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Chemical Properties

*James E. Alexander
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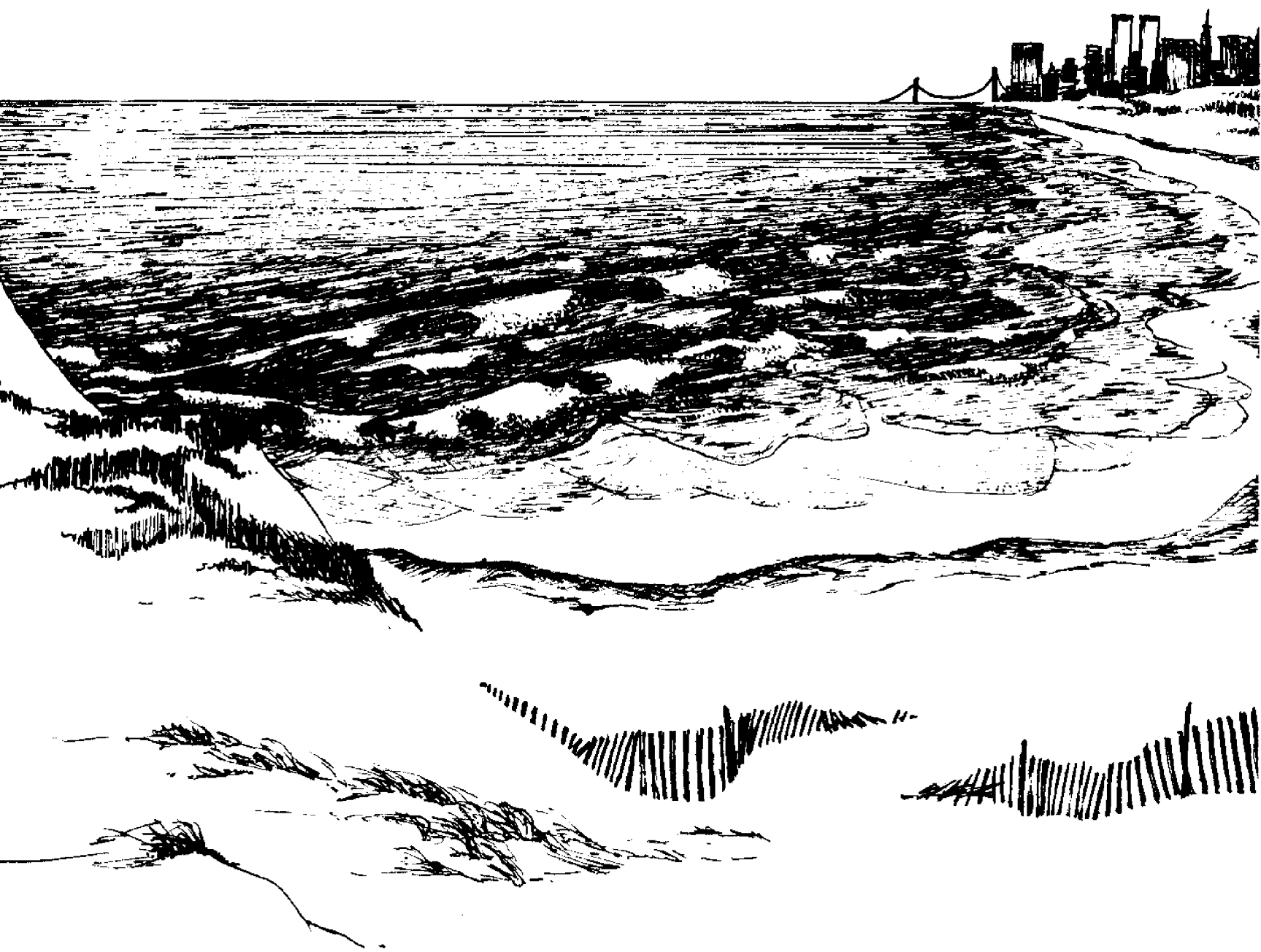
MESA NEW YORK BIGHT ATLAS MONOGRAPH   2

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

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

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

ATLAS MONOGRAPH 2 reviews what is known about the chemical properties of New York Bight—we know relatively little. Temperature-salinity relationships show Bight waters to be two-layered in summer and vertically uniform in winter. In the slightly alkaline Bight waters, concentrations of bulk elements like calcium/, magnesium/, potassium/, and strontium/chlorinity ratios are lower than in the open ocean. Trace metal data are limited but are important in determining chemical input sources and in understanding how dangerous metals like mercury are concentrated in the food chain. Concentrations of micronutrients, nitrogen, phosphorus, and silica reflect responses to pollution as well as to phytoplankton growth. Future chemical studies, says Alexander, should be directed toward determining, among other things, the impact of man's life processes on the chemistry of Bight waters.

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Chemical Properties

James E. Alexander
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MESA NEW YORK BIGHT ATLAS MONOGRAPH **2**

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Elizabeth Corwin Alexander, MS, has worked with Dr. Alexander for many years. Her research has dealt with primary productivity.

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Acknowledgments

Table 1. NODC ocean station data listing chemical parameters: frequency of observations

Year	Salinity	Oxygen	Phosphorus	Total Phosphorus	Nitrite Nitrogen	Nitrate Nitrogen	Silicon	Acidity Alkalinity
1920	2							
1927	4							
1928	5							
1931	12		11					
1932	44	18	17					8
1933	1							
1937	1							
1945	6							
1946	89							
1947	20							
1948	18							
1949	58	54	48					
1951	6							
1956	32	30	30	30	28	30		
1959	1							
1960	80							
1961	10	1						
1963	3	3						
1964	45	34	27	25				
1965	2	1						
1966	6							
1967	33	30						
1968	17	15						
1969	24	22	23	15	20	20	19	
1970	21	20						
1971	9	8						
1972	21		17					

Abstract

Knowledge of the chemical properties of New York Bight is limited due to lack of research. Temperature-salinity relationships indicate a two-layered system in summer and a vertically homogeneous system in winter. The pH of Bight waters generally ranges between 7.6 and 8.4. Average calcium, magnesium, potassium, strontium/chlorinity ratios are usually lower than those found in the open North Atlantic. Trace metal data indicate that more study is needed, especially for cadmium, copper, lead, and zinc. Dissolved oxygen concentrations of surface waters are commonly at or near saturation. Subsurface dissolved oxygen concentrations vary diurnally and seasonally; low subsurface values are attributed to chemical and biological oxygen demand. Concentrations of micronutrients, nitrogen, phosphorus, and silica reflect responses to phytoplankton growth, pollution, and regional variation. No significant radioactivity was found.

Introduction

Although New York Bight has been under study since at least 1920, the first data about the Bight were recorded in the files of the National Oceanographic Data Center (NODC) in 1931, when 11 samples were obtained for phosphorus measurement. Since 1931, temperature and salinity have been rather extensively studied (Bowman and Wunderlich, in press) but the number of chemical determinations has been low (Table 1).

Recent attention on dumping in the Bight has stimulated Middle Atlantic Coastal Fisheries Center, Woods Hole Oceanographic Institution, and State University of New York (SUNY) at Stony Brook to initiate research programs funded by the US Army Corps of Engineers, resulting in large amounts of data not yet held by NODC. This monograph brings together what information is available for a better understanding of the basic chemical oceanography of New York Bight and its major contributing estuary, the Hudson River.

Data Sources

Bibliographies prepared by Ali et al (1973) and NOAA's Environmental Science Information Center of Environmental Data Service (1974) were valuable for compiling pertinent chemical information. Lack of continuity and breadth in the historical data makes interpretation difficult. Since the single most comprehensive study of the distribution of selected chemical parameters, available for this report, was that conducted by Woods Hole Oceanographic Institution in September 1969 (Corwin 1970), this monograph uses those data where possible to depict the broad, spatial distribution of various parameters. All other information—principally the ocean station data of NODC, SUNY at Stony Brook, Middle Atlantic Fisheries Center, New York Ocean Science Laboratory, and NOAA's Marine EcoSystems Analysis Program—was used for comparative purposes.

September 1969

● Surface (1 m or 33 ft)
△ Bottom (20 m or 66 ft)

Temperature (°C)

Salinity (‰)

pH

○——— East River

●——— Hudson River

△——— The Narrows

▲——— Ambrose Channel

□——— Eastern boundary of Bight
(continental shelf edge)

Depth (m)
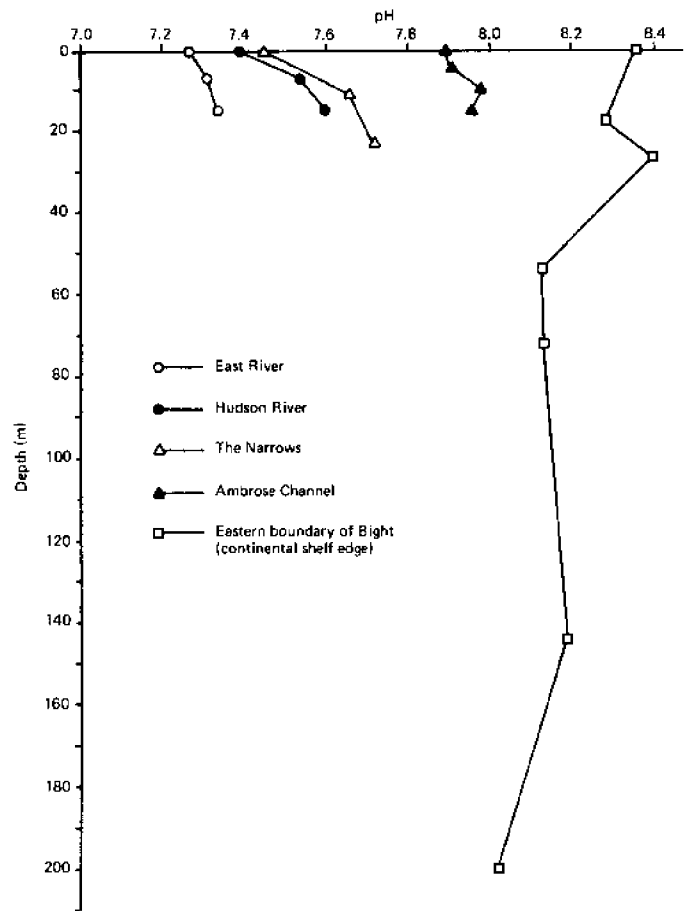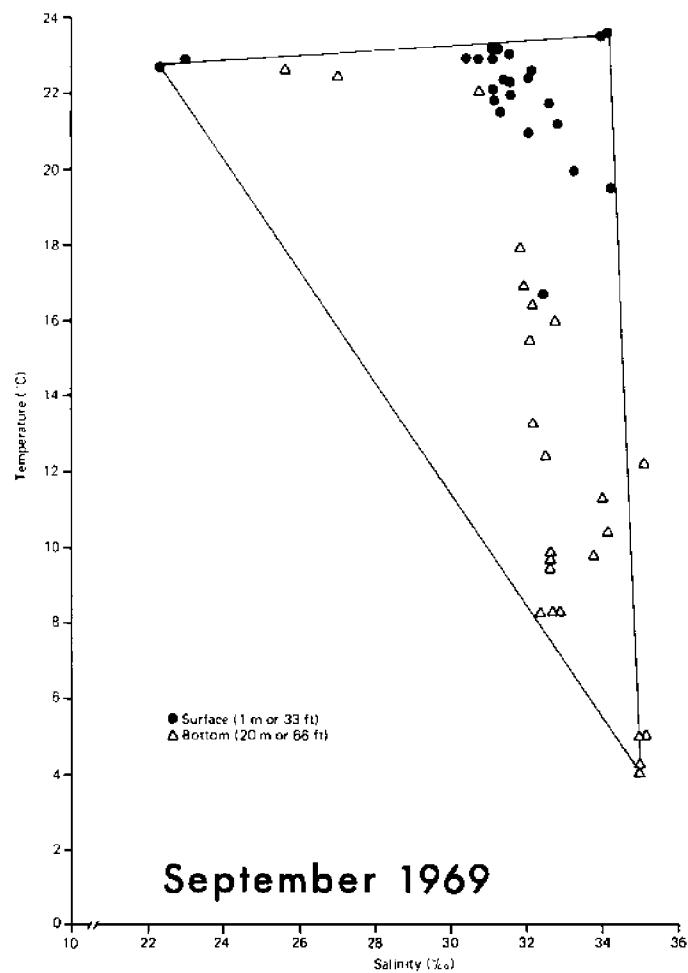
Figure 3. Vertical distribution of pH at selected locations

● Surface (1 m or 3 ft)
△ Bottom (20 m or 66 ft)

April 1971

Temperature (°C)
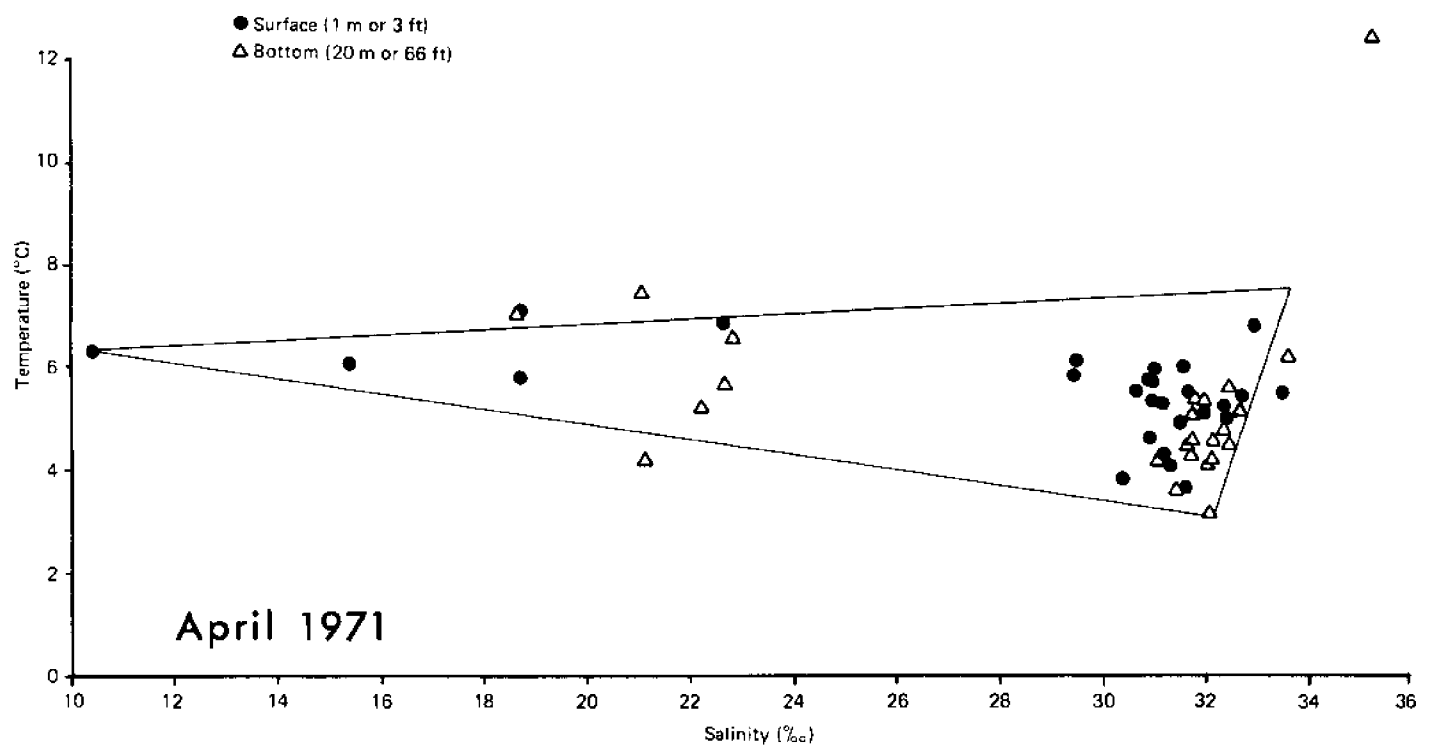
Salinity (‰)

Figure 1. Temperature-salinity relationships in Bight as a whole, September 1969 and April 1971

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Corwin's data (1970) are sufficiently comprehensive and limited in collection time to plot and contour at selected levels in the water column for the Bight as a whole. Depths of 1 and 20 m (3 and 66 ft) were chosen to represent the upper (surface) and lower (bottom) layers; the 20 m (66 ft) depth is below the thermocline. In all instances these data were contoured within the limits of the sampling grid designed by Corwin; lack of data precludes extrapolating to the shoreline. Vertical sections of many of these parameters across the shelf were presented by Ketchum, Redfield, and Ayers (1951), Kester and Courant (1973), and Horne, Mahler, and Rossello (1971). Unless otherwise indicated, tests for relationships and correlations (r) are as described in Youdens (1951).

Physical Parameters

The reader is referred to the National Academy of Sciences/National Academy of Engineering's study (1970) for an excellent discussion of the significance of physical processes and interactions in estuaries and coastal areas.

Two dominant circulation features of the Bight are: (1) an offshore southwesterly drift and (2) an inshore pattern of alternating clockwise gyres and counterclockwise eddies combined with the Lower Bay outflow. Detailed discussions of this circulation may be found in Ketchum et al (1951), Bumpus (1965), Hollman (1970), and Hansen (in press).

Tidal oscillations and winds, along with offshore shelf circulation, are important factors forcing the circulation in the Bight. Ketchum et al (1951) estimated the flushing rate near the Bight apex between Rockaway Point, NY, and Sandy Hook, NJ, to be on the order of six to eight days.

Figure 1 shows temperature-salinity relationships in the Bight. The two-layered system (shown primarily by the temperature difference between surface and bottom waters) present in September 1969 is characteristic of summer conditions in the Bight as a whole; the homogeneity of the system in April is characteristic of winter.

Acidity/Alkalinity (pH). Salt waters are naturally slightly alkaline, maintained by buffering from such systems as the carbon dioxide-bicarbonate-carbonate complex. In the upper Hudson River where the waters are fresh to slightly saline, Eisenbud et al (1965) reported pH values of 6.7 to 7.4; as the waters became more saline in the lower sections of the river, near New York City, Alexander (unpublished data) found the pH ranging between 7.1 and 8.0. The relationship between pH and the salinity of these waters (Figure 2) reflects the mixing of seawater with fresh water, which in turn affects the solubility of carbon dioxide (temperature must also be considered).

The pH of Bight waters generally ranges between 7.6 and 8.4 (Friedman et al 1968; Marine Sciences Research Center 1973). Profiles of pH are shown in Figure 3. Typically, higher pH values are encountered
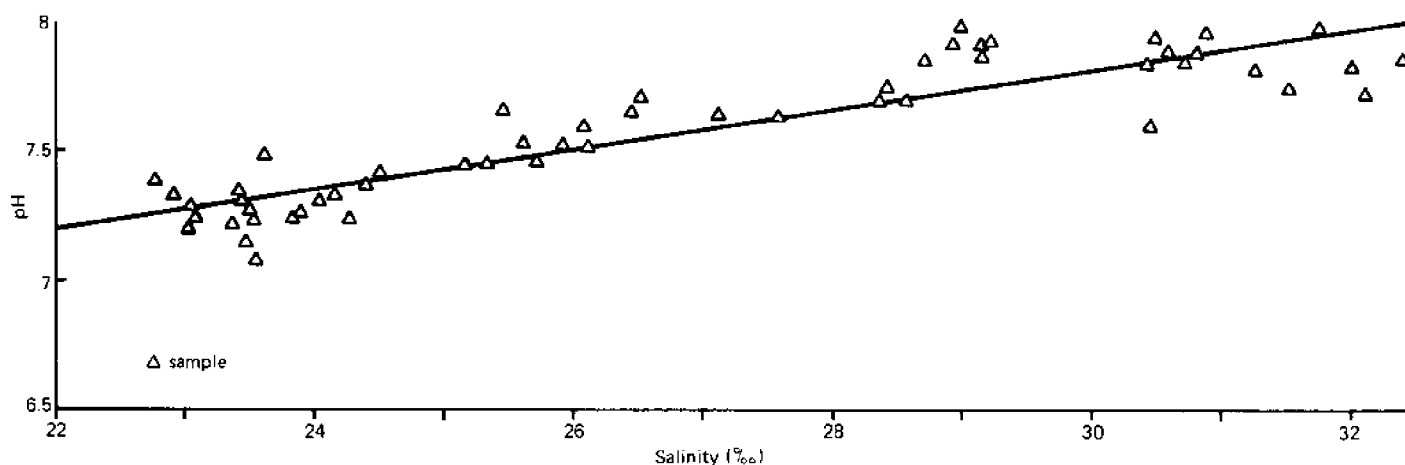
Figure 2. Salinity-pH relationship in New York Harbor, November 1974

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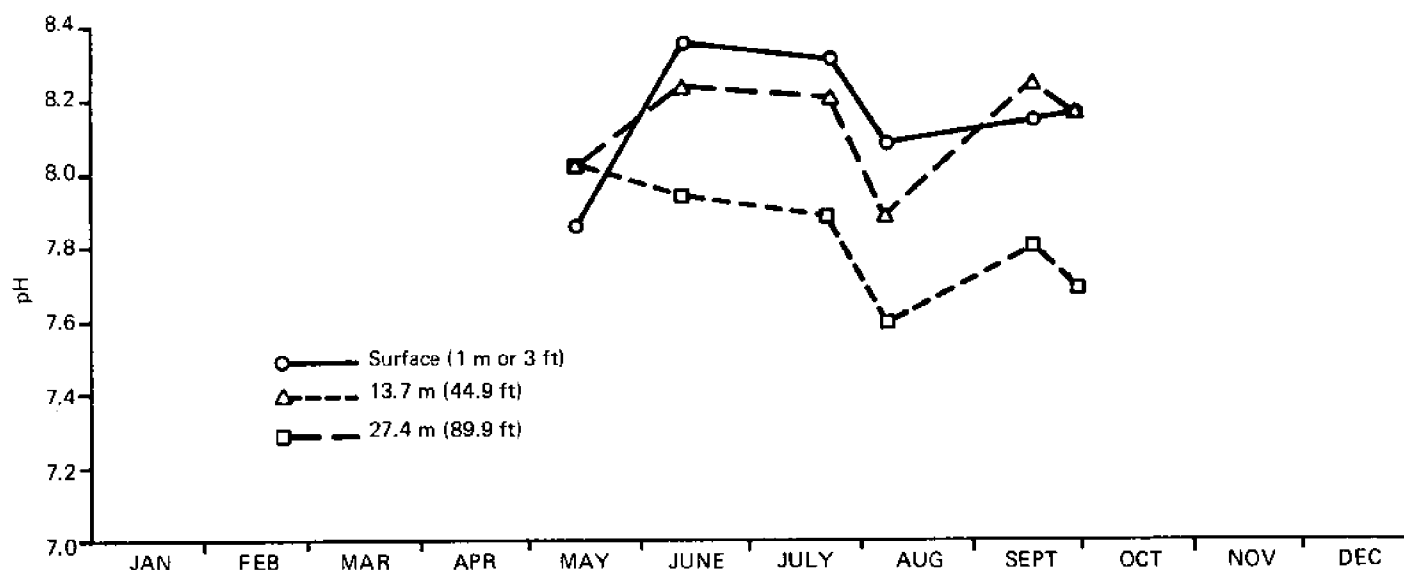
Figure 4. Variation in pH of waters near sewage sludge dumpsite, May-September 1970

near the surface where the water is in near-equilibrium with atmospheric carbon dioxide.

Evidence for some seasonal variation of pH in the Bight apex is indicated in Middle Atlantic Coastal Fisheries Center data. Monthly variations were found at three depths (Figure 4). The low pH in bottom waters during summer is attributed to proximity to the sewage sludge dumping grounds and hence to biochemical processes, such as decomposition of these materials.

Oxidation-Reduction Potential (Eh). The extent to which materials can undergo oxidation-reduction (that is, the gain or loss of oxygen) depends primarily upon the amount of such substances present. In a given system, the proportion of the oxidizable to the reducible components is referred to as the oxidation-reduction potential (Eh), or the redox potential, and is measured in millivolts (mv).

Eisenbud et al (1965) found that the Eh of Hudson River subsurface waters ranged between 185 and 190 mv. The Eh of New York Harbor waters ranged between 208 and 252 mv (Table 2). Factors controlling the low Eh at The Narrows and between Rockaway Point and Sandy Hook are not clear. No strong relationships between Eh and dissolved oxygen were found in the harbor.

Table 2. Oxidation-reduction potential of New York Harbor waters

Depth		Eh (mv)		
		Upper Bay (adjacent to The Battery)		
m	ft	East River	Hudson River	
1	3	247	252	
7	23	244	247	
14.5	47.6	246	242	
		The Narrows		
0	0	217		
12	39	209		
24	79	208		
		Lower Bay		
		Rockaway Point	Ambrose Channel	Sandy Hook
0	0	243	236	224
5	16	237	216	222
10	33	226	226	218

Source: From Alexander, unpublished data

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Bulk Elements

The major constituents of seawater are chloride, calcium, magnesium, sodium, potassium, sulphate, bicarbonate, strontium, boron, bromine, and fluorine (see Table 3 for symbols of elements mentioned). A

review of early studies on the major constituents of seawater was presented by Culkin (1965); a reinvestigation of the bulk elements in the world's oceans was completed and reported by Culkin and Cox (1966) and Morris and Riley (1966).

