, 7;5.4 K: 2;0.9 O: 6;5.4 R: 1;0.5)
		Oct(E: 20;1.8 G: 4;0.5, 1;* H: 3;* I: 1;*
		P: 3;* R: 1;*)
		Nov(D: 1;* G: 6;* H: 1;* P: 2;*)
	1974	Jan(G: 1;*)
		Apr(Q: 1;*, 2;*)
		May(A: 1;0.5 H: 1;0.5)
		Jun(F: 2;* K: 2;0.9 O: 2;0.9 P: 2;0.9)

Appendix Table 9 - continued

Scophthalmus aquosus	1974	Jun(B: 14;2.7 I: 10;1.8 J: 3;0.5 R: 1;0.5)
		Jul(A: 1;* B: 1;* O: 1;* P: 2;*)
		Aug(B: 1;* F: 1;*)
		Sep(D: 1;* I: 1;* K: 2;*)
		Oct(B: 6;1.4 E: 1;*, 52;5.9 F: 1;* G: 25;2.3, 1;* H: 1;* I: 2;* K: 3;* P: 37;9.1 R: 3;*)
		Nov(A: 2;0.5 B: 5;* C: 1;* D: 2;* E: 2;* F: 1;* G: 1;*, 70;9.1 H: 9;0.5 I: 17;2.3, 95;9.5 K: 1;* M: 1;* N: 2;* O: 3;* P: 1;*; 71;9.1 Q: 12;1.8 R: 41;3.6 S: 7;*)
	1975	Jan(C: 1;0.5 F: 1;* G: 14;1.4 I: 29;1.8)
		Feb(L: 1;* P: 1;*)
		Apr(A: 1;* C: 1;* J: 3;* Q: 2;0.5)
		May(A: 5;0.5 C: 6;0.9 H: 4;0.9, 7;1.8 I: 6:0.9 J: 3;0.9 K: 1;* L: 1;* N: 2;0.5 P: 9;1.4 Q: 22;4.5 R: 8;1.4 S: 1;*)
		Jun(F: 4;* K: 1;* O: 2;* P: 2;0.5)
Pseudopleuronectes americanus	1974	Jun(D: 1;* F: 1;* I: 3;*, 21;2.3, 18;0.5 J: 11;1.4 K: 1;* N: 3;0.5 Q: 25;3.2 R: 2;0.5)
		Jul(A: 2;* B: 2;* F: 1;* H: 7;*, 13;1.4 K: 1;* O: 15;0.9, 3;*, 3;* P: 25;2.3 R: 13;0.9, 3;4)
		Aug(O: 1;* Q: 3;0.5)
		Sep(A: 3;* B: 4;0.5 D: 1;* E: 4;0.5, 16;0.9 G: 1;* I: 8;0.5 K: 2;* L: 3;* O: 2;* R: 5;0.5, 14;1.4)
		Oct(B: 1;* D: 27;2.7 E: 3;*, 12;1.4 G: 3;*, 43;3.2, 80;9.5 H: 7;0.5 I: 2;* J: 4;0.5 L: 16;0.9 M: 7;0.9 N: 57;4.5 O: 2;0.5 P: 26;4.1, 44;5.0 R: 35;5.0 S: 10;0.9)
		Nov(A: 8;0.9 B: 2;* C: 2;* D: 32;3.6 E: 13;2.3 G: 11;0.9, 122;14.5 H: 14;* I: 14;1.4, 117;4.1 J: 7;* M: 39;2.7 N: 6;0.9 O: 5;0.5 P: 27;5.0, 85;3.2 Q: 49;2.7 R: 49;5.9 S: 35;5.4)
	1975	Jan(B: 1;* C: 2;0.5 G: 31;1.8, 18;1.4 I: 44;3.2 K: 1;* M: 13;1.4 S: 3;0.5)
		Apr(A: 1;* F: 2;0.9 H: 1;* J: 3;* M: 1;*)
		May(B: 2;0.5 H: 4;0.9, 55;5.9 I: 4;0.5 J: 2;0.5 L: 3;0.5 M: 3;0.9 N: 8;1.4 P: 8;1.8 Q: 9;1.4 R: 7;0.9 S: 9;1.8)
		Jun(A: 15;0.9 D: 2;* N: 5;* O: 9;0.5 P: 20;1.4)
Monacanthus hispidus	1974	Aug(H: 1;*)
		Sep(B: 1;*)