In the Hudson River system and in the Bight, only limited data on the water's major constituents are available. Fabricand, Imbimbo, and Brey (1968) reported on the distribution of calcium, magnesium, potassium, sodium, and strontium, in near-surface Hudson River samples from just below the Tappan Zee Bridge to Troy, NY (Table 4). Their calculations of the contribution of these elements to the Bight, based on a discharge rate of 1,100 m³/sec (290,598 gal/sec) are shown in Table 5.

Precipitation also contributes some bulk elements to the Hudson River and hence to the ocean. The composition of 30-day composites of rainwater

Table 3. Selected chemical elements and symbols

Element	Symbol	Element	Symbol
Aluminum	Al	Mercury	Hg
Arsenic	As	Nickel	Ni
Boron	B	Oxygen	O
Bromine	Br	Phosphorus	P
Cadmium	Cd	Potassium	K
Calcium	Ca	Radium	Ra
Carbon	C	Radon	Rn
Cerium	Ce	Rubidium	Rb
Cesium	Cs	Ruthenium	Ru
Chlorine	Cl	Silicon	Si
Chromium	Cr	Silver	Ag
Cobalt	Co	Sodium	Na
Copper	Cu	Strontium	Sr
Fluorine	F	Sulfur	S
Iron	Fe	Thorium	Th
Lead	Pb	Vanadium	V
Lithium	Li	Zinc	Zn
Magnesium	Mg	Zirconium	Zr
Manganese	Mn		

Source: Webster's New Collegiate Dictionary 1974

Table 5. Contribution rate of dissolved elements to ocean from Hudson River

Element	Rate kg/sec	Rate short tons/day
Calcium	28.0	2,661
Magnesium	7.7	732
Potassium	1.4	133
Sodium	18.0	1,710
Strontium	0.16	15.2

Source: From Fabricand et al 1968

Table 4. Concentration of selected bulk elements in Hudson River

Approximate distance from The Battery km	mi	Ca	Mg	Element (in parts per million) K	Na	Sr
56	45	140.0	456.0	93.00	2,500.0	2.240
90	56	34.2	87.0	19.00	515.0	0.390
130	81	18.0	5.0	0.88	9.7	0.080
180	112	25.4	5.8	1.10	16.3	0.090
210	130	27.4	6.7	1.30	16.1	0.180
240	149	20.8	7.6	1.10	14.7	0.140
Durum et al (1960)		32.0	4.9	2.00	4.8	0.106
Poughkeepsie, NY				2.50	29.0	0.103
Livingstone (1963)		15.0	4.1	2.30	6.3	
World ocean		413.0	1,294.0	387.00	10,760.0	8.000

Source: From Fabricand et al 1968

collected at Mineola, NY, for 1973 is shown in Figure 5. Although regular variations in the amount of calcium, magnesium, sodium, and potassium in rainfall were noted throughout the year, only moderate correlations between two elements and the amount of precipitation showed up—for calcium (−0.644) and for magnesium (−0.701). Sodium, potassium, sulfate, and chloride concentrations were not related to the amount of precipitation, although Pearson and Fisher (1971) found relationships between sodium, chloride, and precipitation in the northeastern United States. According to Gordon (1970), the amount of rainfall in relationship to the Bight "is small in comparison to runoff and inflow of ocean water onto the shelf and can be neglected in general." If this is so, then the rainfall contribution of bulk elements to the Bight would be small compared to that contributed through the Rockaway Point-Sandy Hook region.
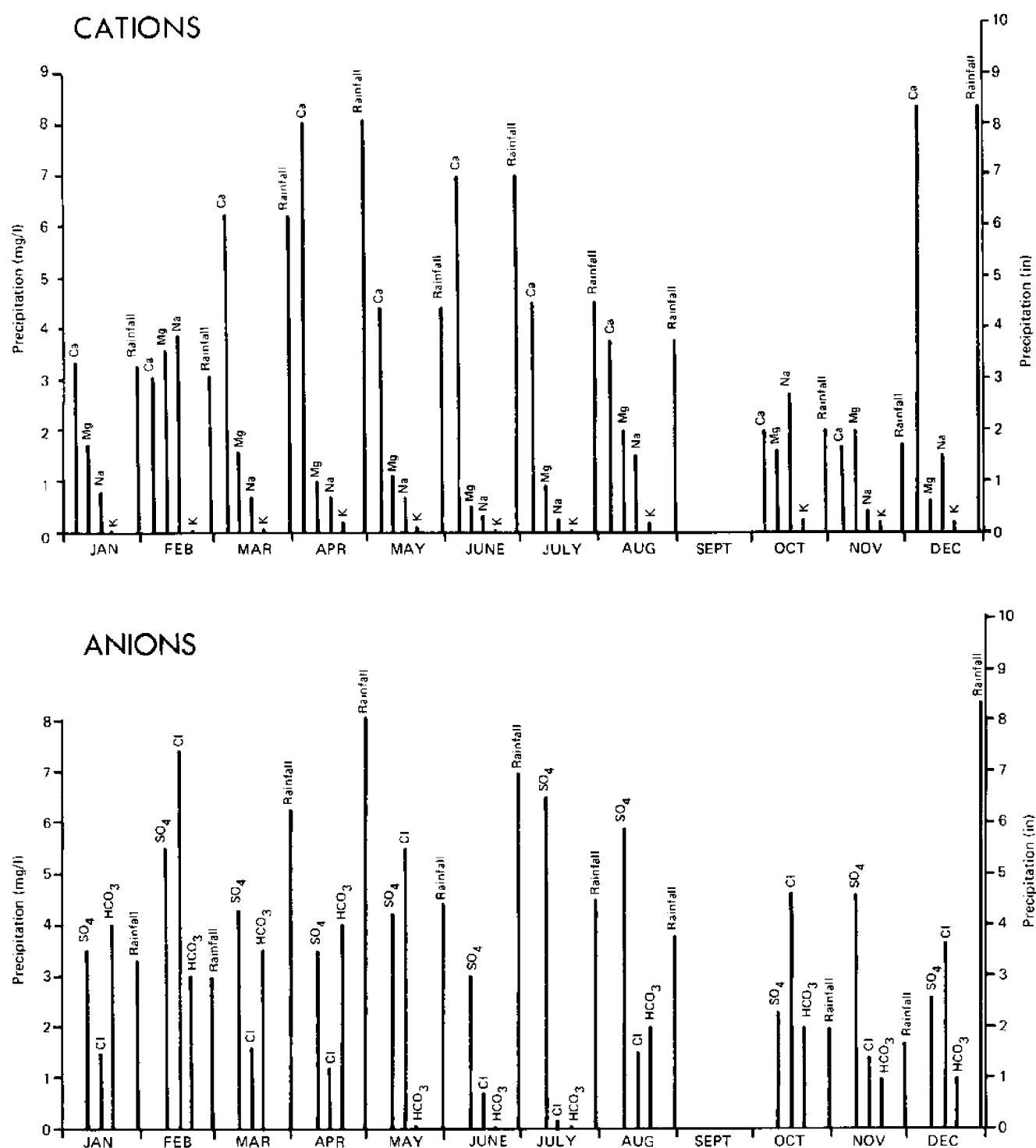

Figure 5. Composition of rainfall in Mineola, NY, 1973

For the open waters of the Bight, only data from Friedman et al (1968) are available at this time. Friedman and his associates compared the chemical characteristics of seawaters and interstitial waters in sediments of contrasting types from the continental shelf. The bulk ions studied were calcium, magnesium, strontium, and potassium in surface and bottom seawater.

In oceanography, rather than discuss the absolute concentration of elements present in major amounts (such as the above) we generally compare their abundance to that of a standard or, in other words, a ratio. The standard in this instance is chlorine, which is present as the chloride ion and makes up some 55% by weight of the dissolved material. Regardless of the *absolute* concentration of the total solids, the *ratios* between the more abundant substances are virtually constant, particularly in the open sea. Larger deviations may be expected in coastal waters, especially at the mouths of rivers. Such ratios are useful in examining processes occurring in a particular region. Data for the Bight are summarized below.

On the inner shelf, calcium concentrations in surface waters at two locations adjacent to Fire Island were 0.346 and 0.342 mg/kg; calcium concentrations in bottom waters (2.5 m or 8.2 ft above the bottom) were 0.357 and 0.355 mg/kg. No significant variations in calcium/chlorinity ratios were found in the surface waters. Only one of five stations showed significant differences in the bottom water calcium/chlorine ratio. In all instances, however, the ratio increased with depth.

The concentration of magnesium also was greater in bottom waters than in surface waters. The range of concentrations on the inner shelf was 1.084 to 1.109 mg/kg (surface) and 1.106 to 1.150 mg/kg (bottom); on the outer shelf the concentrations ranged between 1.48 to 1.88 mg/kg (surface) and 1.261 to 1.573 mg/kg (bottom). With one exception no significant differences were noted between the magnesium/chlorine ratios of the inner and outer shelf and between surface and bottom waters. Because of limited data in the report (Friedman et al 1968), no special importance is attached to the exception.

Surface concentrations of potassium were higher on the outer shelf than on the inner shelf and in all instances were higher in bottom waters than surface waters. Potassium concentrations in surface waters ranged from 0.322 to 0.329 mg/kg (inner shelf) and from 0.339 to 0.348 mg/kg (outer shelf); bottom waters contained 0.336 to 0.348 mg/kg (inner shelf) and 0.377 to 0.394 mg/kg (outer shelf). No consistent pattern of changes in the potassium/chlorine ratios were found.

Strontium concentrations in surface and bottom waters ranged between 7.30 and 7.35 mg/kg; no real differences were noted between the two levels. Outer shelf waters contained from 7.47 to 7.54 mg/kg in surface waters and from 7.51 to 7.98 mg/kg in bottom waters. Strontium/chlorine ratios generally decreased with depth.

The average element/chlorinity ratio of these four elements is shown in Table 6. As expected for coastal waters, ratios for the Bight are generally lower than those presented by Culkin and Cox (1966) for the open North Atlantic. The difference is attributed to the diluting effects of runoff and precipitation.

Table 6. Average element/chlorinity ratios (mg/kg/Cl °/oo)

	Ca/Cl	Mg/Cl	K/Cl	Sr/Cl
New York Bight[a]	0.0208	0.0652	0.0195	0.419
North Atlantic[b]	0.02128	0.06691	0.0206	0.40

Sources: [a]From Friedman et al 1968
[b]Culkin and Cox 1966

Trace Elements

Trace elements, such as iron, copper, zinc, cobalt, and manganese, are generally present in minute quantities in seawater. Their significance, in actual concentration and in existing form, lies in their relationship to the biota. In appropriate form and concentration, they act as biostimulants or biodepressants. The ability of certain elements to be concentrated many-fold via the food chain has led to dangerous situations, such as the mercury problem in Minamata, Japan.

Since Richards (1956) commented on the general lack of knowledge about the distribution of trace elements in the sea, the marine scientific community has increased efforts to obtain appropriate data. Concern over the impact of selected trace metals upon marine ecosystems has greatly stimulated research in this area. Unfortunately, the state-of-the-art has dictated that only selected forms of a given metal can be determined—generally the total soluble and particulate fractions. Because of growing evidence that many trace elements exist primarily as a metal-

organic complex, we urgently need to develop appropriate methodologies for determining the nature of metal-organic compounds in the sea.

The Public Health Service (1965) of the US Department of Health, Education and Welfare (HEW) measured the trace element content of surface waters at a station near Poughkeepsie, NY, as part of a national survey from September 1958 to June 1963. Samples were collected weekly, filtered, and analyzed, usually by spectrograph (which spreads radiations into a spectrum). Since this method is not at all sensitive to trace amounts, many metals went undetected and the tabulated data indicated only upper limits. Howells and Bath (1969) listed the concentration of selected trace elements for the interval 1962-1969. Concentration average and range found are shown in Table 7.

Table 7. Average concentration of trace metals in Hudson River at Poughkeepsie, NY, 1962-1969

Element	Concentration (µg/l)	
	Average	Range
Arsenic	32.3	10.0 to 50.0
Cadmium	6.9	1.0 to 16.0
Chromium	6.9	2.0 to 10.0
Copper	25.4	7.0 to 72.0
Iron	44.6	7.0 to 154.0
Manganese	2.6	0.8 to 4.5
Nickel	5.6	1.0 to 12.0
Silver	0.6	0.3 to 1.2
Zinc	43.4	8.0 to 75.0

Source: From Howells and Bath 1969

Although the copper, iron, and manganese appear to be comparable within the concentration and concentration ranges presented by Goldberg (1965) and Riley (1965), the concentrations of the remaining trace elements appear to be higher than

might be anticipated for this region. Whether this reflects analytical difficulties or man-induced input to the river remains unclear.

No significant long-term trends were found in these data, but several important interelement relationships were present (Table 8). By establishing such interrelationships one may, at times, infer the source of the material—for example, strong chromium-nickel relations suggest industrial input to the river. We have established such relationships by determining the correlation coefficient, r. The greater the distance of r from zero, the less likely that the two variables are independent. In this monograph we consider r values greater than 0.75 as strong and significant and warranting further investigation, especially cadmium relationships.

In summer 1965 and fall 1966 Howells and Bath (1969) investigated the distribution of selected trace metals in the Hudson River from 43 to 138 km (27 to 86 mi) north of Battery Park, Manhattan (Table 9). Strong relationships existed between location and concentration of iron, zinc, and strontium in November 1966; concentration of both iron and zinc increased with distance above Battery Park, whereas strontium concentration decreased. In summer 1965 (a period of low runoff), iron concentration decreased with distance above Battery Park. No significant correlations with distance were found for the remaining parameters. It is probable that the above correlations were influenced by the river's runoff characteristics. For a more complete discussion of these data see Lauer (1970).

Fabricand et al (1968) found chromium, cobalt, iron, lead, lithium, manganese, nickel, and rubidium in such low concentrations that with their methods they were unable to quantitatively determine them. Copper ranged from less than 5 to 11 µg/l and varied inversely with the salinity of the water ($r = -0.864$).

Table 8. Interelement correlation coefficients, Poughkeepsie, NY, 1962-1969

	Fe	Mn	Zn	Cu	Cd	Cr	Ni	Pb	As	Ag
Fe	1.000	−0.453	0.599	0.123	−0.325	−0.049	−0.346	0.148	−0.507	−0.358
Mn		1.000	−0.192	−0.065	0.113	0.281	0.327	−0.329	0.365	0.204
Zn			1.000	−0.778	−0.144	−0.111	−0.221	0.180	−0.204	−0.109
Cu				1.000	−0.261	−0.388	−0.107	−0.122	−0.055	−0.308
Cd					1.000	0.845	0.938	0.750	0.824	0.993
Cr						1.000	0.814	0.649	0.598	0.847
Ni							1.000	0.834	0.917	0.944
Pb								1.000	0.727	0.744
As									1.000	0.841
Ag										1.000

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Element	Summer 1965 (µg/l)		Fall 1966 (µg/l)	
	Average	Range	Average	Range
Aluminum	192.0	20.0 to 550.0	—	—
Chromium	—	—	1.8	0.5 to 4.0
Copper	31.5	17.0 to 78.0	122.2	22.0 to 260.0
Iron	95.0	10.0 to 280.0	82.5	60.0 to 130.0
Manganese	75.0	1.0 to 400.0	6.7	3.0 to 11.0
Nickel	24.8	15.0 to 44.0	1.8	1.0 to 4.0
Silicon	0.76	0.05 to 2.0	270.8	120.0 to 570.0
Zinc	98.5	4.0 to 310.0	8.8	6.0 to 15.0

Source: From Howells and Bath 1969

The seasonal cycle of iron in the Hudson River along a fixed transect opposite Indian Point, NY, is shown in Figure 6. Over one year (1969) the differences among the three locations across the river were not statistically significant. The observed changes in iron concentration (maximum in spring and minimum in summer) are undoubtedly related to the flow characteristics of the river. The distribution of zinc and lead showed similar patterns, whereas the amount of manganese, copper, cadmium, and nickel was independent of time and location.

Klein et al (1974) reported the average distribution of copper, chromium, nickel, zinc, cadmium, lead, and mercury at 12 stations in New York Harbor and in the Bight from September 1972 to June 1973. Their results generally showed that during this time the Hudson River contained significantly less copper, nickel, zinc, cadmium, and lead than the lower East
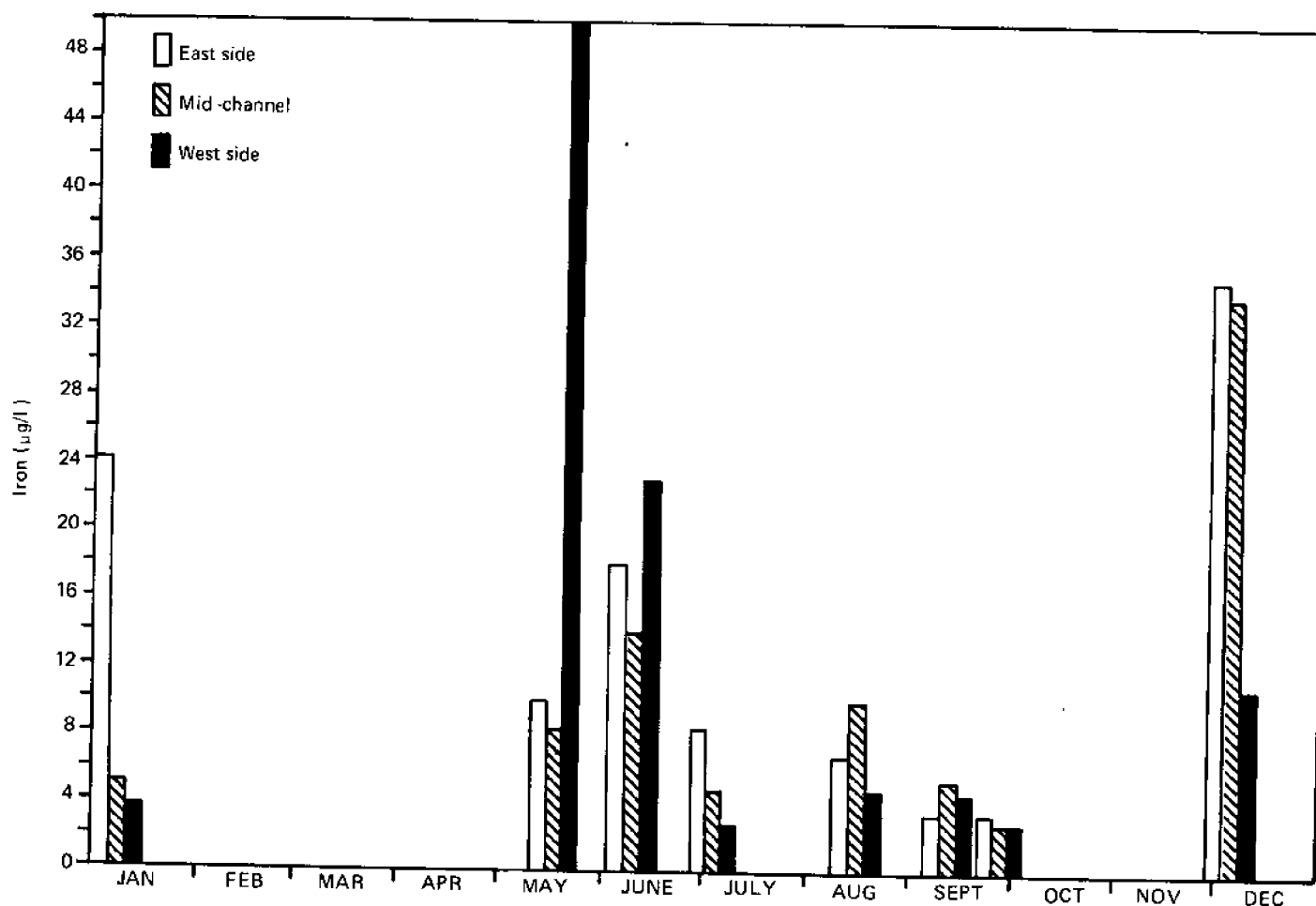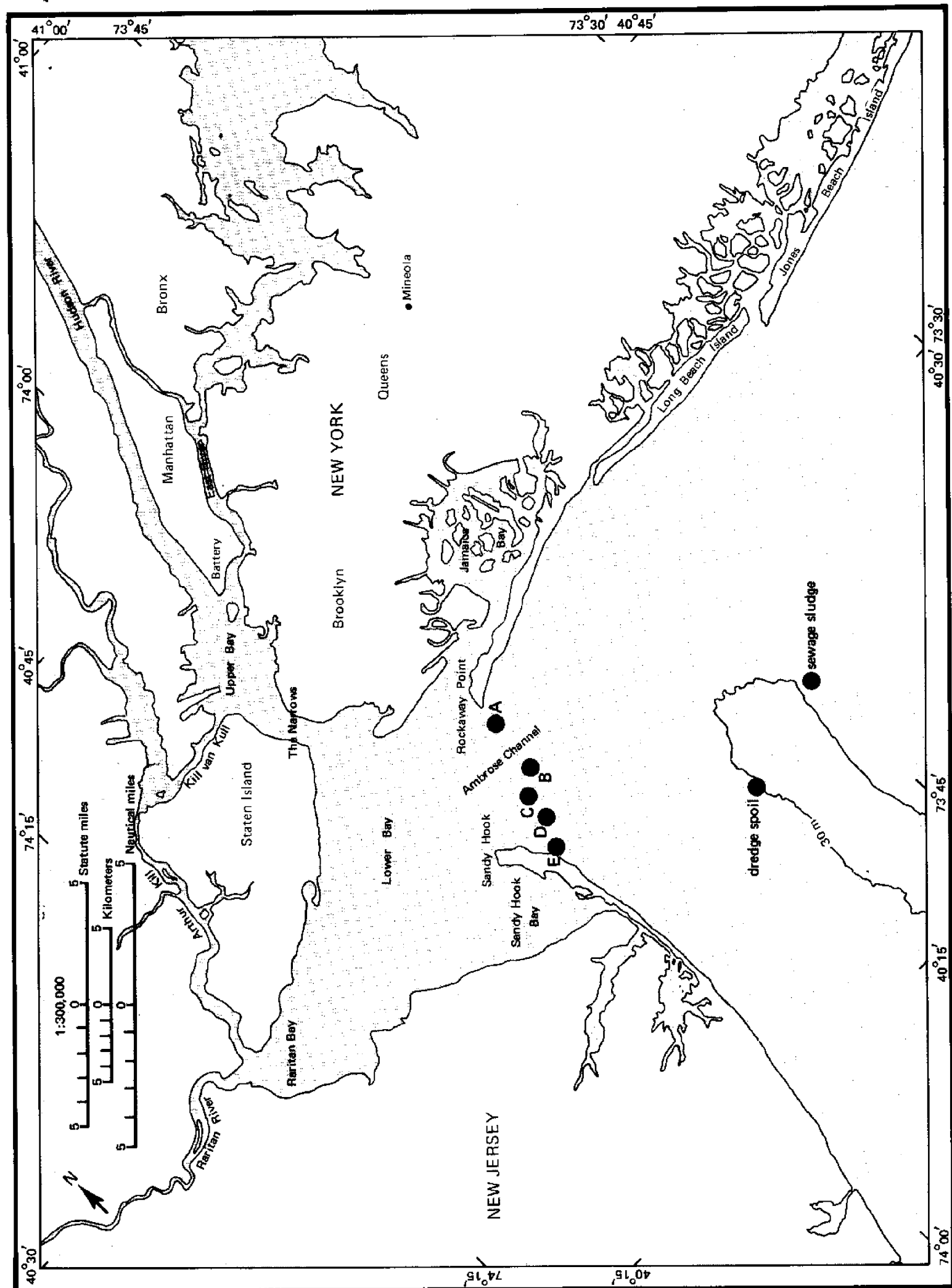

Figure 6. Seasonal cycle of iron in Hudson River near Indian Point, NY, 1969

Map 1. Station locations, 8-9 November 1973

River; less copper and zinc but more chromium than the upper East River; and less copper, nickel, zinc, cadmium, and mercury than the Kill van Kull. Jamaica Bay contained more copper and less lead than the Hudson River.

Unfortunately, in all trace element studies discussed, no data were presented for the particulate fraction. Alexander, Hollman, and White (1974) examined the temporal and spatial distribution of selected trace metals along the Sandy Hook-Rockaway transect (Map 1) in November 1973. Their results showed that particulate lead, cadmium, cobalt, and nickel were always less than 0.5, 0.1, 0.2, and 0.2 μg/l, respectively. Figure 7 shows the relationship between time, the velocity profile, and the concentration of particulate iron and copper in the water column. Both elements showed a strong relationship to the tide stage: maximum values for particulate iron and copper were generally present in the upper portion of the water column just after maximum ebb; minimum concentrations ($\angle$50 μg Fe/l and $\angle$0.6 μg Cu/l) were present at maximum flood tide. The least change in concentration over the tidal cycle was observed at station B. Station A was unique in that the highest concentrations of particulate iron and copper were present in the lower portion of the water column.

Alexander and his colleagues hypothesized that their data could be explained if "pools"* of water containing differing concentrations of heavy metals were moving with the tide through each station. If this were so, then the observed metal values should vary inversely, as does salinity, and a high negative correlation should therefore exist. Moderate to strong correlations existed between trace metals and salinity at stations C, D, and E but not at A and B (Table 10). The lack of correlation at stations A and B was attributed to the different history of the "pools." The reader is referred to the report of Klein et al (1974) for a discussion of the varying qualities of the water column.

Although no significant differences were found between the mean particulate iron and copper concentrations for both the flooding and ebbing tides, significant differences were noted when the mean concentration of the metal present in the water

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*These "pools" are best explained thus: imagine standing in the air above a station and being able to see iron, copper, and salinity in the surface water flowing from Lower Bay into the Bight. You would see a continuous hourglass configuration in which the bulges would be "pools" of high metal concentration and low salinity and the narrow sections between the bulges would be "pools" of low metal concentration and high salinity.

Table 10. Correlation coefficients between salinity and particulate iron and copper, 8-9 November 1973

	Station[a]				
	A	B	C	D	E
Copper	−0.364	−0.258	−0.754	−0.908	−0.954
Iron	−0.340	−0.020	−0.581	−0.860	−0.888

[a] Refer to Map 1 for station locations

Source: Alexander et al 1974

column was tested between maximum flood-maximum ebb (when the water is falling) and maximum ebb-maximum flood (when the water is rising). With the exception of particulate iron at station B, all these data were statistically different. This indicates that the presence of a "pool" of elevated heavy metal concentrations can be detected at a station well into the flood stages.

Strong correlations were found between particulate iron and copper (Table 11). The particulate iron and copper data of Piotrowicz et al (1972) also show a strong correlation (r = 0.968).

Table 11. Correlation coefficient between particulate iron and copper, 8-9 November 1973

	Station[a]				
	A	B	C	D	E
Correlation Coefficient	0.256	0.921	0.885	0.958	0.928

[a] Refer to Map 1 for station locations

Source: Alexander et al 1974

Mean particulate zinc concentrations present in the water column in November 1973 are shown in Table 12. Although limitations were imposed on these zinc data, the trends observed were similar to those for particulate iron and copper. Least concentrations were found at station B.

Table 12. Mean particulate zinc concentration, 8-9 November 1973 (μg/l)

	Station[a]				
	A	B	C	D	E
Rising[b]	3	3	2	4	4
Falling[c]	3	1	2	2	2

[a] Refer to Map 1 for station locations
[b] Calculated from maximum ebb to maximum flood
[c] Calculated from maximum flood to maximum ebb
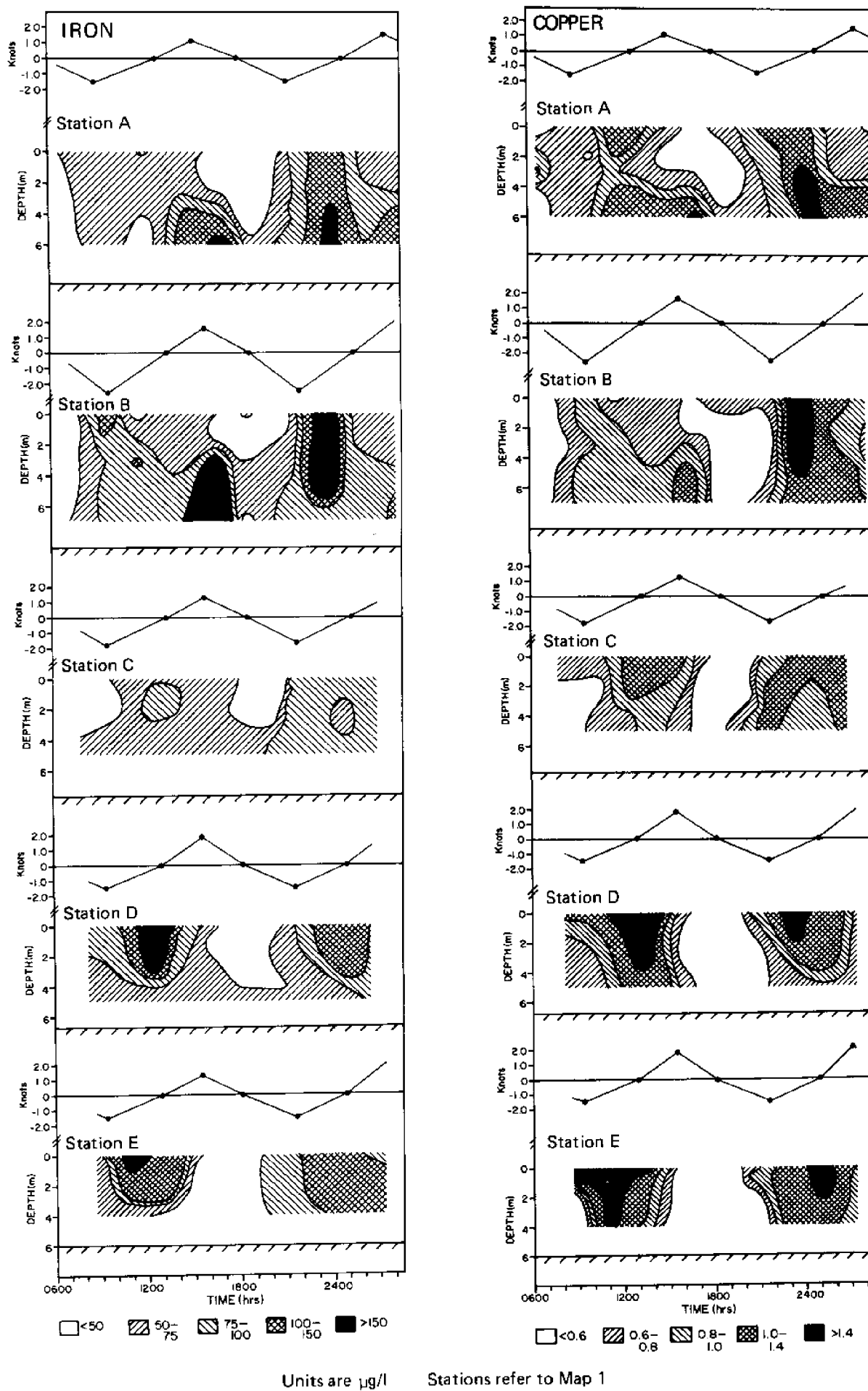
Source: From Alexander et al 1974

Figure 7. Distribution of particulate iron and copper along Sandy Hook-Rockaway transect, November 1973

Alexander et al (1974) also found that total soluble zinc concentrations near Rockaway Point were generally less than 10 $\mu g/l$, whereas near Sandy Hook, the concentrations ranged from 16 to 26 $\mu g/l$.

Total soluble lead concentrations averaged less than 3 $\mu g/l$ for all stations except station E. No significant differences in concentration existed between the rising and falling tides.

No correlation between cadmium, cobalt, and salinity or tidal stage was found. In general, cobalt and cadmium concentrations were less than 0.5 $\mu g/l$. The highest observed concentrations of soluble cobalt and cadmium were 0.6 and 1.0 $\mu g/l$, respectively.

Mean concentrations of three total soluble trace metals during flood and ebb tidal cycles and during rising and falling tides are shown in Table 13. Mean concentration of total soluble nickel was generally higher on the flood and the rising tide. These data were found to be statistically significant only for station C during flood and ebb.

Table 13. Mean concentrations of three total dissolved trace metals, 8-9 November 1973

($\mu g/l$)

	Station[a]				
	A	B	C	D	E
Copper					
Flood	8.8	7.2	4.5	8.8	7.5
Ebb	5.5	3.9	5.9	3.8	5.8
Rising	6.5	6.2	6.1	9.2	9.0
Falling	6.1	4.4	4.7	2.9	3.6
Iron					
Flood	5.4	5.3	5.6	4.5	2.3
Ebb	4.0	6.1	5.7	5.5	4.0
Rising	4.3	6.5	7.4	8.2	3.8
Falling	4.5	4.7	4.6	2.1	3.4
Nickel					
Flood	13.8	21.1	19.1	18.9	9.1
Ebb	8.5	20.6	5.9	13.4	7.5
Rising	10.5	14.2	12.2	19.0	10.4
Falling	8.6	19.7	8.7	9.7	5.5

[a]Refer to Map 1 for station locations

Source: From Alexander et al 1974

The distribution of total soluble iron over this same tidal cycle is shown in Figure 8. With one exception the concentration of total soluble iron was less than 20 $\mu g/l$. Evidence of the relationship found for particulate iron was also present in the soluble iron data, namely, the highest concentrations were
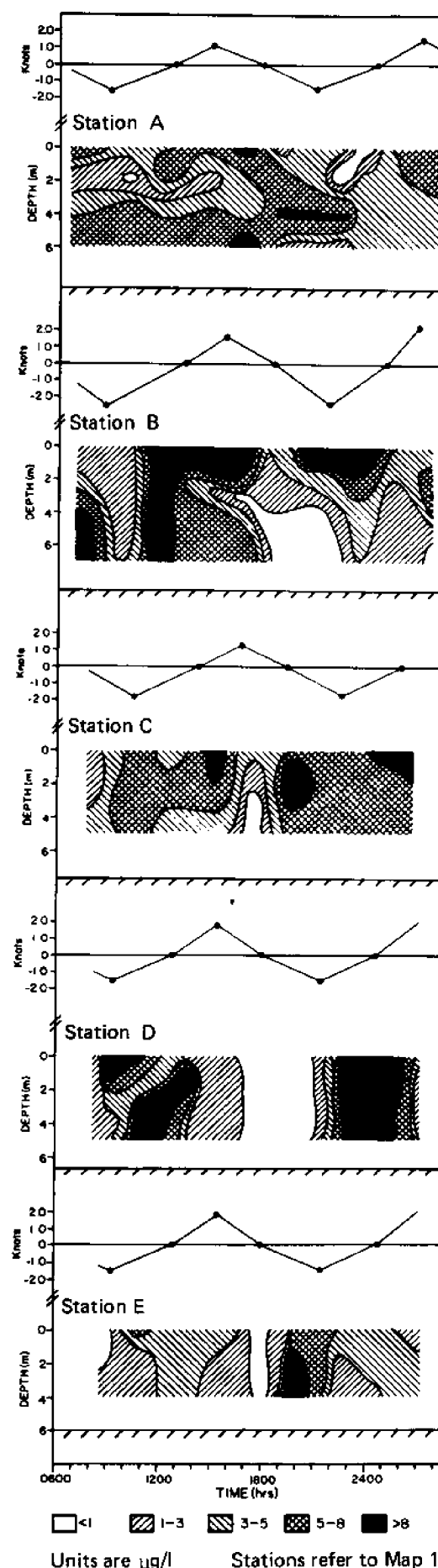

Figure 8. Variations in total soluble iron concentrations along Sandy Hook-Rockaway transect, November 1973

generally present in the water column at the beginning of the rising tide. Significant differences in the concentration of total soluble iron between the various tidal stages were only found at station D during the rising and falling tide (Table 13). No significant correlations were found between total soluble iron and copper, lead, cadmium, and nickel. Alexander et al (1974) noted that iron existed primarily in the particulate form and that no significant relationships existed between particulate and total soluble iron.

Historically, data on the distribution of heavy metals are scarce. Only the data of Ketchum et al (1951), Klein et al (1974), and Middle Atlantic Coastal Fisheries Center (1972) were available for comparison with Alexander's data. The average concentrations of iron, copper, nickel, zinc, cadmium, and lead from these four data sources are shown in Table 14. Iron concentrations reported by Ketchum et al represent discreet analyses for reducible iron, whereas those of Klein et al represent composite sample analyses for total iron.

Although the range of iron found by Alexander et al (1974) is comparable to that of Ketchum et al, Alexander's average concentration was lower. This was attributed to a difference in tidal sampling time, which would markedly influence the data. The high iron values found by Middle Atlantic Coastal Fish-

eries Center are attributed to the unusual conditions resulting from the disposal activities in their study area. For the other five metals, only the data of Klein and Alexander were available.

No real differences were apparent in the two sets of nickel data, but Klein's results for copper, cadmium, and lead were higher than Alexander's. The precise reasons for these differences are not immediately apparent, although the time of year may be relevant since Klein's data were collected from June to September 1973, whereas those of Alexander et al were collected in November. The flow characteristics of the river are expected to be different between these two sampling times.

Chromium concentration in Sandy Hook and Raritan bays in summer 1971 was reported by Mytelka (1973) to be less than 10 $\mu g/l$. Average concentrations for copper, nickel, zinc, cadmium, mercury, and lead are shown in Table 15. The

Table 15. Average concentrations of selected trace metals in Raritan and Sandy Hook bays, summer 1971

| | Concentration ($\mu g/l$) | | | | | |
	Cd	Cu	Pb	Hg	Ni	Zn
Sandy Hook Bay	0.9	64	4	0.23	46	44
Raritan Bay	2.4	73	6	0.25	45	127

Source: Mytelka 1973

Table 14. Average metal concentrations in Bight apex

| Metal | Concentration ($\mu g/l$) | | | | Reference[a] |
| | Average | | Range | | |
	Particulate	Total Soluble	Particulate	Total Soluble	
Cadmium	na	3.1	na	na	(3)
	<0.1	<0.1	—	<0.1-0.8	(1)
Copper	na	80	na	na	(3)
	0.8	5.6	0.29-3.02	<0.2-19.6	(1)
Iron	na	88[b]	na	20-180[b]	(2)
		50[c]		nd-2,089[d]	(4)
	74.1	4.6	20.3-258.1	<0.3-25.6	(1)
Lead	na	140	na	na	(3)
	<0.5	<3	—	<0.5-8	(1)
Nickel	na	10	na	na	(3)
	<0.2	11.3	—	<0.4-72.4	(1)
Zinc	na	11	na	na	(3)
	—	19	—	1-120	(1)

[a]References: (1) Alexander et al 1974
(2) Ketchum et al 1951
(3) Klein et al 1974
(4) Middle Atlantic Coastal Fisheries Center 1972

[b]Reducible iron
[c]Total iron
[d]Dump area

nd—not detectable
na—not available

observed differences in copper and zinc concentrations in Sandy Hook and Raritan bays were statistically significant.

Piotrowicz et al (1972) determined the trace element composition of the near-surface layers in Lower Bay and in the open waters of the Bight. Aluminum, copper, iron, lead, manganese, and vanadium were determined in the upper 100 to 150 μm of the water column and at a depth of 20 cm (8 in). The highest metal concentrations were found near shore. Surface layers were enriched in particulate lead, and this (along with vanadium concentrations) was attributed in part to fallout of atmospheric particulates. Present in the data were strong correlations between particulate iron-aluminum, copper, and lead.

In the open waters of the Bight apex, Ketchum et al (1951) calculated that the amount of reducible iron delivered to the vicinity of Scotland Lightship by river effluents ranged from 112 tons per day in April 1948 to an average low of 50 tons per day for the remainder of that year. In August 1949 an observed decrease of 15 tons delivered was attributed to a change in industrial disposal practices upstream in the Raritan River. The investigators also found that the greatest seasonal changes in the amount of reducible iron occurred in the waters near Sandy Hook. Elsewhere in the study, high concentrations were generally associated with salinity as previously discussed. During the warm months local concentrations of iron in deep waters were greater than in the surface layer, attributed to particulates sinking through the thermocline. This was particularly evident in the western sections of the Bight. The data of Vaccaro et al (1972) support the increase in iron in deep waters, although only particulate iron concentrations were reported.

Oxygen

The concentration of oxygen near the surface is generally close to or above saturation in the open waters of the Bight. In New York Harbor the opposite is true (Table 16), reflecting the high biological oxygen demand (BOD) and chemical oxygen demand (COD) placed on the harbor waters.

The data of both Backus (1951) and Hardy (personal communication 1974) incidate that oxygen saturation in the waters of Upper Bay ranges from 63% to over 100%, depending on location. Backus also demonstrated that in The Narrows oxygen values fluctuate with the tide; for example, in spring and summer the oxygen content is greater on the ebb

Table 16. Distribution of oxygen in New York Harbor, November 1974

Depth		% saturation		
		Upper Bay (adjacent to The Battery)		
m	ft	East River	Hudson River	
0	0	33.6	37.9	
7	23	31.5	38.4	
14.5	47.6	31.1	39.5	
		The Narrows		
0	0	38.2		
12	39	46.2		
24	79	50.4		
		Lower Bay		
		Rockaway Point	Ambrose Channel	Sandy Hook
0	0	72.0	72.2	74.5
5	16	70.5	54.0	73.8
10	33	58.7	54.7	74.0

Source: From Alexander, unpublished data

than on the flood, whereas the reverse is true for fall and winter. He further states that

> regardless of the tide the following pattern is discernible from the rivers through the Narrows and on out to the New York Bight: minimum values (less than 40 percent saturation) are observed in the Harlem River; values in the East River were higher than the Harlem and decrease in passing south and west; values in the Hudson River were higher than those of the Lower East River and decrease passing south, doing so particularly rapidly in the Spuyten Duyvill region where effluent from the Harlem appears to be received. Values increase in the Upper Bay and the Narrows and rise rapidly, once through the Narrows, to conditions of saturation or supersaturation in the New York Bight.

Similar patterns are apparent in the November 1974 data (Table 16).

Oxygen concentrations as low as 33% saturation were reported for western Sandy Hook Bay in June 1962 by Kawamura (1966). These low oxygen values contrast to those reported by Backus (1951) and Cummings (1971), where summer saturation values ranged from 60% to over 100%. Kawamura offered no explanation for the observed low values; but Clark's data (1963) indicate that the oxygen characteristics of the waters in this region are affected by the low oxygen concentrations of both the Raritan River and the Arthur Kill.

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Oxygen-demanding materials in New York Harbor are derived principally from three sources (Parsons et al 1973):

(1) municipal sewage from New York City, both treated and untreated;

(2) municipal and industrial wastes from New Jersey, all receiving some treatment; and

(3) a net flux to the harbor from the East River.
Torpey (1967) reviewed the historical development of pollution in New York Harbor, saying that "by 1906 pollution was so advanced that it became necessary to form the Metropolitan Sewerage Commission of New York in order to study the effects of, and remedies for, the growing problems in the Harbor." He noted that the average dissolved oxygen concentration as early as 1916 was 47% and that by 1937 this had dropped to an average of 40% saturation.

These low values were attributed to the increasing amounts of wastewater entering the harbor. The effect of construction of new waste treatment facilities upon harbor water quality was reflected in the increase in average oxygen present in the waters during summer 1965—to 45% saturation (Smith 1970). Torpey indicated that these oxygen levels relate to a pollution-loading level of carbonaceous pollutants requiring 9 to 60 kg (20 to 132 lb) of oxygen per day per acre; at rates above this, anaerobic conditions will result. Backus (1951) considered the historical trends in oxygen concentrations and indicated that a substantial increase in oxygen saturation values occurred between 1939 and 1949, relating to improvements in waste disposal systems. The low average oxygen saturation values found by Alexander in 1974—36% for the East River, Hudson River, and The Narrows combined—is attributed to the smaller amount of available data as well as to temporal changes.

Map 2 depicts oxygen distribution at 1 and 20 m (3 and 66 ft) in the water column during September 1969 (Corwin 1970). As in Table 16, substantive increases in the dissolved oxygen concentration of the waters have occurred by the time the combined outflows of the New York Harbor system reach the Rockaway Point-Sandy Hook area.

Bight surface waters are generally at or near oxygen saturation. Except for waters off the New Jersey coast and in the Bight apex, oxygen concentrations at 20 m (66 ft) ranged between 55% and 90%. At the sewage sludge dumpsite, 1.6 ml/l of oxygen (26% saturation) were present at 20 m (66 ft); the water depth here is 26 m (85 ft). Pearce

(1969) found oxygen saturation values as low as 10% at the center of the dumping area. Ketchum et al (1951) noted that oxygen saturation values in the bottom waters of the sewage sludge disposal site were at 50% in 1948-1949. We attribute the low oxygen concentrations at the sewage sludge disposal site to overburdening of the assimilative capacity of the waters. A second region of low oxygen (26% saturation) at the 20 m (66 ft) level was present off southern New Jersey in September 1969.

Waters flowing south along the New Jersey coast generally contained lower concentrations of dissolved oxygen than the waters to the east, indicating that the source of these low oxygen waters is either New York Harbor or the dumping grounds, or both. Horne et al (1971) observed that "the river may well be a worse threat to the marine environment than the dump in this regard." The oxygen data collected by Crawford (1952) in the vicinity of Sandy Hook tend to substantiate Horne's statement.

Subsurface concentrations of dissolved oxygen vary seasonally. In Figure 9 the low concentrations present in September below 10 m (33 ft) are attributed to the stability of the water column and the presence of a high BOD and COD. Below 10 m (33 ft) the oxygen concentration decreased from 4.5 ml/l to less than 2.7 ml/l (44% saturation). By
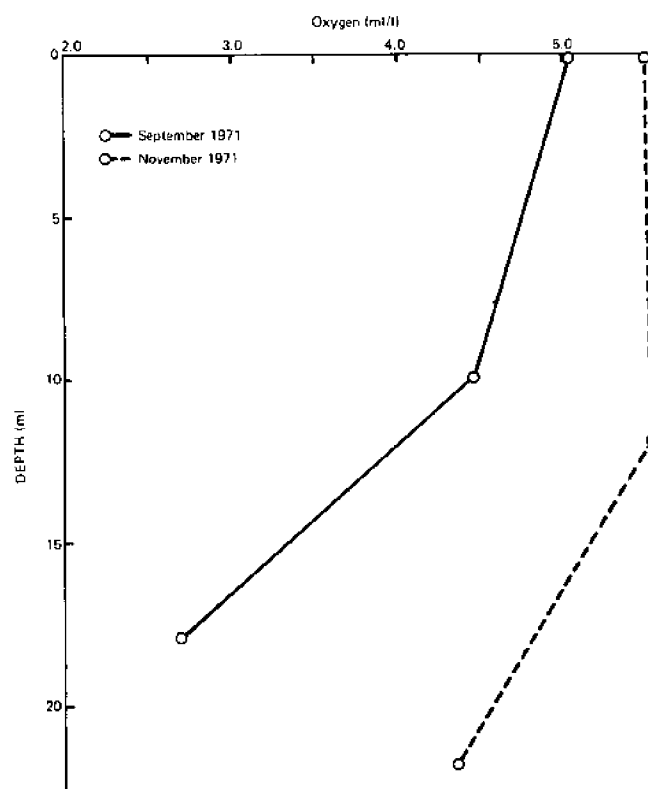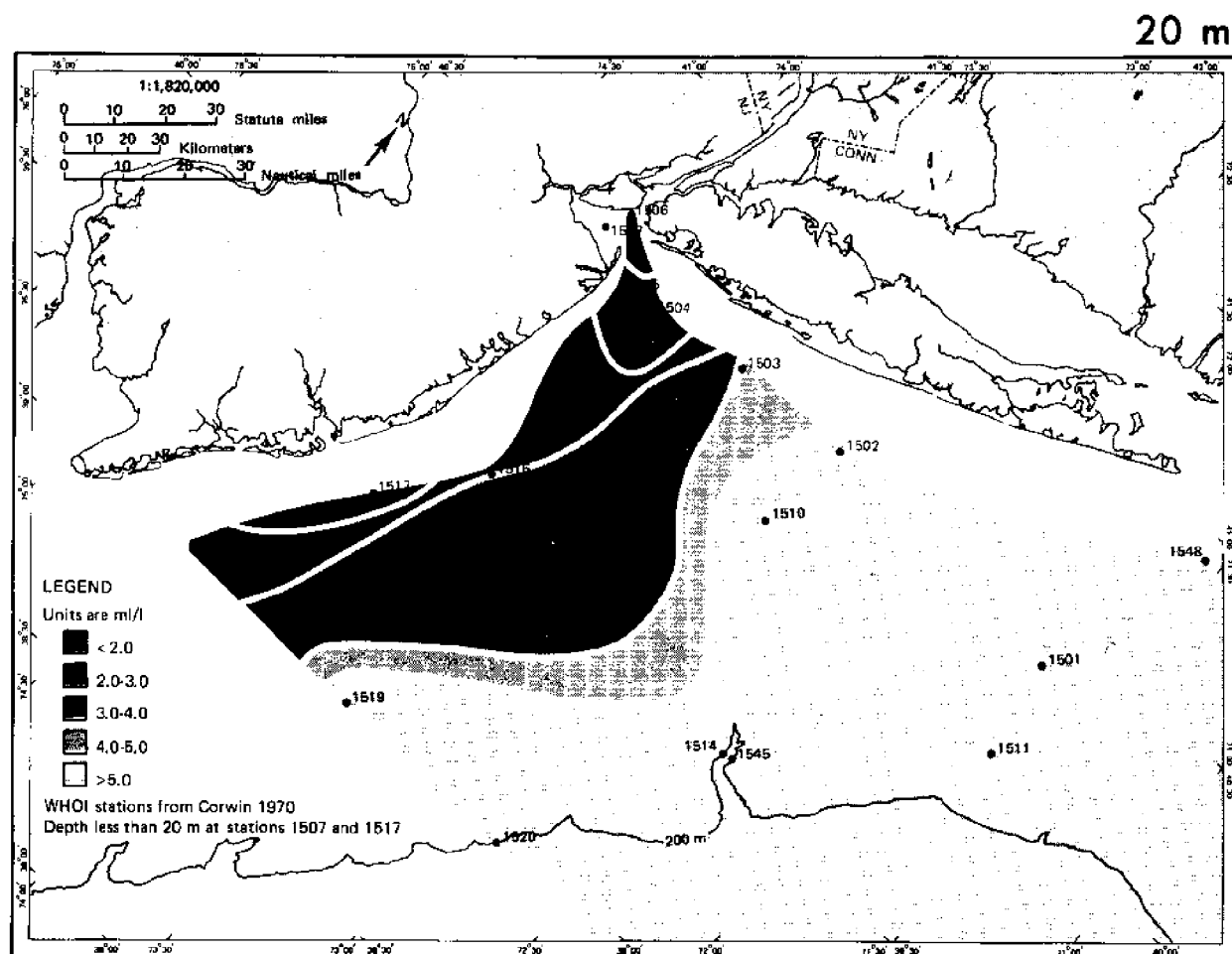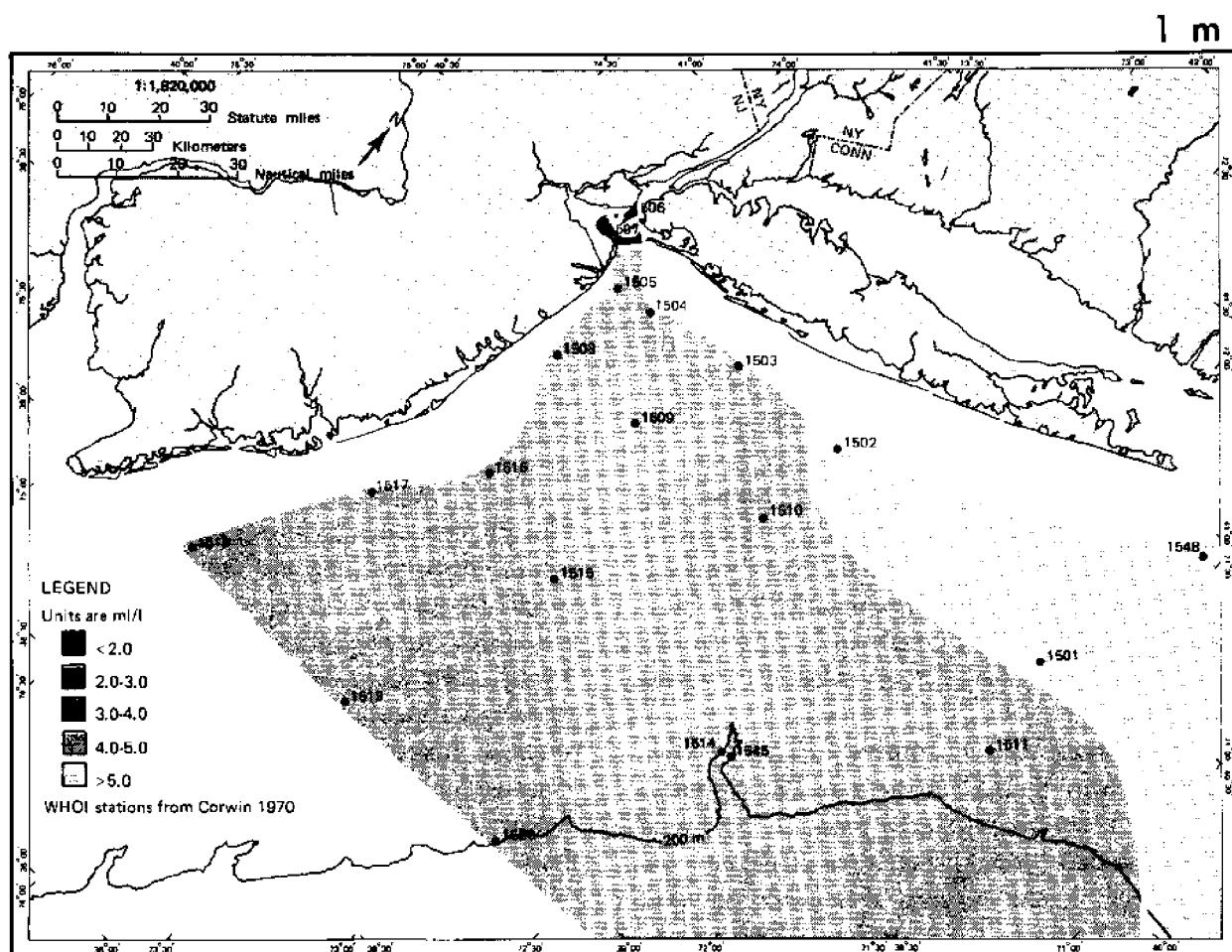

Figure 9. Vertical profile of dissolved oxygen at northeastern edge of sewage sludge dumpsite, September and November 1971

Map 2. Dissolved oxygen: distribution, September 1969

November the effect of autumnal mixing had become apparent and the dissolved oxygen concentration had increased to 71%. Hardy's data (personal communication 1974) indicate that by April the dissolved oxygen concentrations of the water column in the entire Bight were at or near saturation, and in most instances supersaturated. The only continuous seasonal oxygen data available for the sewage sludge dump area are those of Middle Atlantic Coastal Fisheries Center (1972), which indicate that the lowest oxygen concentrations are found at depth during late summer and are seasonally replenished.

In the nearshore waters immediately south of Jones Beach and Fire Island Inlet (Long Island) the oxygen content was generally at or above saturation except in midsummer when bottom water concentrations were reduced to approximately 70% saturation at those stations, apparently influenced by the outflow from Great South Bay (Marine Sciences Research Center 1973).

To understand the chemistry of the waters within this region, diurnal changes in the chemical characteristics must be separated from the seasonal changes. Alexander (unpublished data) followed the diurnal changes in the oxygen concentration at a fixed point south of Long Beach, Long Island (40°30.0'N, 73°44.0'W), in November 1972. The

waters at this time of year were still below saturation (Figure 10). The lack of periodicity in the waters above 15 m (49 ft) reflects the influence of mixing processes coupled with a low photosynthetic rate. The variation observed in deep waters was influenced by tidal conditions as determined by changes in salinity at this station. High concentrations of oxygen were present in waters moving into the area from the open waters of the Bight.

Micronutrient Elements

Phosphorus occurs in seawater as dissolved phosphate, dissolved organic compounds, insoluble and absorbed phosphates in suspension, and organically combined phosphorus in suspension (Armstrong 1965). Normally, only reactive phosphate, total dissolved phosphate (the difference between this and reactive phosphate is usually referred to as organic dissolved phosphate), and particulate phosphate are determined. Particulate phosphate refers to that fraction of the sample retained by a 0.45 micron filter pad. In the Bight, only Middle Atlantic Coastal Fisheries Center studies considered other forms of the element; these were inorganic and organic phosphate.
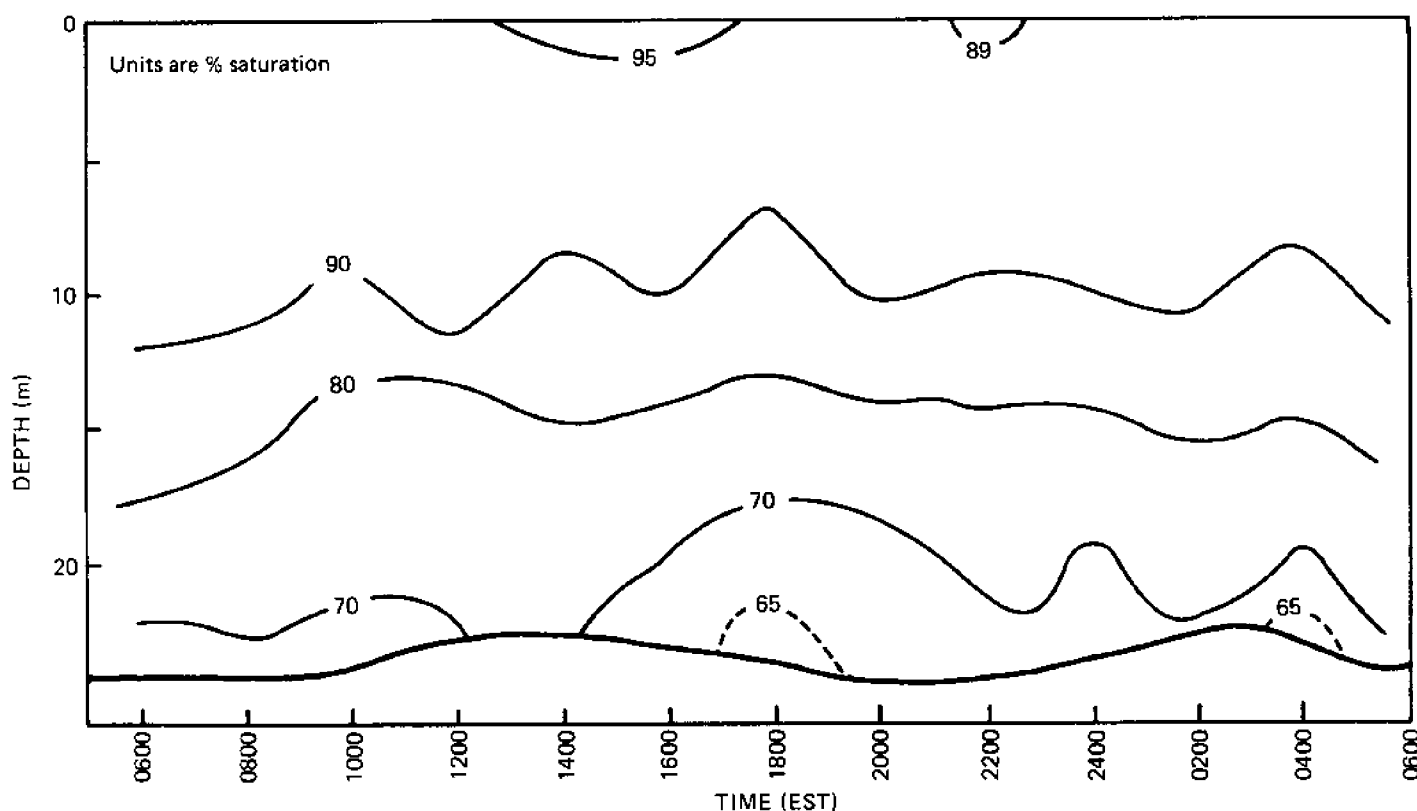

Figure 10. Diurnal variations in dissolved oxygen concentrations south of Long Beach, Long Island, November 1971

Early studies generally incidated that organic phosphorus in seawater is present in smaller amounts than the inorganic fractions (Armstrong 1965). Redfield, Smith and Ketchum (1937) showed that the percent of organic and inorganic phosphorus present in the water column varied seasonally and that the former decreased in concentration with depth. The same is also true for New York Bight.

Three stations were selected from Corwin's data (1970) to represent conditions at the eastern edge of the Bight, the apex, and lower New York Harbor. Although total phosphorus (Table 17) was less in the eastern Bight than to the west, no significant differences were found between the proportion of inorganic and organic phosphates at these stations. These data were typical of conditions during September 1969, however. To determine seasonal changes in the proportion of these fractions to each other, Alexander's unpublished data were used. During the ebb tide the waters off Montauk Point are an admixture of Peconic Bay, Lake Montauk, Long Island Sound, Block Island Sound, and Atlantic coastal waters. Large seasonal trends are apparent in Figure 11. The total amount of phosphorus in surface and bottom waters was highest during late fall and winter and lowest in summer; these differences are largely attributed to variations in surface inflow from Long Island Sound. Organic phosphorus constituted a significant fraction of total phosphorus during the warm months only; particulate phosphorus was generally dominant during the remainder of the year. These data are like those of Ryther and Yentsch
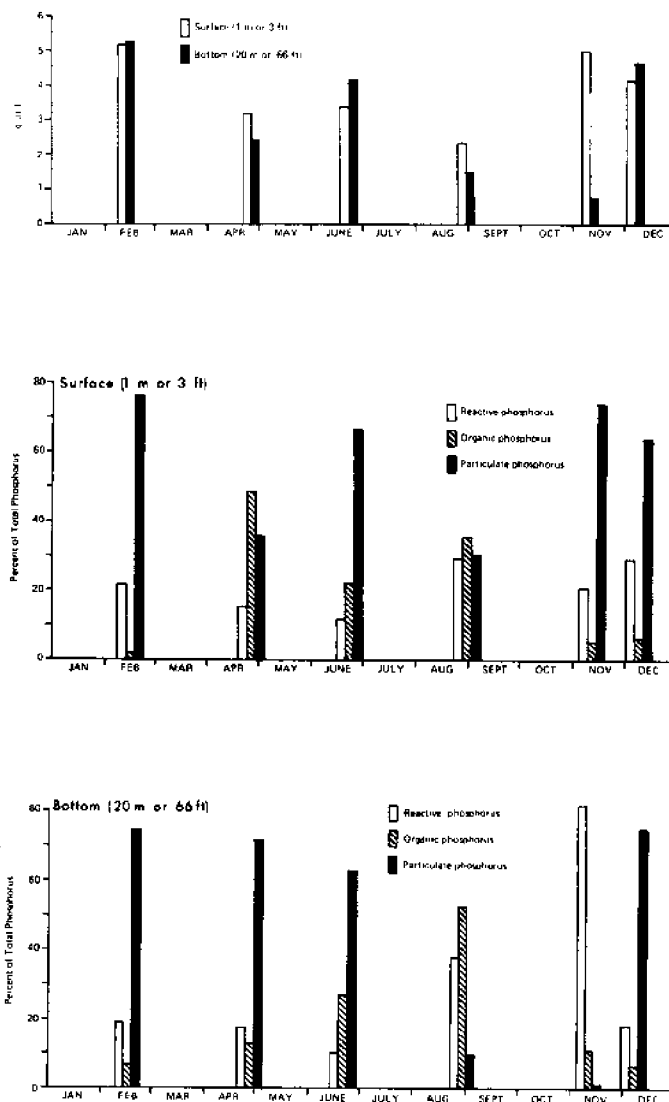

Figure 11. Seasonal variation of phosphorus in surface and bottom waters off Montauk Point, NY, 1972

Table 17. Vertical distribution of phosphorus, September 1969

39°28.7'N, 73°19.6'W					40°24.2'N, 73°50.2'W					40°39.6'N, 74°08.7'W				
Depth		Total	R	O	P	Depth		Total	R	O	P	Depth		Total	R	O	P
m	ft	(µg-at/l)	%	%	%	m	ft	(µg-at/l)	%	%	%	m	ft	(µg-at/l)	%	%	%
1	3	0.49	53.1	38.8	8.2	1	3	2.10	47.6	37.6	14.8	1	3	1.27	57.5	29.1	21.3
10	33	0.34	47.1	44.1	8.8	5	16	2.19	33.8	43.8	22.4	5	16	1.39	51.8	27.3	20.9
25	82	0.41	61.0	29.3	9.8	15	49	1.98	66.2	25.3	8.6						
30	98	0.82	45.1	45.1	9.8												
35	115	0.87	58.8	32.0	7.9												
40	131	0.86	67.4	27.9	4.7												
45	148	1.03	73.8	23.3	2.9												
50	164	1.93	43.5	—	1.6												
55	180	1.11	82.9	14.4	2.7												
60	197	1.06	75.5	21.7	2.8												
65	213	1.05	82.9	15.2	1.9												
75	246	1.38	60.1	37.7	2.2												
100	328	1.17	74.4	23.1	2.6												

Source: Alexander 1973

R—reactive phosphorus
O—organic phosphorus
P—particulate phosphorus

(1958), who also demonstrated that concentrations of phosphorus were highest during winter months (at least at the 10 m or 33 ft level).

The data of Middle Atlantic Coastal Fisheries Center (Pearce 1969) indicate that organic phosphate is the principal form from February until May and again in September. Particulate phosphate was not determined.

The lateral distribution of reactive, organic, and particulate phosphorus in the Bight is shown in Maps 3 to 5. The increase of reactive phosphorus with depth is apparent in the entire region, as is a decrease in concentration with distance from shore (Map 3). Near the apex, at depths of 20 m (66 ft) and more, the waters were characterized by amounts of phosphorus greater than 1.0 μg-at/l (the actual amount found divided by the atomic weight of phosphorus/l). Organic and particulate phosphorus (Maps 4 and 5) generally decreased with depth and with distance from shore.

The distribution of the various forms of phosphorus in New York Harbor in November 1974 is shown in Table 18. In general, reactive and particulate phosphorus concentrations were greater in Upper Bay than in the vicinity of Rockaway Point and Sandy Hook. Organic phosphorus (total dissolved minus reactive) concentrations were variable. These distribution patterns are characteristic of summer conditions in temperate climates, where the effect of seasonal warming of surface waters results in a pronounced stabilization of the water column. In the Bight the depth of the thermocline in September 1969 varied from 8 to 13 m (26 to 43 ft) in the apex, 15 to 25 m (49 to 82 ft) in waters to the east. Such a pronounced stratification of the water column greatly restricts vertical mixing and partly accounts for the high concentration of phosphorus in deep waters at this time of year.

The low phosphorus levels in the upper portion of the water column are attributable to phytoplankton activity, whereas high phosphorus concentrations in the lower portion of the water column represent reduced phytoplankton activity (due to diminished light) and decomposition exceeding production. The result is a net accumulation of phosphorus in these bottom waters. Such degradation processes are also oxygen-demanding, accounting in part for the low oxygen levels in deep waters.
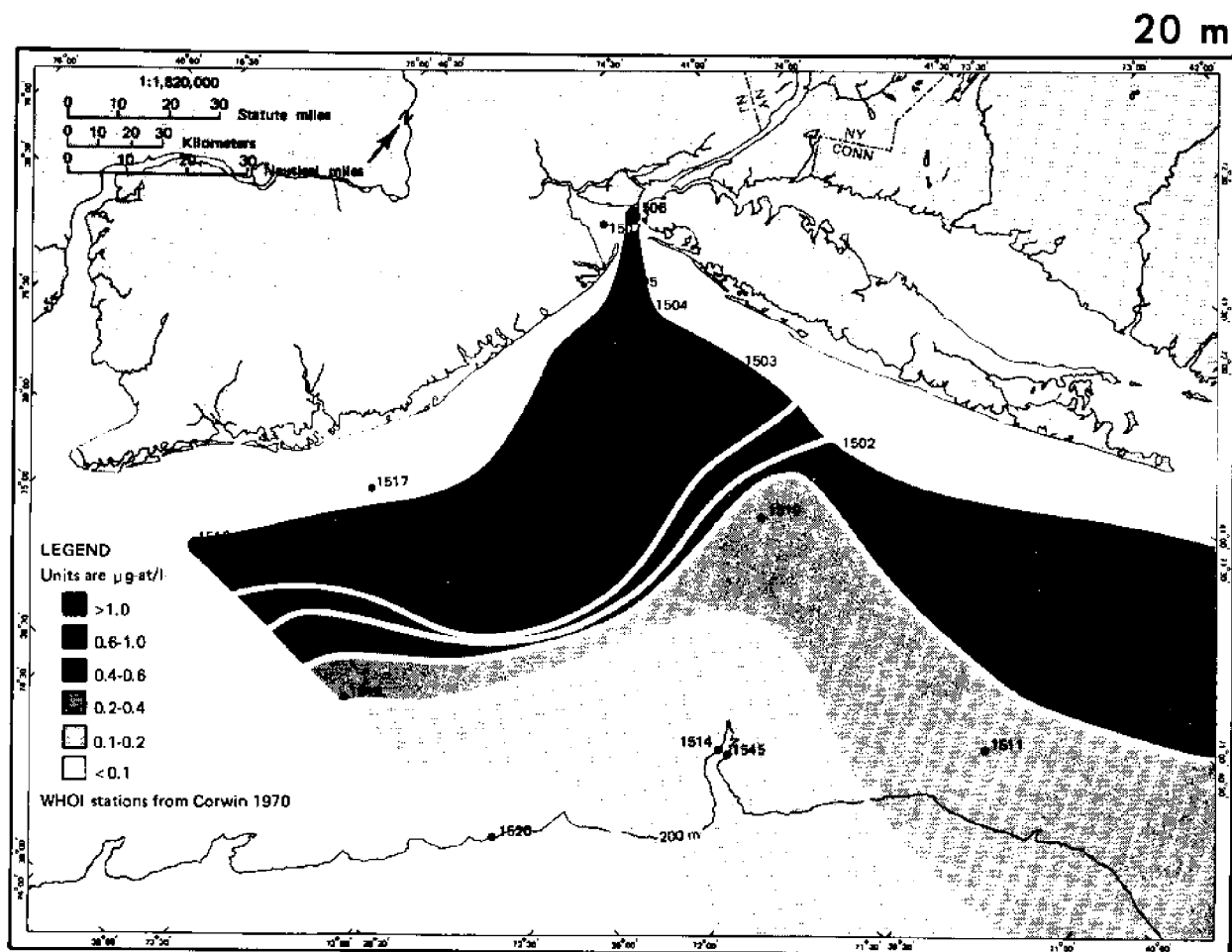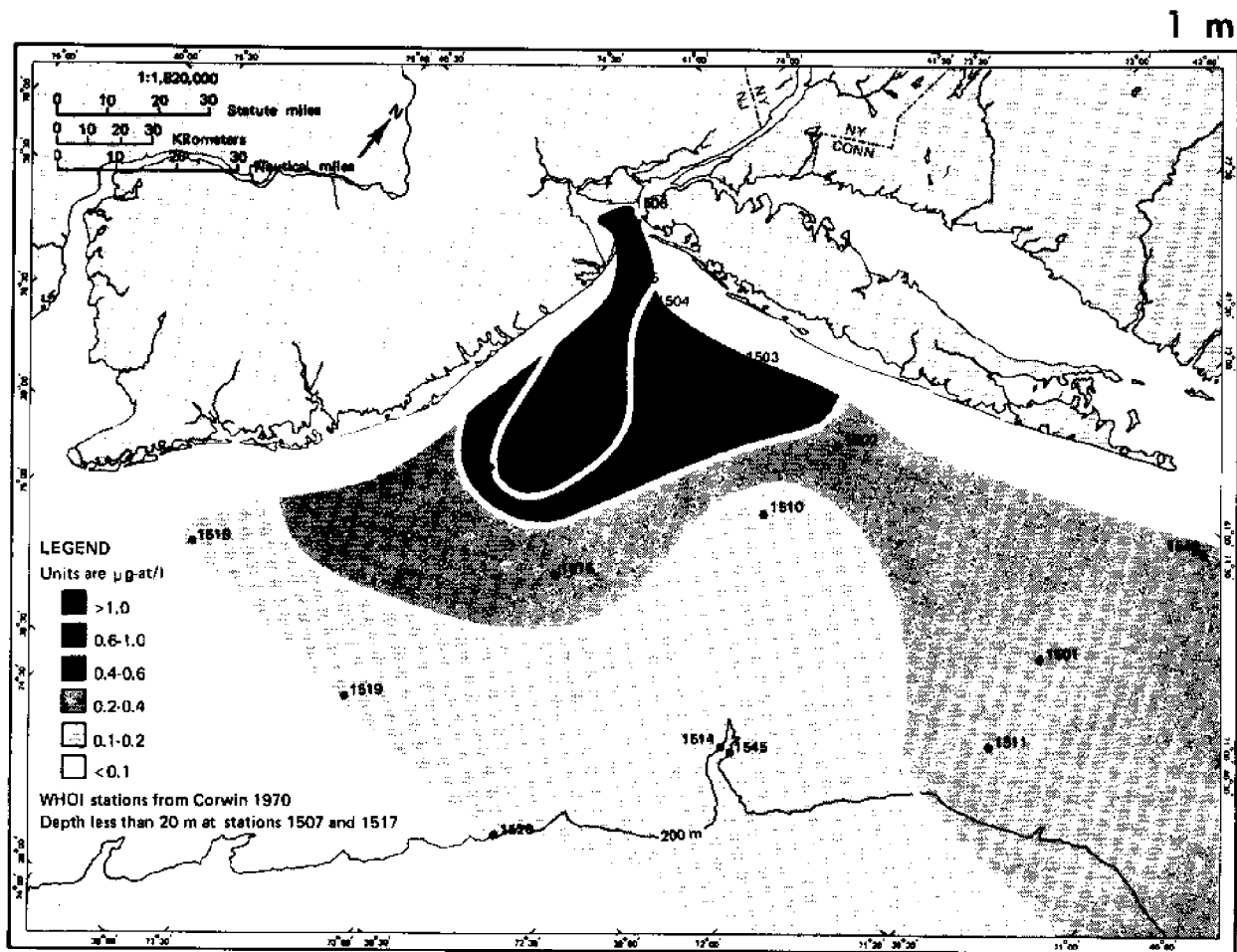
Table 18. Average distribution of phosphorus in New York Harbor, November 1974

Depth — μg-at/l

Upper Bay (adjacent to The Battery)

m	ft	East River			Hudson River		
		R	O	P	R	O	P
0	0	4.39	0.83	2.28	3.87	0.41	1.98
7	23	4.22	0.77	2.62	3.52	0.75	2.78
14.5	47.6	4.25	0.83	2.73	3.91	0.80	2.80

m	ft	The Narrows		
		R	O	P
0	0	3.85	0.94	2.39
12	39	2.99	0.65	2.66
24	79	2.75	0.60	3.25

Lower Bay

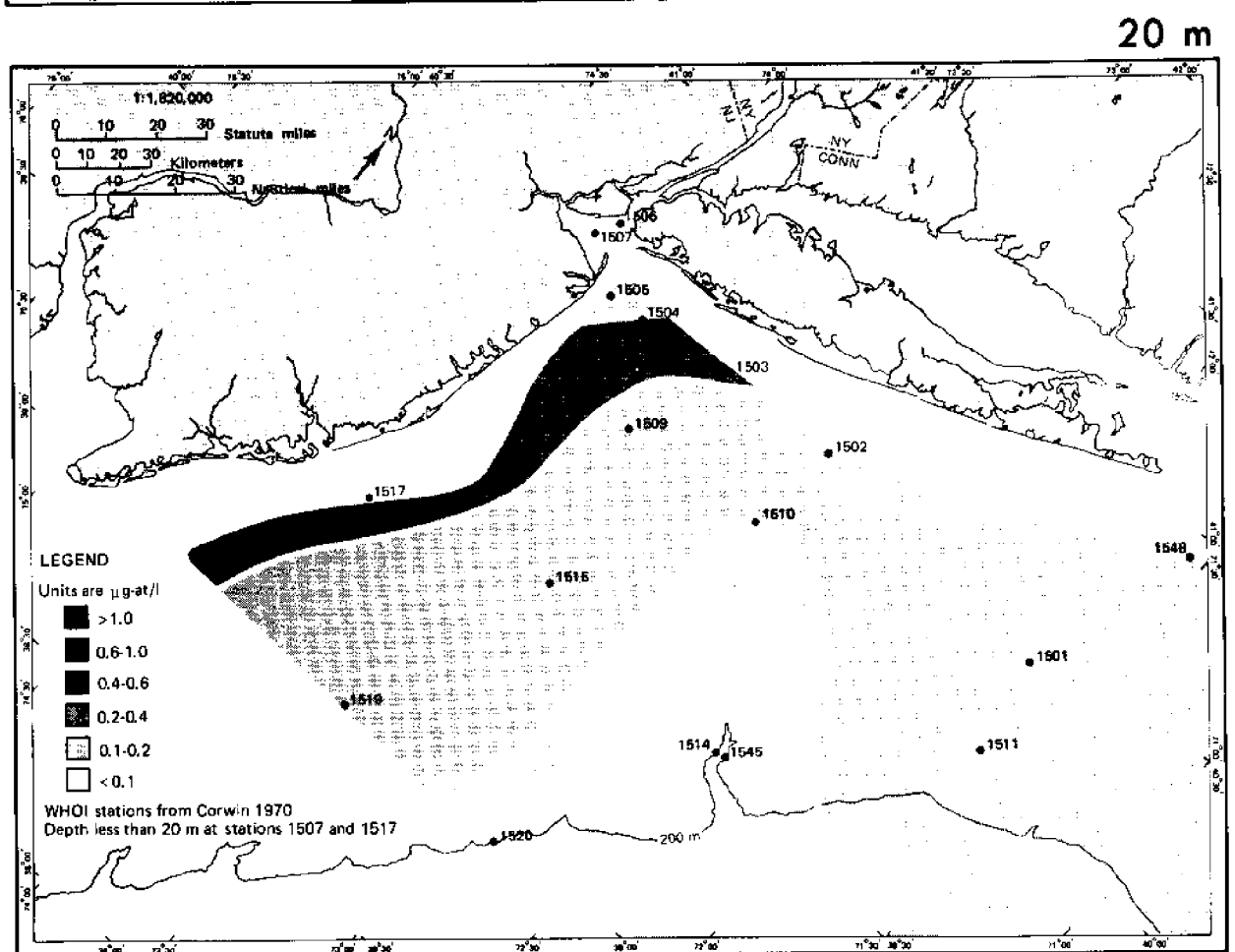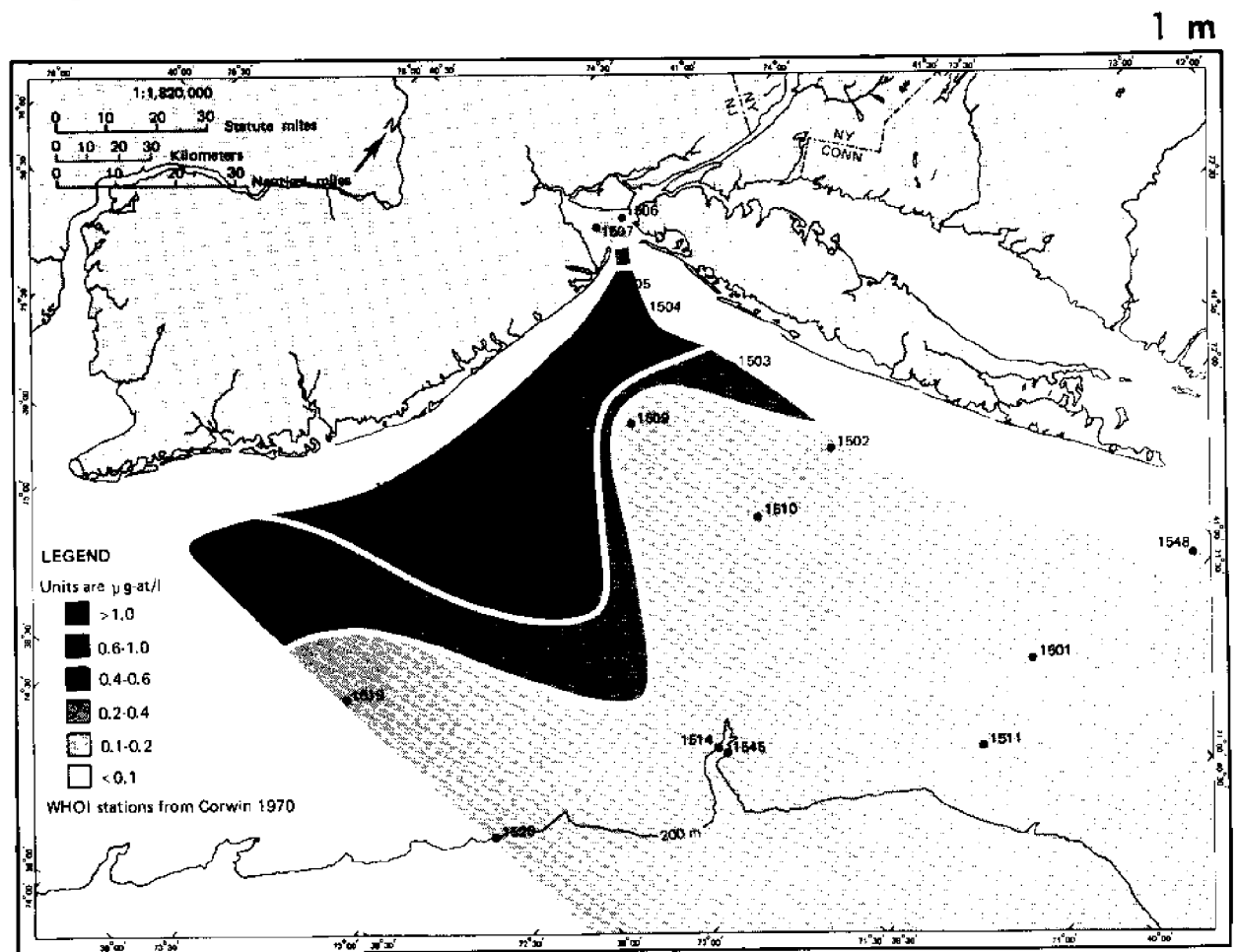| m	ft	Rockaway Point			Ambrose Channel			Sandy Hook		
		R	O	P	R	O	P	R	O	P
0	0	1.32	0.39	0.73	2.16	0.90	1.10	1.93	1.01	0.52
5	16	1.21	0.61	0.98	1.84	0.39	1.52	1.93	0.95	1.77
10	33	1.06	0.41	0.74	1.84	0.79	0.93	1.88	0.72	1.48

R—reactive phosphorus
O—organic phosphorus
P—particulate phosphorus
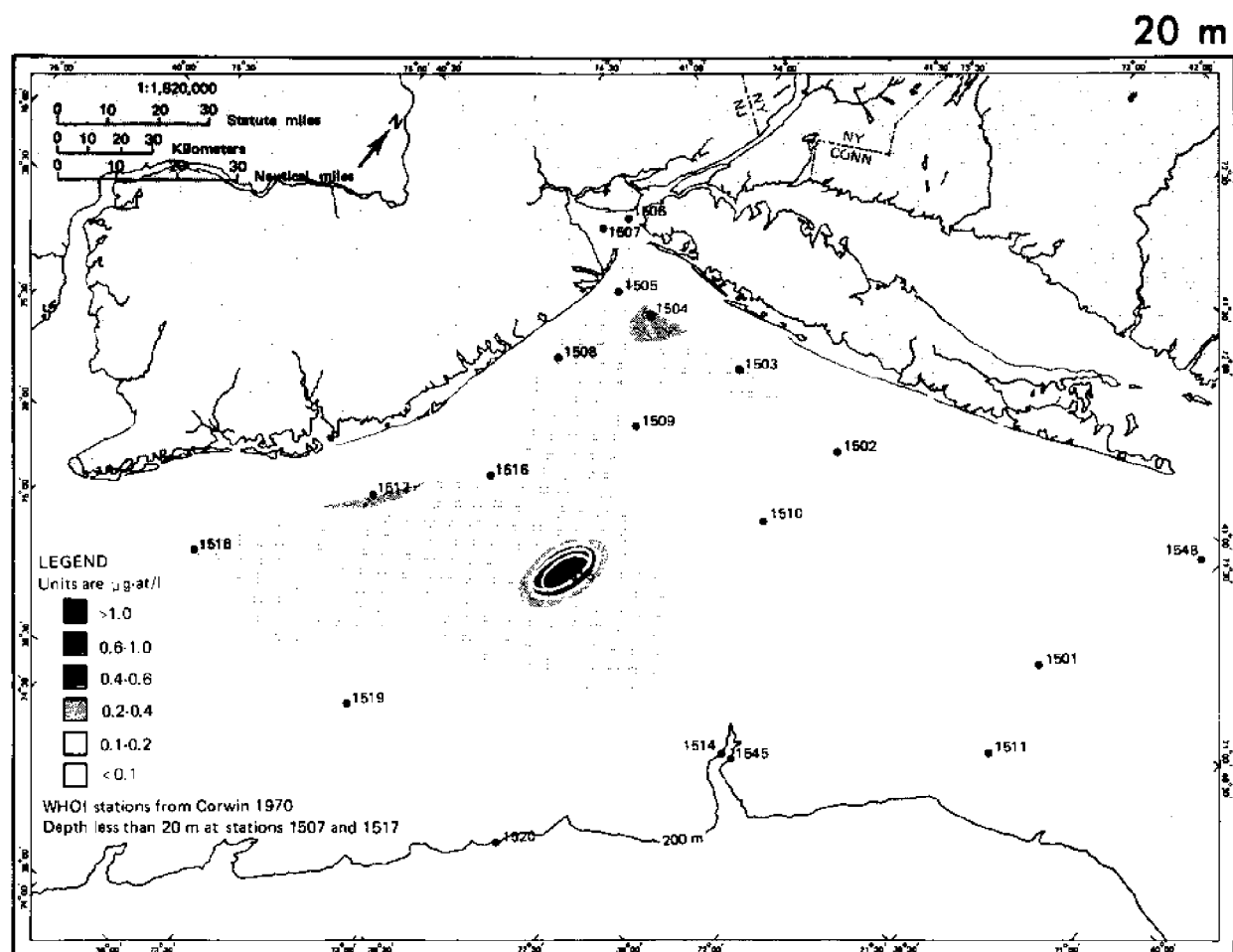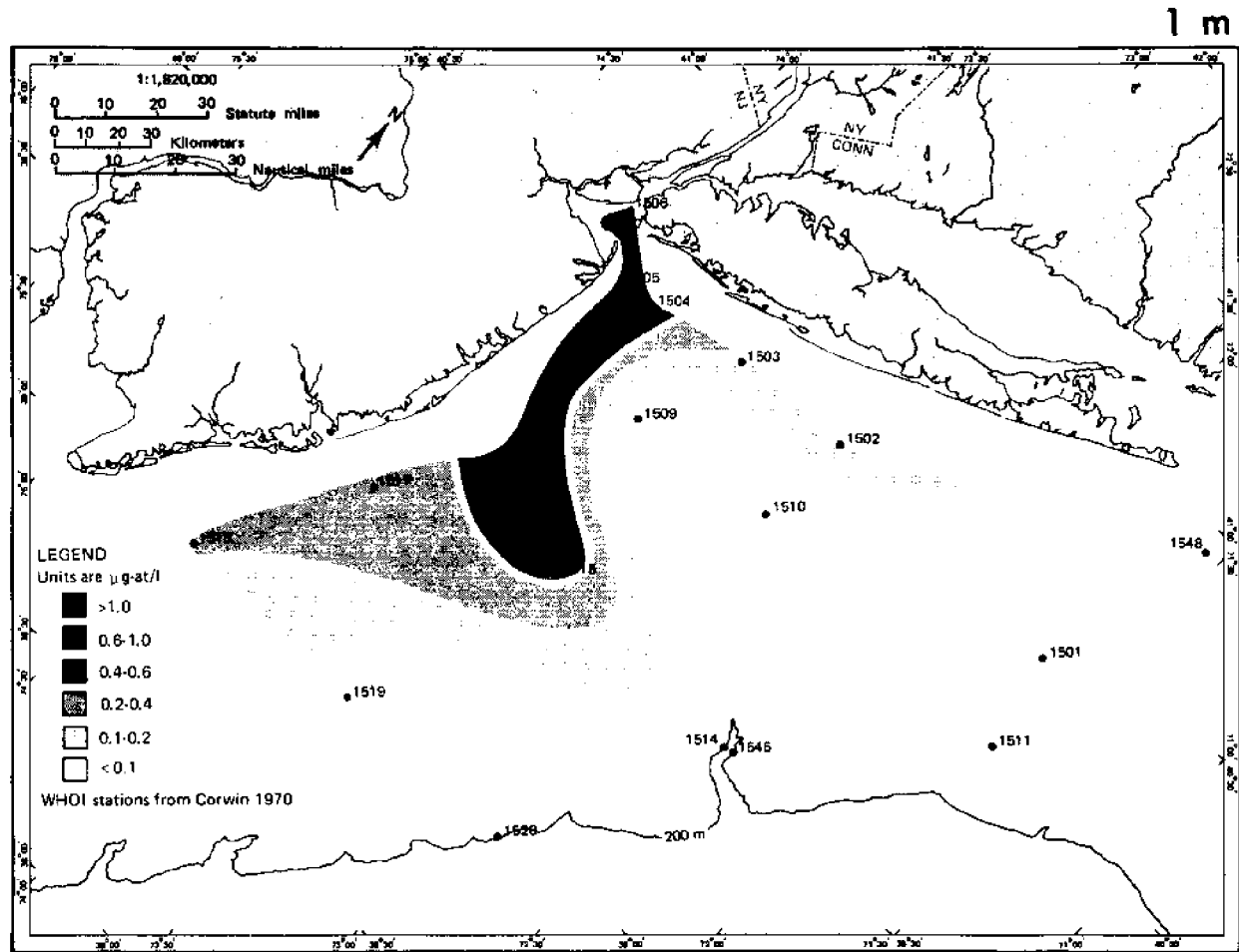
Source: From Alexander, unpublished data

Map 3. Reactive phosphorus: distribution, September 1969

1 m

LEGEND

Units are µg-at/l

- >1.0
- 0.6-1.0
- 0.4-0.6
- 0.2-0.4
- 0.1-0.2
- <0.1

WHOI stations from Corwin 1970
Depth less than 20 m at stations 1507 and 1517

20 m

LEGEND

Units are µg-at/l

- >1.0
- 0.6-1.0
- 0.4-0.6
- 0.2-0.4
- 0.1-0.2
- <0.1

WHOI stations from Corwin 1970

Map 4. Organic phosphorus: distribution, September 1969

1 m

20 m

LEGEND

Units are μg-at/l

- ■ >1.0
- ■ 0.6-1.0
- ■ 0.4-0.6
- ▦ 0.2-0.4
- ▢ 0.1-0.2
- □ <0.1

WHOI stations from Corwin 1970

Depth less than 20 m at stations 1507 and 1517

Map 5. Particulate phosphorus: distribution, September 1969

1 m

20 m

The fall overturn of the water marks the end of summer conditions, resulting in a more uniform vertical distribution of phosphorus. By late winter and early spring the vertical distribution of reactive phosphorus is essentially uniform throughout the region (Hardy, personal communication 1974).

Alexander (1973) observed the diurnal variations in reactive and particulate phosphorus at a station in the Bight apex in November 1971 (Figure 12). Waters above 10 m (33 ft) generally showed no evidence of temporal variation and generally contained less than 0.6 μg-at/l of reactive phosphorus. The observed changes in deeper waters were attributed primarily to tidal influences. In these studies the diurnal variation of particulate phosphorus was also determined, and the results showed little evidence of a diurnal cycle.

Early recognition of (1) the importance of certain forms of nitrogen as a micronutrient (along with phosphorus) and (2) the significance of the ratio of nitrogen to phosphorus to the balance of the ecosystem at the primary level has resulted in much data on the distribution of these two nutrients in marine waters.

Corwin (1970) determined the distribution of ammonia, nitrite, and nitrate nitrogen across the Bight. High concentrations of ammonia were present in the waters of Lower Bay (Map 6). In the near-surface waters at two stations (1506 and 1507 in Map 6) near Staten Island, ammonia concentrations ranging from 33 to approximately 42 μg-at/l were found. At 20 m (66 ft) the concentration ranged from 20 to 23 μg-at/l. In a subsequent investigation of the distribution of nitrogenous materials in New York Harbor, Alexander (unpublished data) found nitrogenous materials primarily concentrated in Upper Bay and The Narrows (Table 19).

The low concentrations of dissolved organic nitrogen, ammonia, nitrite, and nitrate nitrogen between Sandy Hook and Rockaway are attributed primarily to dilution and biological uptake. Evidence for the latter is shown in the increased chlorophyll concentration in these waters (Table 20). At station B (Map 1) particulate and organic nitrogen ranged between 83 and 92 μg/l in the water column. Ammonia concentrations in Bight surface waters in September 1969 were generally less than 2.0 μg-at/l, although elevated concentrations were present in the waters along the New Jersey coast (Map 6).

Duedall, Bowman, and O'Connors (1975) found that ammonia concentrations in surface and bottom waters ranged between 500 and 200 μg-at/l, following sewage sludge dumping at the dumpsite in the Bight apex. Ammonia concentrations less than 1 μg-at/l
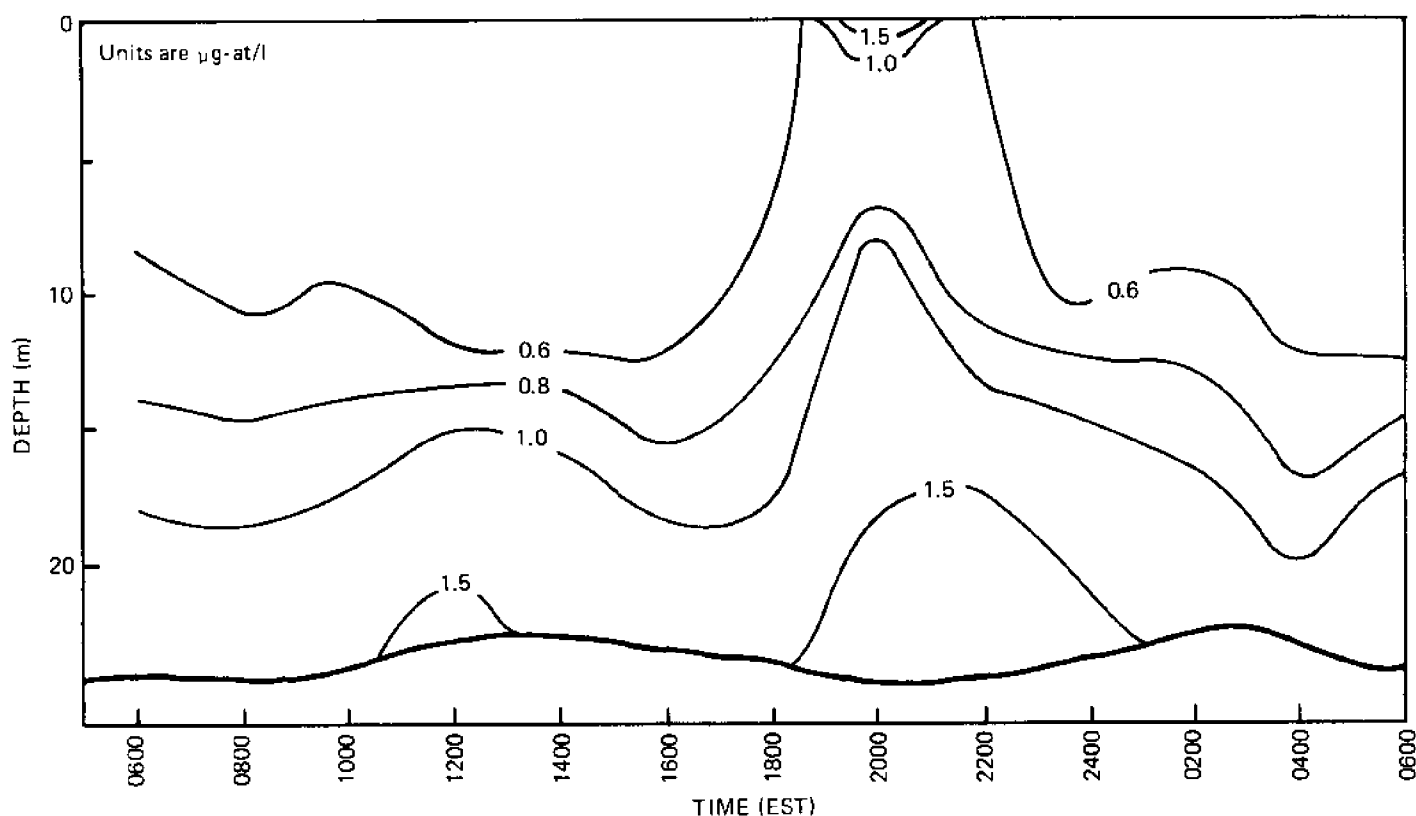

Figure 12. Diurnal variations in reactive phosphorus, November 1971

Table 19. Distribution of nitrogenous materials in New York Harbor, November 1974

Depth μg-at/l

Upper Bay (adjacent to The Battery)

m	ft	East River				Hudson River			
		N	NH_3	NO_2	NO_3	N	NH_3	NO_2	NO_3
0	0	26.8	44.8	4.2	22.3	40.9	36.1	3.5	23.6
7	23	33.9	24.8	4.2	21.7	34.3	33.5	3.2	19.7
14.5	47.6	31.3	41.4	4.2	21.5	25.7	34.1	3.1	19.3

The Narrows

m	ft	N	NH_3	NO_2	NO_3
0	0	36.8	44.7	3.6	19.3
12	39	24.8	29.5	2.8	15.7
24	79	26.3	28.4	2.5	14.5

Lower Bay

		Rockaway Point				Ambrose Channel				Sandy Hook			
		N	NH_3	NO_2	NO_3	N	NH_3	NO_2	NO_3	N	NH_3	NO_2	NO_3
0	0	9.4	7.0	0.9	5.6	12.4	18.1	2.0	14.2	10.6	23.8	1.9	12.1
5	16	18.1	3.5	0.6	1.4	4.8	13.2	1.5	10.1	11.9	20.4	1.8	12.9
10	33	18.3	2.4	0.6	—	6.8	8.4	1.3	9.6	7.2	14.7	1.8	12.1

N—dissolved organic nitrogen
NH_3—ammonia
NO_2—nitrite nitrogen
NO_3—nitrate nitrogen

Source: From Alexander, unpublished data

Table 20. Distribution of chlorophyll a in New York Harbor, November 1974

Depth μg/l

Upper Bay (adjacent to The Battery)

m	ft	East River	Hudson River
0	0	1.4	0.9
7	23	1.9	1.7
14.5	47.6	2.7	2.5

The Narrows

m	ft	
0	0	2.1
12	39	4.1
24	79	5.1

Lower Bay

m	ft	Rockaway Point	Ambrose Channel	Sandy Hook
0	0	2.1	6.0	5.4
5	16	2.0	4.1	5.6
10	33	1.5	4.3	5.2

Source: From Alexander, unpublished data

were present in surface waters surrounding the dumpsite, whereas bottom waters contained from 1 to 9 μg-at/l. At stations east and north of the dumpsite ammonia concentration was less than 1 μg-at/l and showed little evidence of a vertical gradient. The investigators suggested that substantial quantities of ammonia may be released into the atmosphere in this area.

Nitrite is the intermediate form of nitrogen between ammonia and nitrate nitrogen. In New York Harbor nitrite concentrations ranged up to 4.2 μg-at/l, whereas in the Bight less than 0.1 μg-at/l was generally present (Map 7). High concentrations of nitrite nitrogen were present at 20 m (66 ft) in the apex.
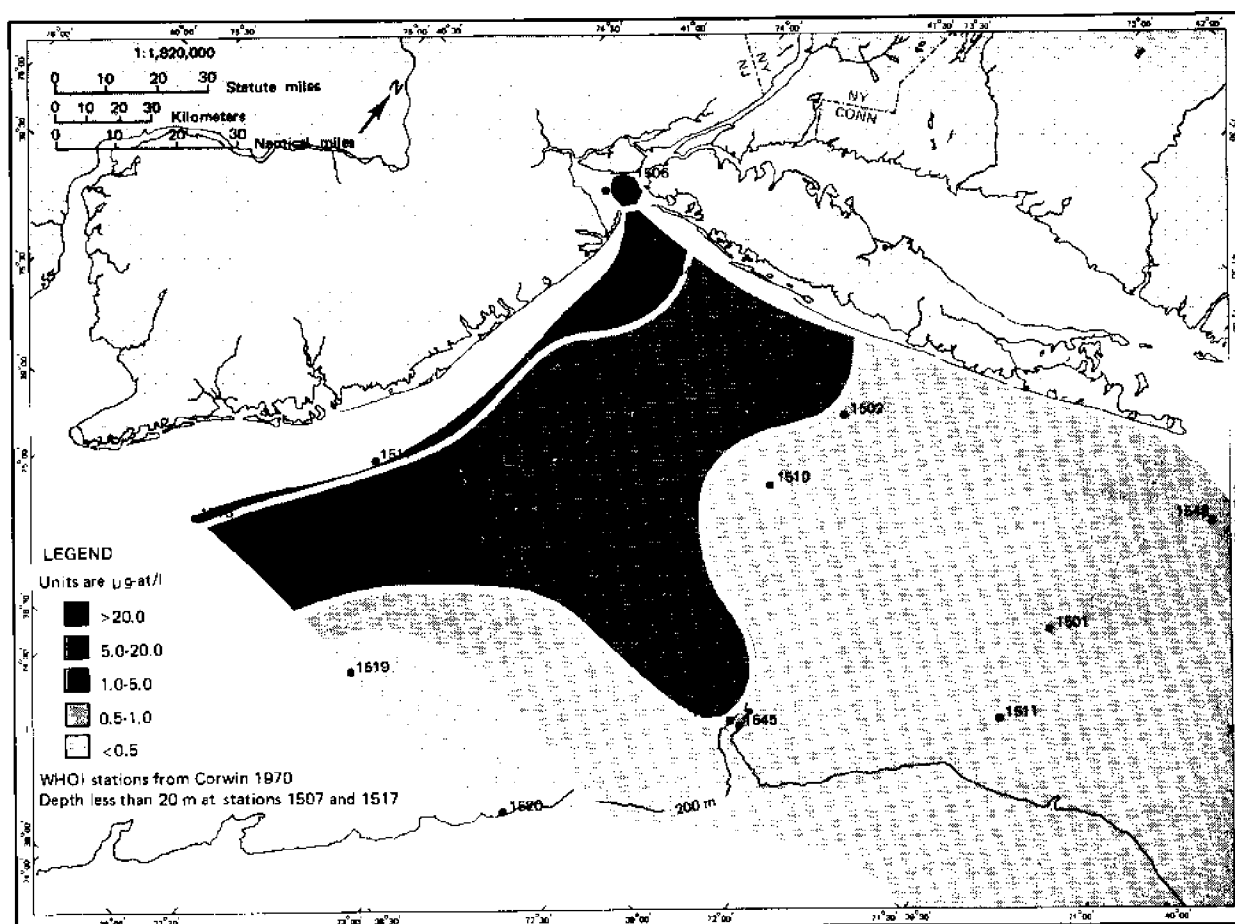
Duedall and his associates (1975) observed seasonal variation of nitrate concentrations, ranging from approximately 5 μg-at/l in April to over 60 μg-at/l in November in surface waters in the vicinity of Rockaway Point and Sandy Hook. As is common in temperate, coastal waters in the fall, nitrate concentrations are low and generally uniform with
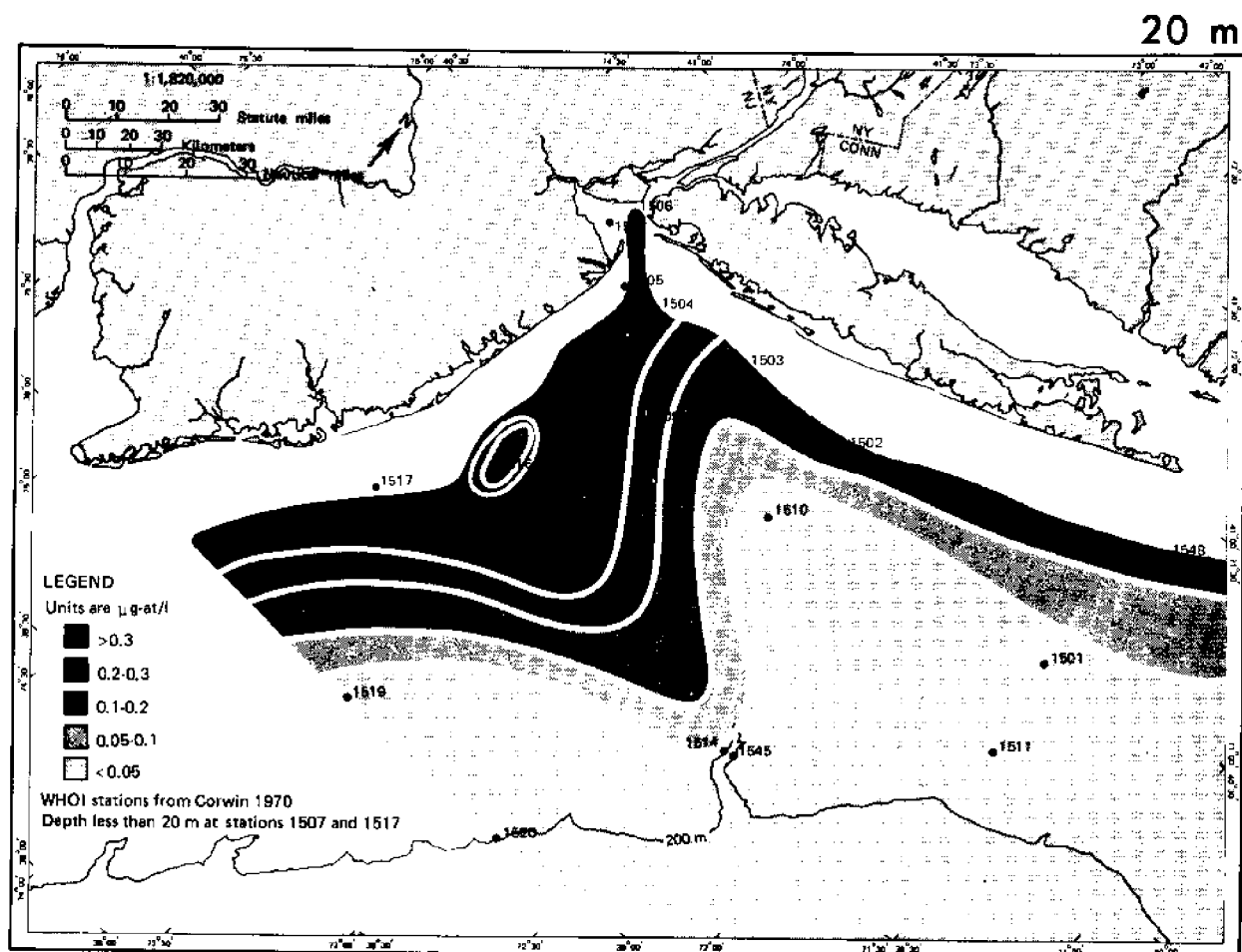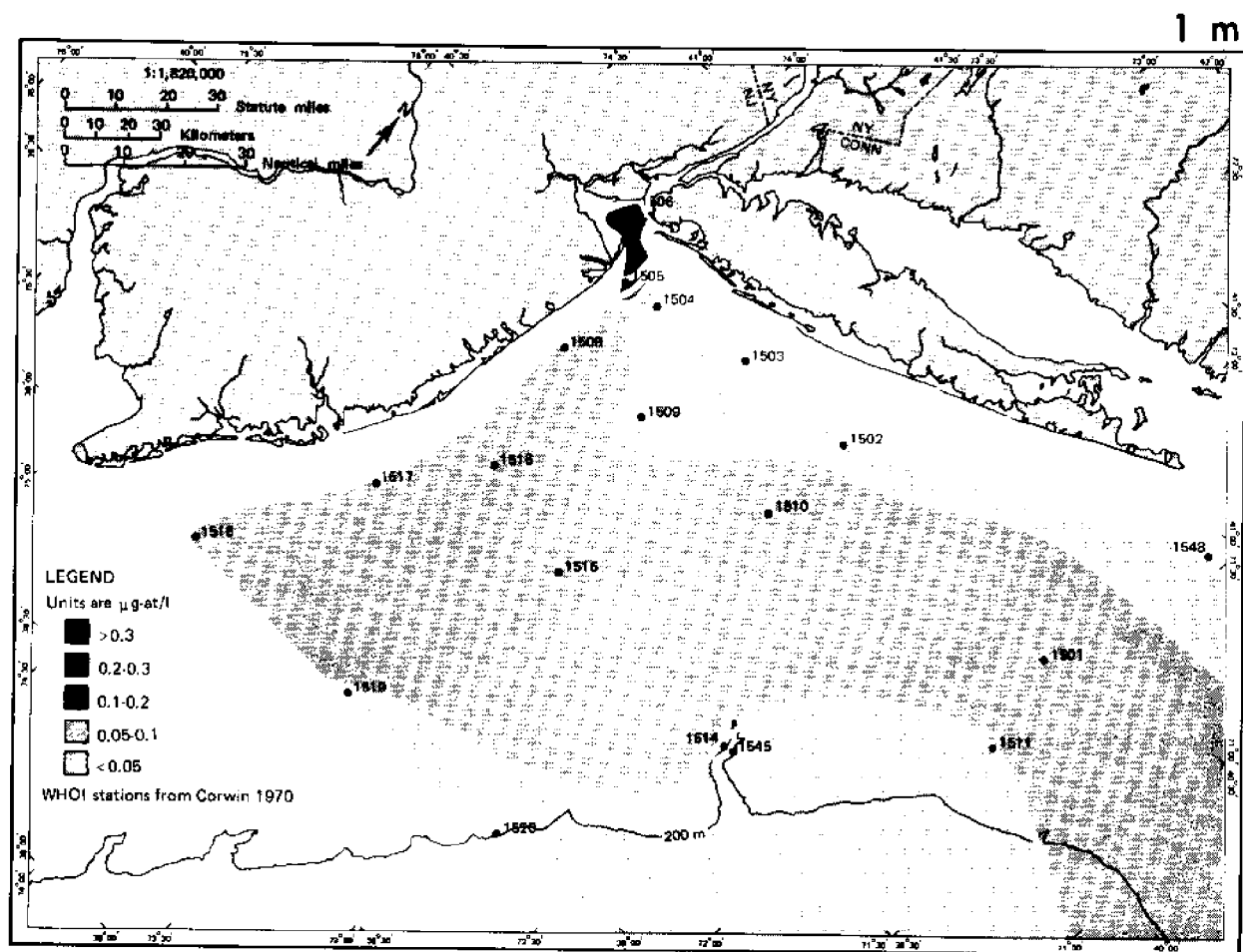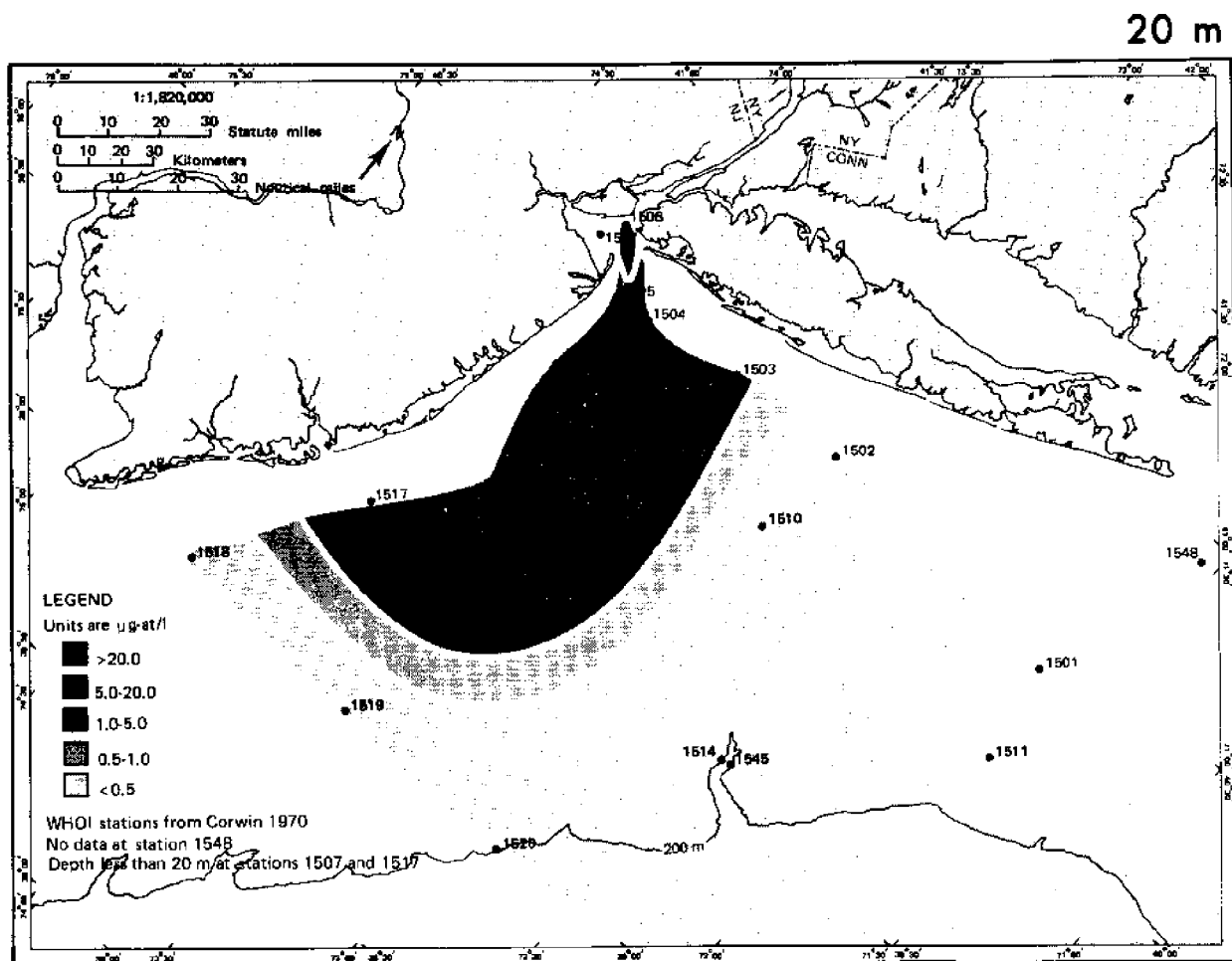
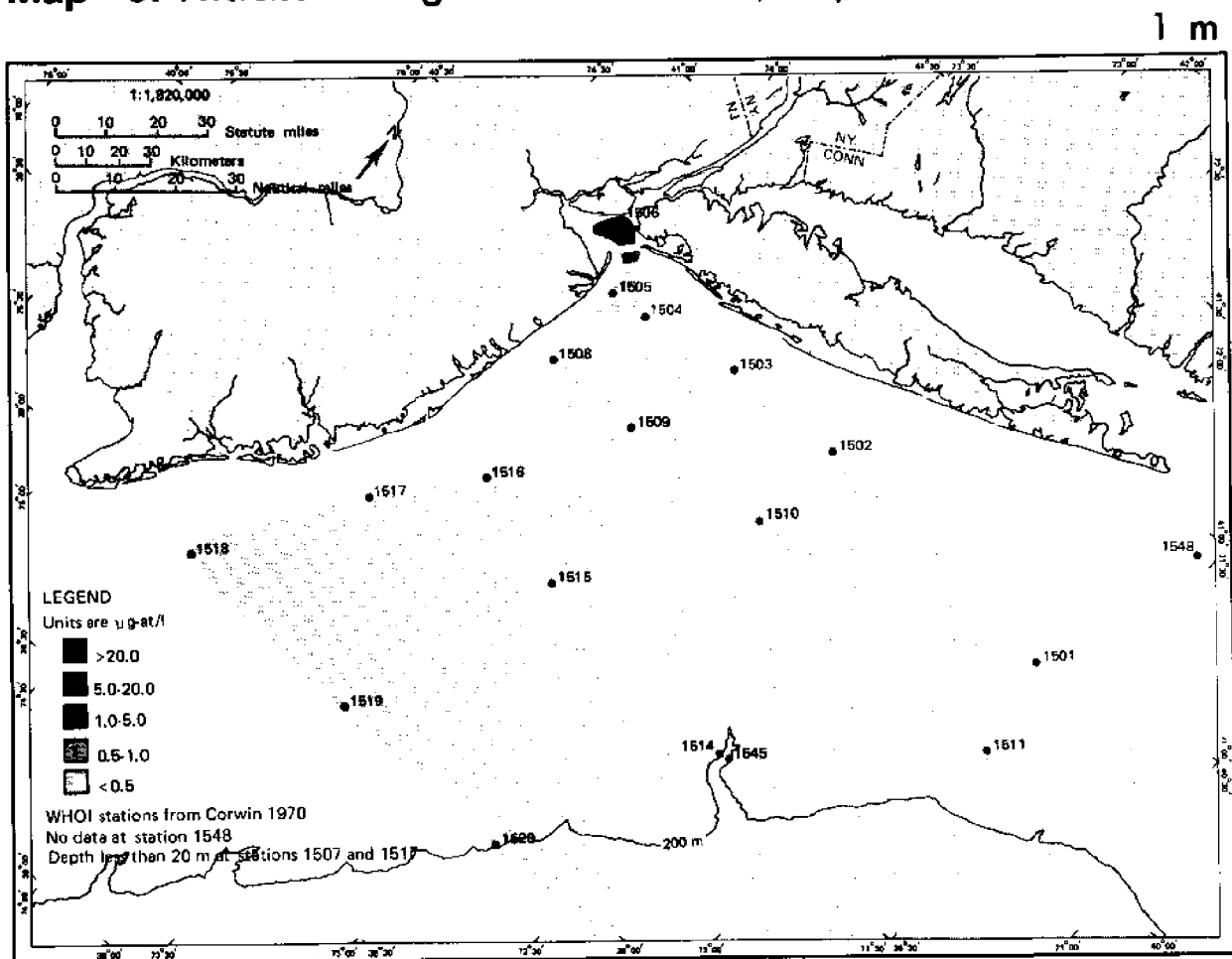# Map 6. Ammonia: distribution, September 1969

1 m
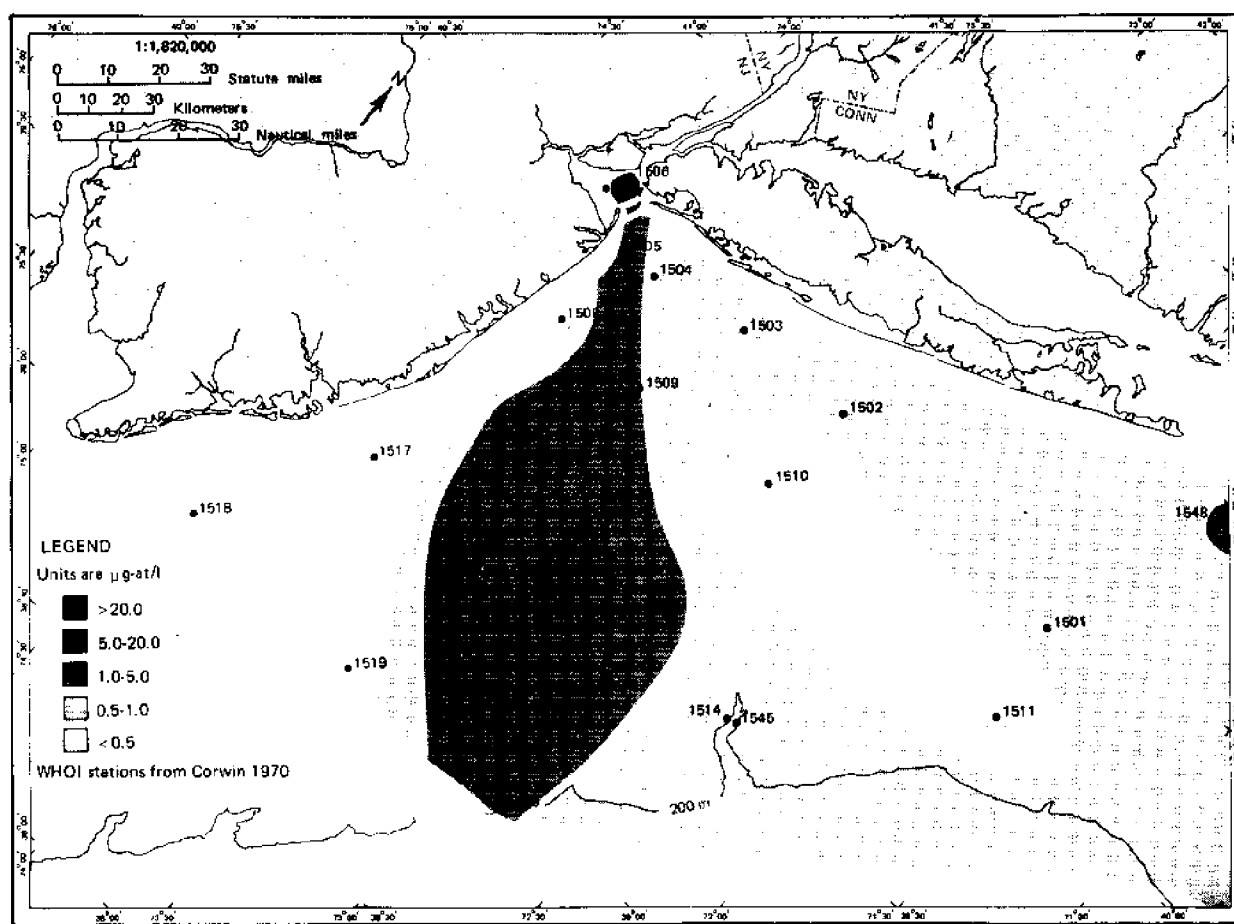
20 m

Map 7. Nitrite nitrogen: distribution, September 1969

1 m

LEGEND
Units are µg-at/l

> 0.3
0.2-0.3
0.1-0.2
0.05-0.1
< 0.05

WHOI stations from Corwin 1970

20 m

LEGEND
Units are µg-at/l

> 0.3
0.2-0.3
0.1-0.2
0.05-0.1
< 0.05

WHOI stations from Corwin 1970
Depth less than 20 m at stations 1507 and 1517

Map 8. Nitrate nitrogen: distribution, September 1969

1 m

20 m
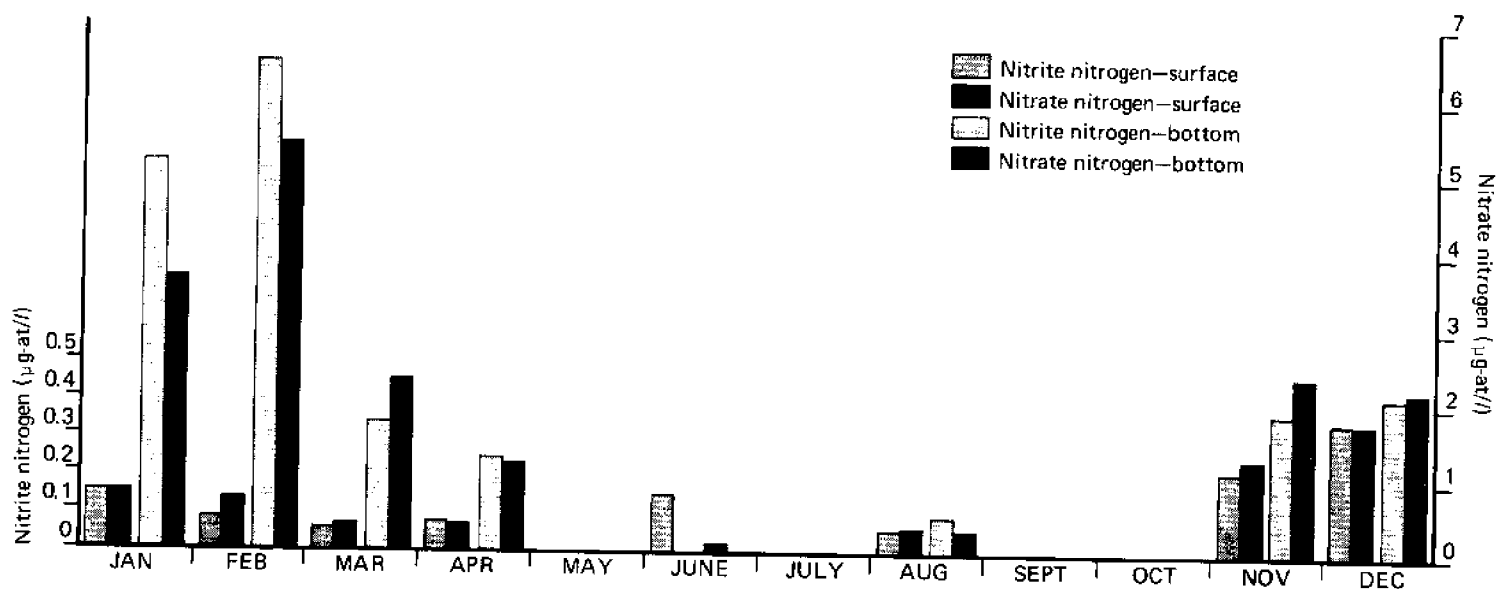
Figure 13. Seasonal variation of nitrite and nitrate nitrogen off Montauk Point, NY, 1972

depth. During September the observed concentrations (Corwin 1970) were less than 0.5 μg-at/l except in the Bight apex and in New York Harbor (Map 8). At 20 m (66 ft) concentrations ranged between 1 and 5 μg-at/l in the apex and between 6 and 12 μg-at/l in the harbor. In November 1974 concentrations ranged up to 23.5 μg-at/l in the harbor (Table 19).

Seasonal variation of nitrite and nitrate in the Bight is shown in Figure 13. Nitrate is generally the dominant form of the two in surface and bottom waters; both are present in highest concentrations during winter months. Ryther and Yentsch (1958)

reported similar results for the combined fractions (ammonia + nitrite + nitrate) for 1956-1957 in the Bight.

A comparison of nitrogen and phosphorus data reveals that both nitrite and nitrate nitrogen are stripped from the water column more completely than is phosphorus. This is particularly evident in the seasonal variation in the nitrogen-to-phosphorus (N/P) ratio (Figure 14). Ketchum, Vaccaro, and Corwin (1958) found similar seasonal ranges in the N/P ratio in shelf waters; selected stations in deep offshore waters had a ratio of 12:1 and showed little
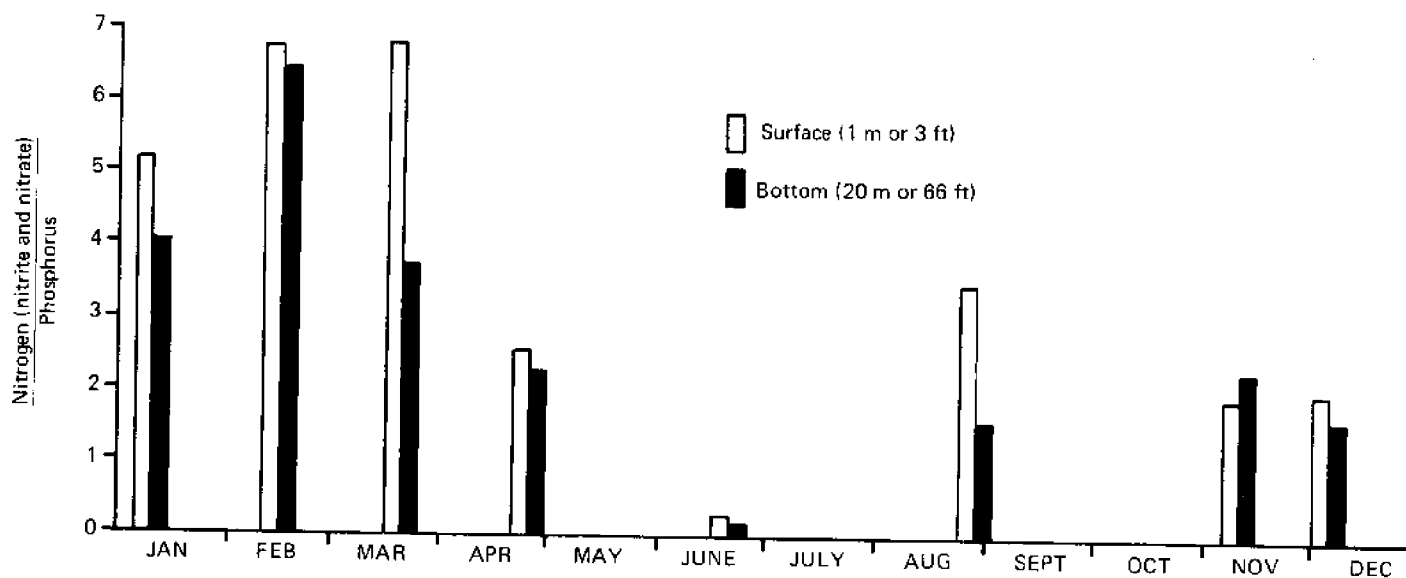
Figure 14. Seasonal variations in nitrogen/phosphorus ratio in waters off Montauk Point, NY, 1972

evidence of seasonal variation in concentrations at the oxygen-maximum, nutrient-maximum layer (Horne et al 1971). In Lower Bay, ratios of 10:1 and 17:1 were present.

These N/P ratios indicate that in shelf waters nitrogen is a major limiting factor. The effect of increased concentrations of nitrogen indicated in the N/P ratios in Lower Bay is evident in Ryther and Dunstan's (1971) comment that "the water at that location (station 1507) was a bright apple-green in color and contained nearly a pure culture of a small green alga." In subsequent studies the authors noted that the growth response of *Skeletonema costatum* to ammonium enrichment was much greater than to phosphorus enrichment except in Lower Bay and at the dredge spoil dumpsite.

Vaccaro (1963) and Duedall et al (1975) indicated that ammonianitrogen is an important component of the nitrogen cycle, especially in those intervals when nitrate has been mostly stripped from the water.

Silica is an essential nutrient for the growth of diatoms and other silaceous organisms. Its most probable soluble form is orthosilicic acid. Seawater contains suspended siliceous materials of both biogenic and nonbiogenic origin. No data concerning measurement of suspended silica in Bight waters were found; most silica determinations were made on unfiltered samples. The distribution of soluble silica in New York Harbor in November 1974 is shown in Table 21. Upper Bay is characterized by higher concentrations than Lower Bay; this distribution is related to the salinity of the system. The low concentration in Lower Bay may be explained by dilution, biological uptake, or reaction with suspended aluminosilicates, according to Burton and Liss (1968) and Bien, Contois, and Thomas (1958).

Duedall (personal communication 1974) observed tidal and seasonal fluctuations in the silicate concentrations of both surface and bottom waters between Sandy Hook and Rockaway Point. In general, surface waters contained more silicate than deep waters, and the observed concentrations were generally less than 15 μg-at/l in surface waters and less than 10 μg-at/l in bottom waters.

Corwin (1970) found that in September (Map 9) Bight surface waters contained less than 2.5 μg-at/l. Below the thermocline higher concentrations were present, generally between 2.5 and 10 μg-at/l. At the Bight apex, concentrations ranged between 10 and 20 μg-at/l.

Table 21. Average distribution of silicates in New York Harbor, November 1974

Depth				μg-at/l		

Upper Bay (adjacent to The Battery)

m	ft	East River	Hudson River
1	3	22.6	22.3
7	23	22.1	20.3
14.5	47.6	22.4	18.8

The Narrows

0	0	20.6	
12	39	17.1	
24	79	16.4	

Lower Bay

		Rockaway Point	Ambrose Channel	Sandy Hook
0	0	8.4	16.1	12.4
5	16	8.2	16.8	11.7
10	33	9.2	13.6	11.0

Source: From Alexander, unpublished data

Alexander (unpublished data) studied seasonal fluctuations in silicate for both surface and bottom waters at a station off Montauk Point. As is typical for these coastal waters, high concentrations were present during winter (Figure 15), attributed to high stream discharge from Connecticut rivers. Diurnal fluctuations were also noted in waters south of Jones Beach in November.

Organic Compounds

Chlorophyll measurements are generally used in biologically related studies to indicate the quantity of phytoplankton population in a given volume of water. Spatial and temporal changes in these concentrations are also useful to interpret observed changes in parameters such as the micronutrients.
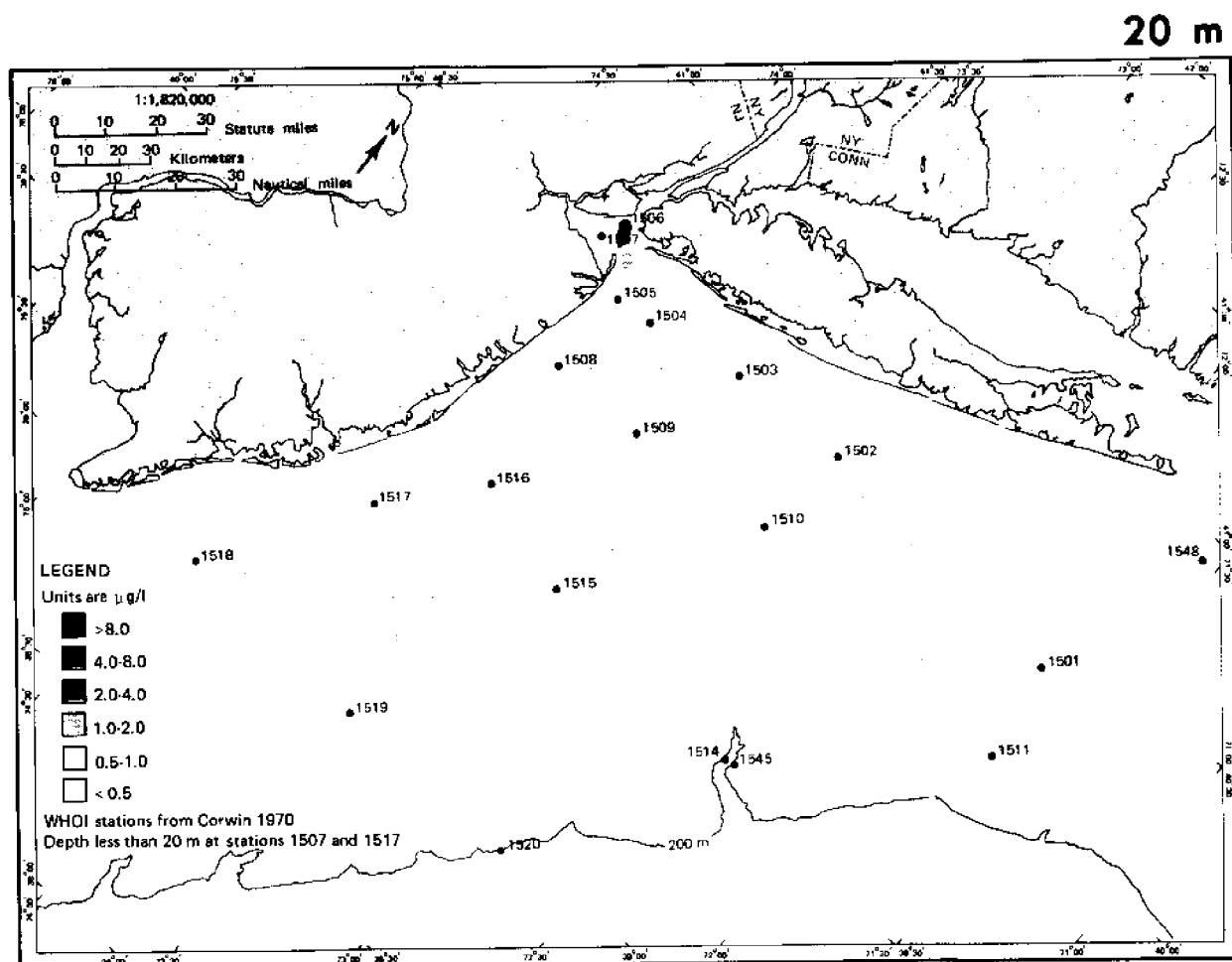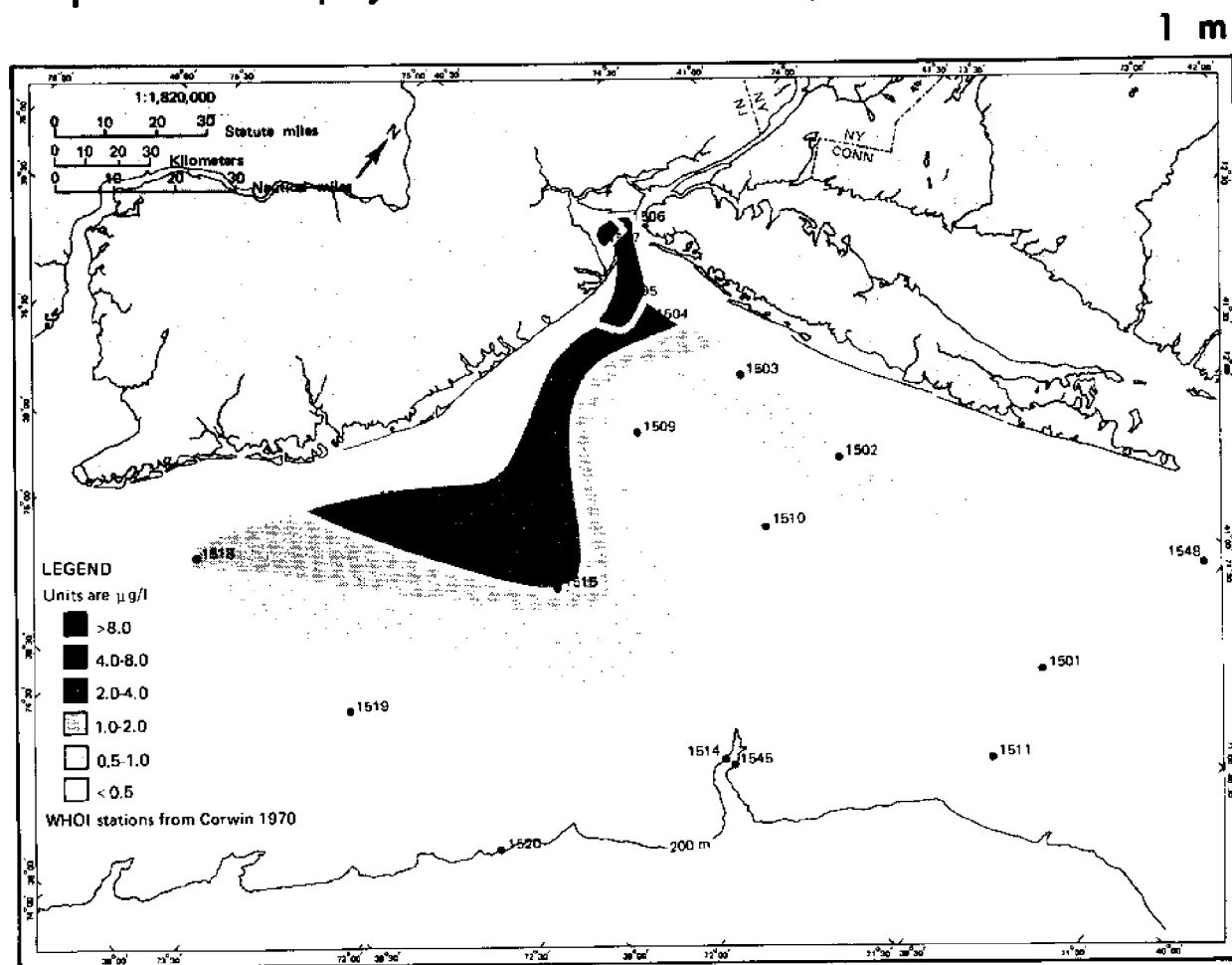
The distribution of chlorophyll *a* in September 1969 is shown in Map 10. The increased concentration of the pigment in the upper portion of the water column is in part a function of phytoplankton dependence upon light for photosynthetic activity. The increased concentrations in the Bight apex reflect phytoplankton response to increased micronutrient concentrations.

Map 11 depicts the distribution of chlorophyll *a* in surface waters in April 1970. Large increases

Map 9. Silica: distribution, September 1969

1 m

20 m
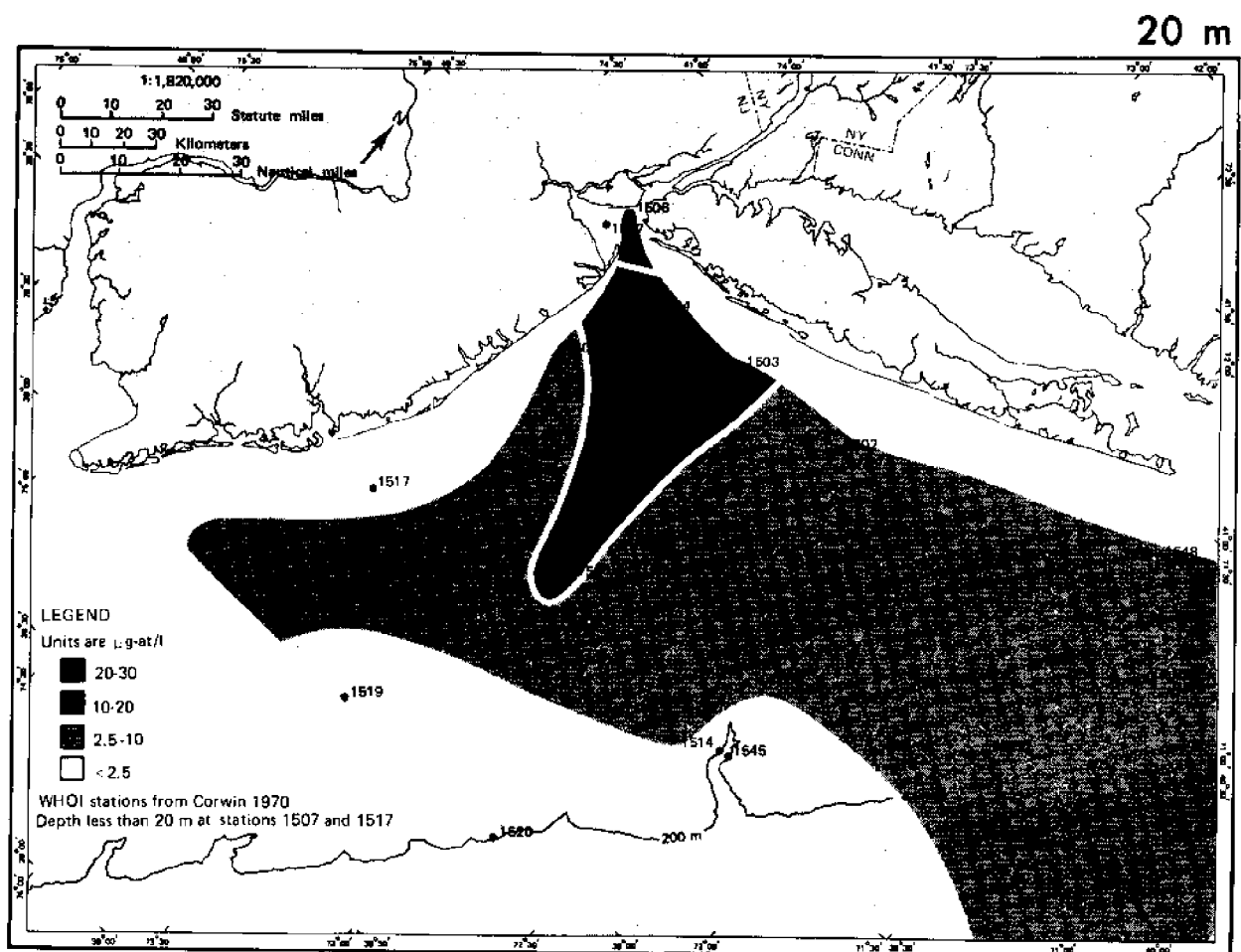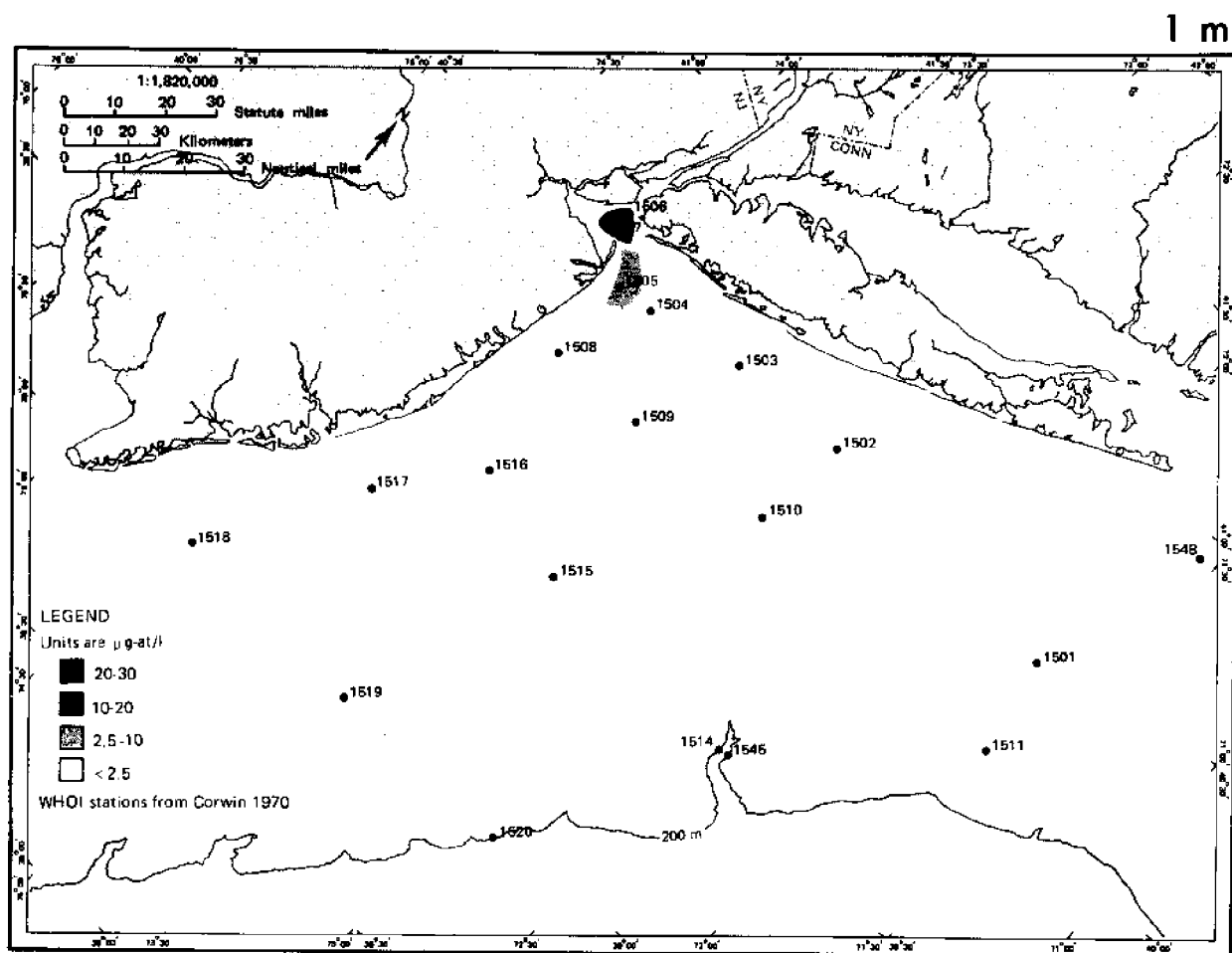
Map 10. Chlorophyll *a* : distribution, September 1969
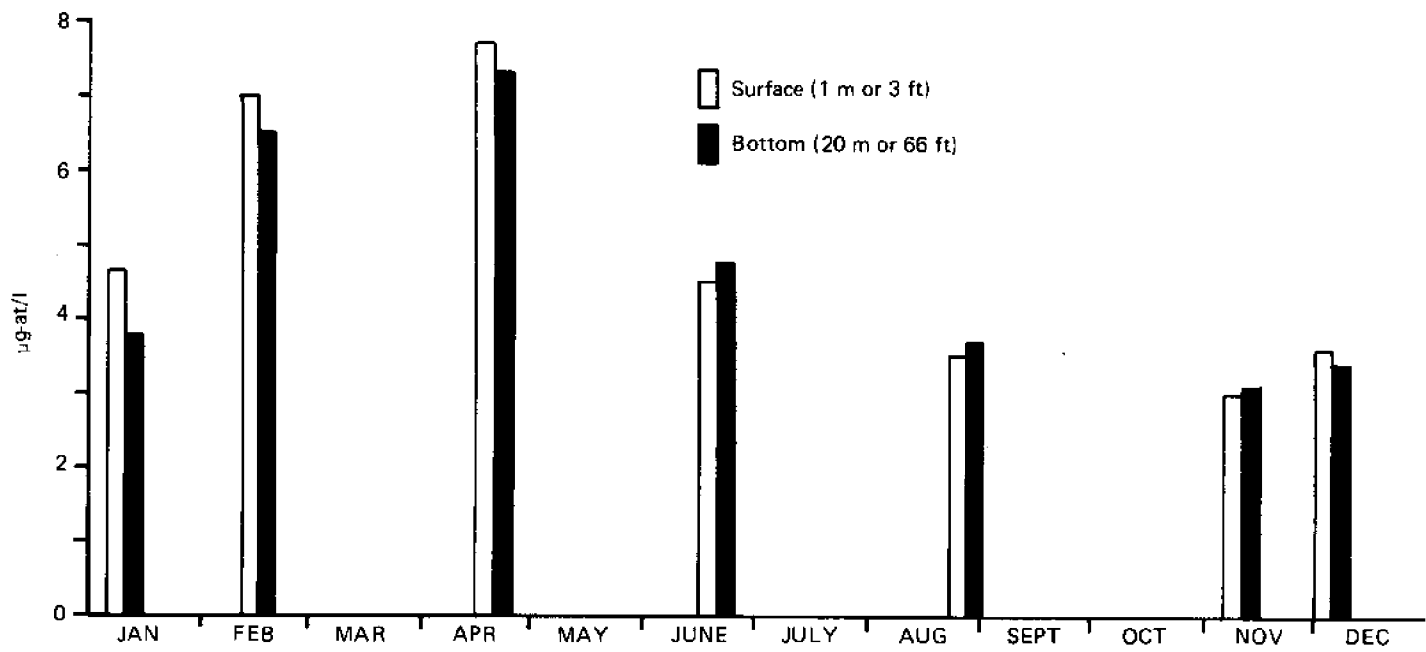
1 m

20 m

38

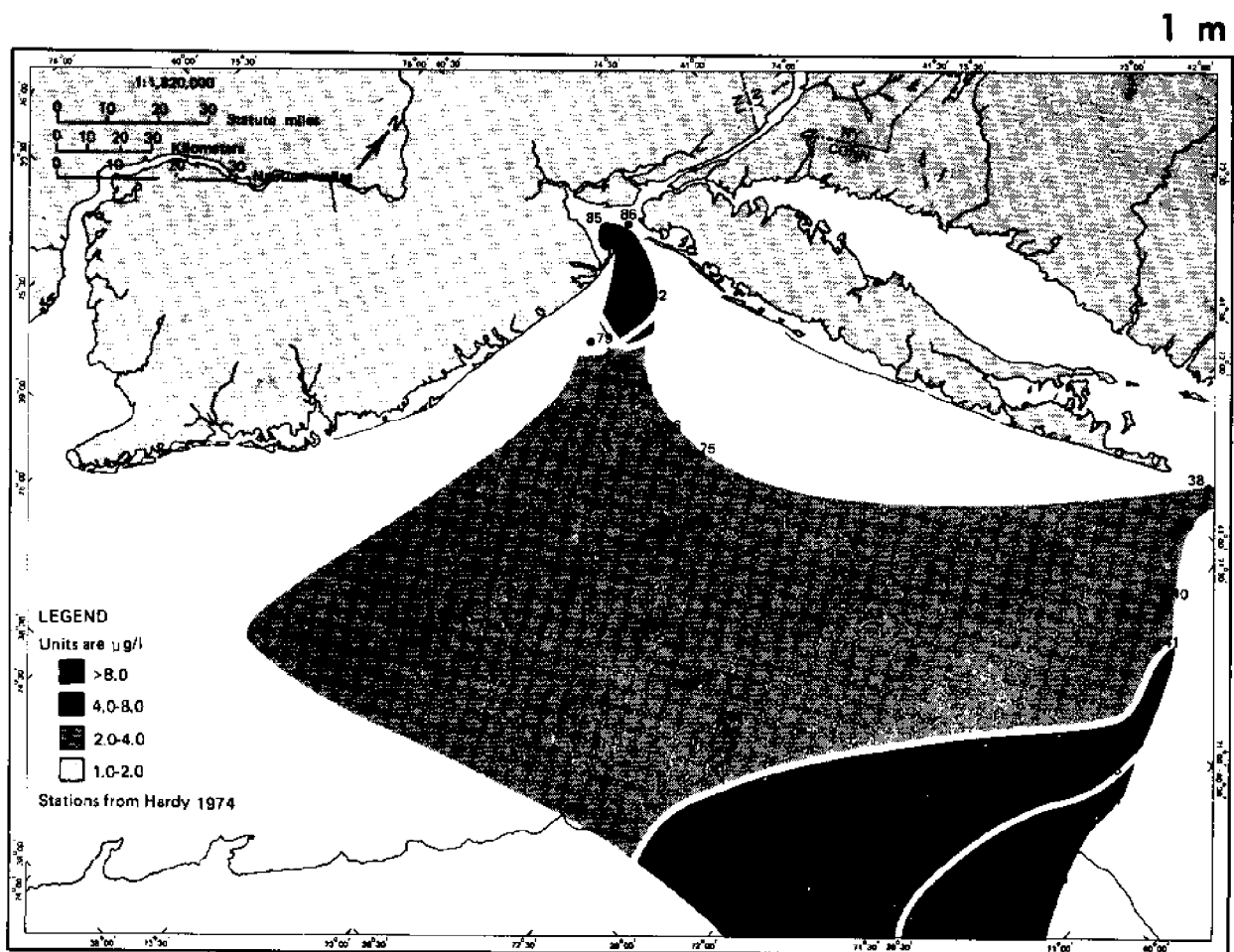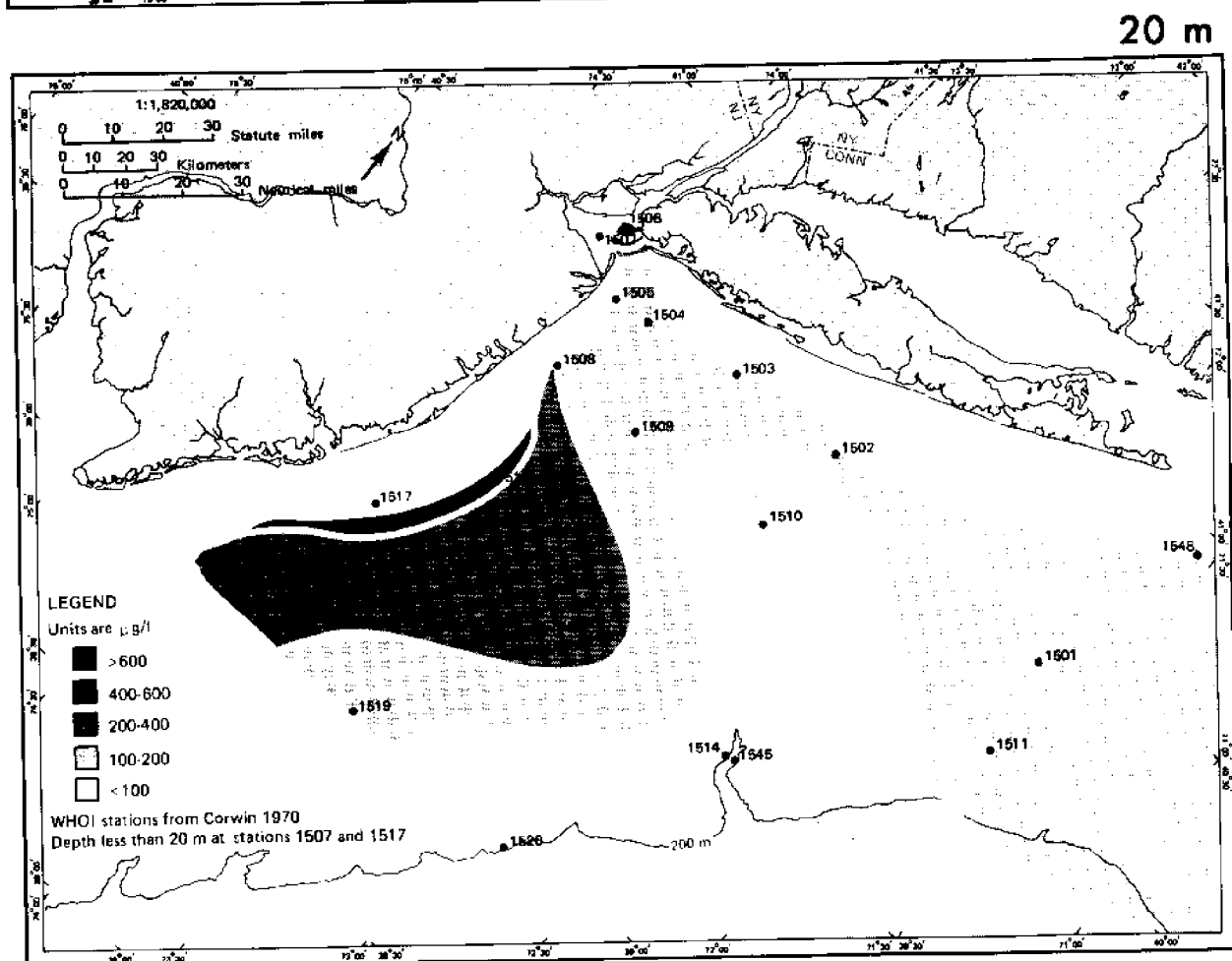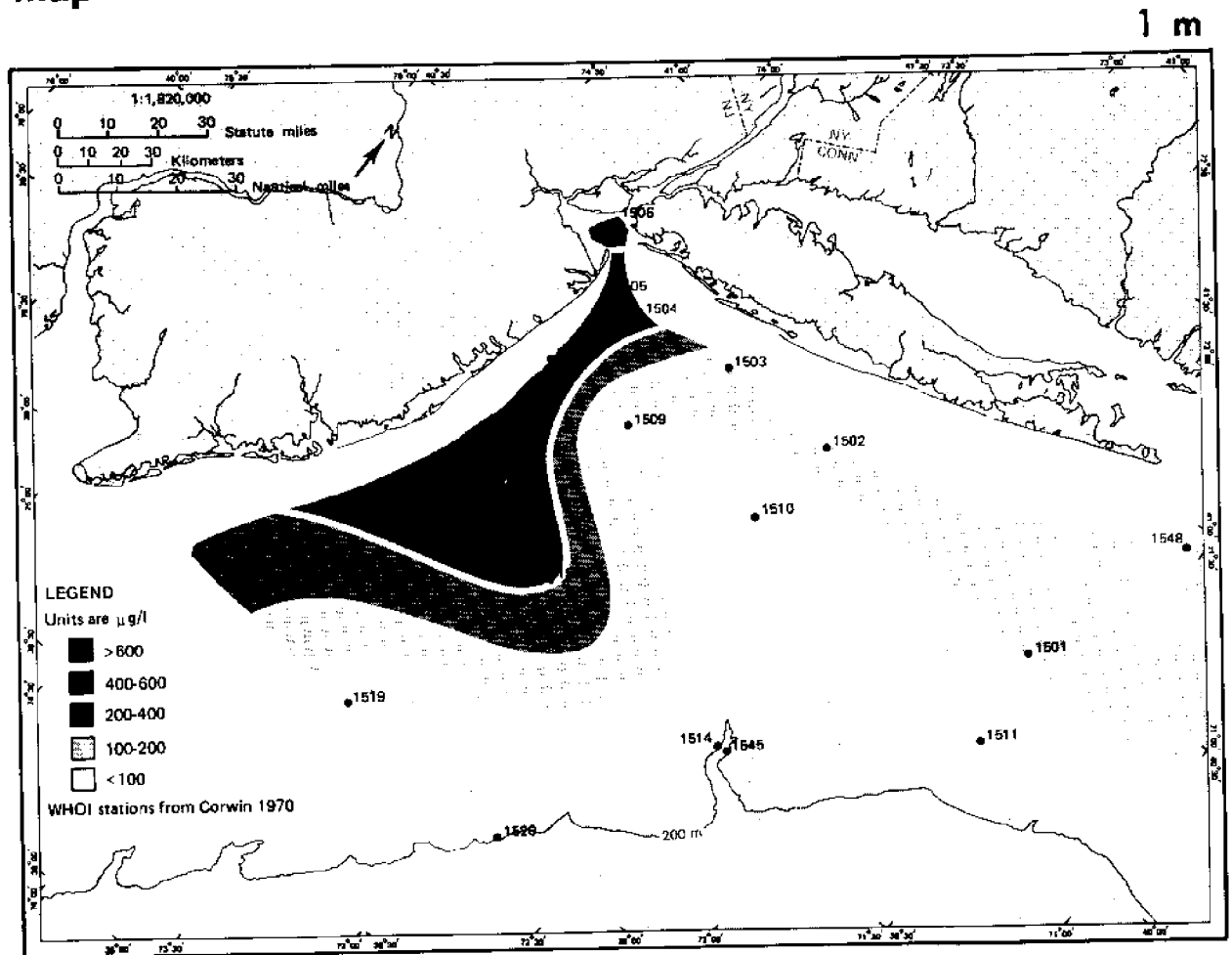**Figure 15.** Seasonal variation of silica in waters off Montauk Point, NY, 1972

Map 11. Chlorophyll *a* : distribution, April 1970

1 m

LEGEND

Units are µg/l

- >8.0
- 4.0-8.0
- 2.0-4.0
- 1.0-2.0

Stations from Hardy 1974

Map 12. Particulate carbon: distribution, September 1969

1 m

LEGEND

Units are µg/l

- >600
- 400-600
- 200-400
- 100-200
- <100

WHOI stations from Corwin 1970

20 m

LEGEND

Units are µg/l

- >600
- 400-600
- 200-400
- 100-200
- <100

WHOI stations from Corwin 1970
Depth less than 20 m at stations 1507 and 1517

occurred in pigment concentrations in the intervening six months, and in almost all instances concentrations were over 4 μg/l. In Raritan Bay, concentrations over 100 μg/l were reported by Hardy (personal communication 1974).

Data reported by Corwin (1970) contain information on particulate carbon distribution for September 1969 (Map 12). The highest amounts of particulate carbon were found in lower New York Harbor where the concentration of particulate carbon ranged between 773 and 1,300 mg/l. In the Bight apex and the waters to the east the particulate carbon concentrations decreased with depth and distance from shore. Concentrations ranging between 400 and 600 mg/l were present at 20 m (66 ft) near the New Jersey coast; at the same depth along the southern shore of Long Island and east of New Jersey concentrations were less than 200 mg/l.

Figure 16 depicts the relationship between particulate carbon and chlorophyll a in surface waters in September 1969. Similar relationships were present at 20 m or 66 ft (r = 0.819).

No significant differences in the concentration of total dissolved organic carbon over a tidal cycle were found in the waters between Sandy Hook and Rockaway Point by Alexander et al (1974), nor were any significant correlations found between salinity, total dissolved iron, and total dissolved organic carbon at any of the stations. The mean concentration of dissolved organic carbon is shown in Table 22.

Total organic carbon concentrations in Raritan and Sandy Hook bays averaged 9.1 mg/l with no

Table 22. Mean concentration of dissolved organic carbon in water column along Sandy Hook-Rockaway transect, November 1973

| | mg/l | | |
	Rockaway Point	Ambrose Channel	Sandy Hook
Flood	12.7	14.5	15.3
Ebb	14.3	14.5	15.8
Rising	15.3	14.5	14.7
Falling	13.6	14.5	15.7

Source: From Alexander et al 1974

significant differences between the two areas (Mytelka 1973).

Nitrogenous compounds are important in controlling primary production (Ryther and Dunstan 1971) but the role of organic nitrogen compounds in these activities have not yet been completely clarified. Urea, the end product of nitrogen metabolism, has been suggested as a source of nitrogen, important in phytoplankton physiology (Ryther 1954; Guillard 1963; Newell, Morgan, and Cundy 1967; McCarthy 1970).

Remsen (1971) determined the distribution of urea in lower New York Harbor and in the Bight. The concentration of urea in surface waters ranged from an average of 1.3 μg-at/l in open waters to 11.2 μg-at/l in the harbor. Wide fluctuations with depth were also noted. By percentage, urea was generally the dominant form of nitrogen in the upper 25 m (82 ft) of shelf waters. Hardy's data (personal communi-
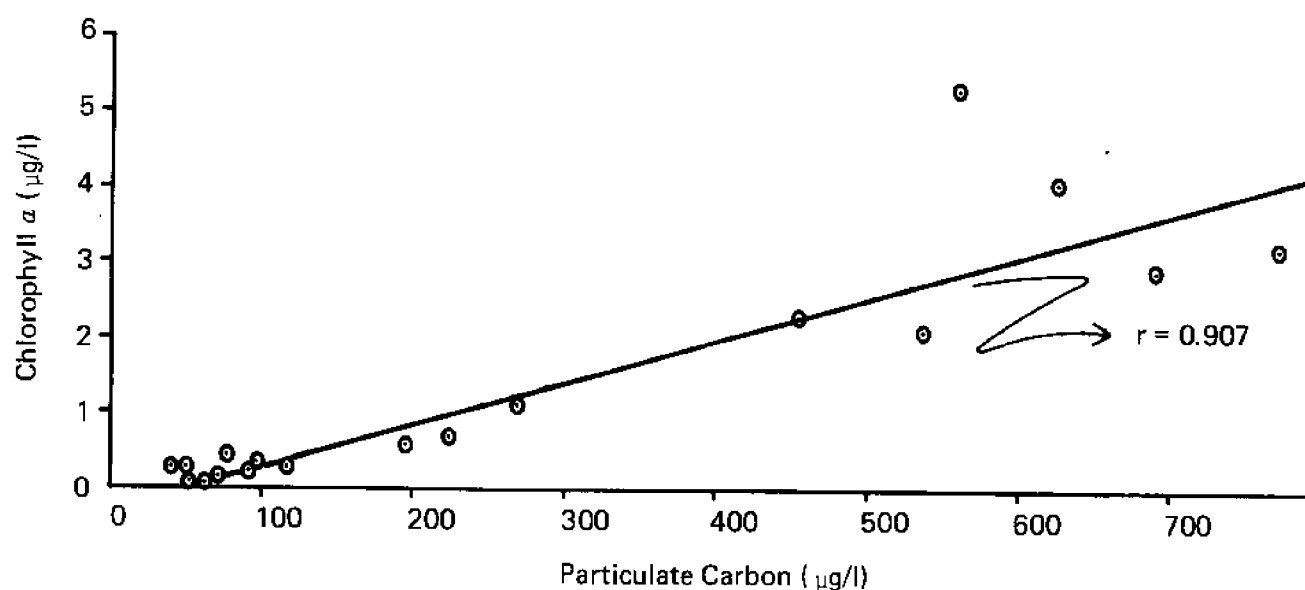

Figure 16. Relationship between particulate carbon and chlorophyll a at one-meter depth, September 1969

cation 1974) indicate that concentrations of urea fluctuate seasonally. For example, in harbor waters concentrations up to 69.2 μg-at/l were present in August 1971; in April, urea concentrations were generally less than 15 μg-at/l. Similar variations were found in open waters where summer and winter values approximated 1 μg-at/l and less than 0.5 μg-at/l, respectively.

Radioactive Materials

Radionuclides in the Hudson River have been monitored by both the Public Health Service (HEW) and the Institute of Environmental Medicine of the New York University Medical Center. The Public Health Service (1965) determined both suspended and dissolved beta radioactivity at a station near Poughkeepsie, NY. Beta activity levels generally indicate atmospheric fallout, and nuclear and energy plant discharges. The results indicated that radioactivity was only slightly more associated with the dissolved than the suspended fraction during the monitoring interval.

Investigators from the Institute of Environmental Medicine (1966, 1968) studied the distribution of selected radionuclides in Hudson River waters, sediments, and biota from 1964 to 1968. The nuclides ^{144}Ce, ^{137}Cs, ^{40}K, ^{228}Ra, ^{106}Ru, ^{54}Mn, ^{60}Co, ^{65}Zn, ^{95}Zr, and ^{90}Sr (see Table 3) were the ones usually measured. The investigators discontinued the determination of suspended solids after the first year due to low activity and consequent doubtful validity of the numbers.
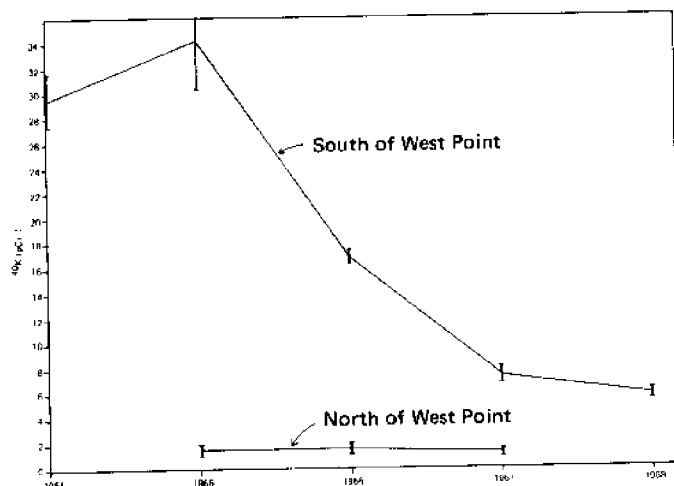
The results of these studies show that ^{40}K was the significant radionuclide in the river, followed by ^{226}Ra and ^{228}Ra. Figure 17 shows the mean concentration of ^{40}K in surface waters above and below West Point, NY, (their delineation point between estuarine and freshwater environments) from 1964 to 1968.

High concentrations of ^{40}K during the early years of the studies were attributed to a drought, with its low river flow and consequent increased saltwater intrusion (unfortunately, no salinity data were included). The gradual decline of ^{40}K concentrations since 1965 was attributed to increased river flow.

The ^{226}Ra and ^{228}Ra concentrations were variable, approximately 0.1 pico Curies/liter (pCi/l), and showed no consistent trends. The fission products ^{137}Cs and ^{144}Ce in the three years of observations generally declined in concentration in the area north of West Point, while to the south only ^{137}Cs decreased. ^{106}Ru concentrations generally declined only in the waters south of West Point. Limited determinations of ^{90}Sr were conducted, and the observed concentrations were approximately 1.8 and 1.0 pCi/l in 1965 and 1966, respectively.

Lentsch (1969) noted that among the potential sources of radioactive materials in the Hudson River— soil leachates, atmospheric fallout, and industrial processes—the prime source of radioactive substances is atmospheric fallout. Evidence for this was obtained from ^{137}Ca/^{90}Sr ratios. The quantity of the activation products ^{60}Co and ^{54}Mn was generally below detection limits (except in 1964 and 1968) and this was cited as evidence that atmospheric fallout is the principal contributor of radioactivity to the river upstream.

Simpson, Rouen, and Mathier (1973) found that the major input of radon to Hudson River estuary waters was from sediments. Radon is lost primarily by radioactive decay. Average concentrations were near 1.5 disintegrations per minute per liter (dpm/l) with a range of 0.5 to 3 dpm/l; the mean life of a radon atom was from three to five days.

Feely et al (1973) made thorium (^{228}Th) measurements in the near-surface waters of the continental shelf from Long Island to Cape Hatteras. The activity ratios found (0.02 to 0.06) indicated a mean residence time of one to two months. Such short residence times in these waters, compared with 8 to 18 months in the western Sargasso Sea, were attributed to increased productivity of shelf waters.

Figure 17. Mean ^{40}K concentrations in Hudson River, 1964-1968

This review of available information on New York Bight's chemical oceanography shows clearly that much more detailed investigations are required—not only to see how dynamic processes interact with the water's chemistry, but also to learn even the basic descriptive details of how much, when, and where. The lack of knowledge is not unique to Bight waters. Anderson (1973) says that "unfortunately, most of the basic marine chemical processes, their controls, mechanisms, alterations by outside influences (for example, pressure), and their effects upon man's utilization of the oceans, are not well understood. The number of organic compounds in the sea far exceeds that of all inorganic species combined, yet little is known of their involvement in trace-element chemistries." No extensive trace element data exist for the Bight. Until these data and data on classical chemical parameters are collected, proper management of the Bight will be difficult. Information on chemical input from the Hudson River and New York Harbor is urgently needed; significant sources of inputs should be identified and characterized, both quantitatively and qualitatively. The fate of such materials in the Bight must be determined.

Future chemical studies of the Bight should be directed towards determining the processes and mechanisms governing the inorganic and organic composition of these waters; the chemical fluxes through the region, including air-sea and sediment-sea exchanges; and the impact of life processes on the chemistry of these waters.

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