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The Hudson Estuary

Weiss, Dennis

Rachlin, J. W.

Coch, N. K.

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TRIP A - 2: THE HUDSON ESTUARY

D. WEISS, Department of Earth and Planetary Sciences, The City College of New York of C.U.N.Y., New York, New York 10031; J.W. RACHLIN, Department of Biology, Lehman College of C.U.N.Y., Bronx, New York 10468; and N.K. COCH, Department of Earth and Environmental Sciences, Queens College of C.U.N.Y., Flushing, New York 11367.

The Hudson Estuary Survey

The City Institute of Marine and Atmospheric Sciences' Hudson Survey program began in October, 1973 with a series of initial cruises to establish a viable survey track and sampling protocol. A series of 23 stations (Fig. 1, Table 1) were selected as the survey track and these stations have been sampled once per month. The entire survey area covers a linear distance of approximately 115 mi extending from Saugerties, New York on the north (station 1) to a southernmost station (16B), 3.5 mi northeast of Sandy Hook, New Jersey, at the apex of the New York Bight. Since the survey represents a multidisciplinary effort, the following sampling activities were performed at each station:

A. Precision depth recording
B. Three bottle hydrocast to take samples from the surface, mid-depth, and bottom of the water column.
C. Bottom sediment collection using a Peterson grab sampler.
D. Phleger core sampling.
E. Secchi disc transparency.
F. Salinity, temperature, and dissolved oxygen determinations at every two meters of depth from surface to bottom.

The effort to date represents over 58 actual ship days on the estuary during 16 cruises on the Institute's 88 ft research vessel the R.V. Commonwealth. The following is a series of papers presenting some of the preliminary results of this survey in the broad areas of the physical, chemical, geological, and paleontological observations obtained during the first eighteen months of study.

Geologic Setting and History of the Hudson Estuary

The Hudson River and Estuary is one of the major waterways of the eastern part of the United States. It begins in the southern part of the Adirondack Mountains and flows southward approximately 300 km to its mouth at New York City. About 34,650 km^2 of the southeastern part of New York, northeastern New Jersey, and southwestern New England comprise the watershed of the Hudson River and Estuary.

The depth of the estuary in the area of this trip remains relatively constant. From south of The Highlands to The Narrows and from north of The Highlands to Poughkeepsie, water depths average 15 to 16 m. It is in the gorge of the Hudson Highlands that the river abruptly reaches depths of as much as 55 m. Both in The Highlands and north to Poughkeepsie, the main channel of the estuary covers the full width of the valley, which is between 1200 and 1500 m wide. South of The Highlands, in Haverstraw Bay and the Tappan Zee, broad expanses of shallow water border the main channel of the estuary. Here,

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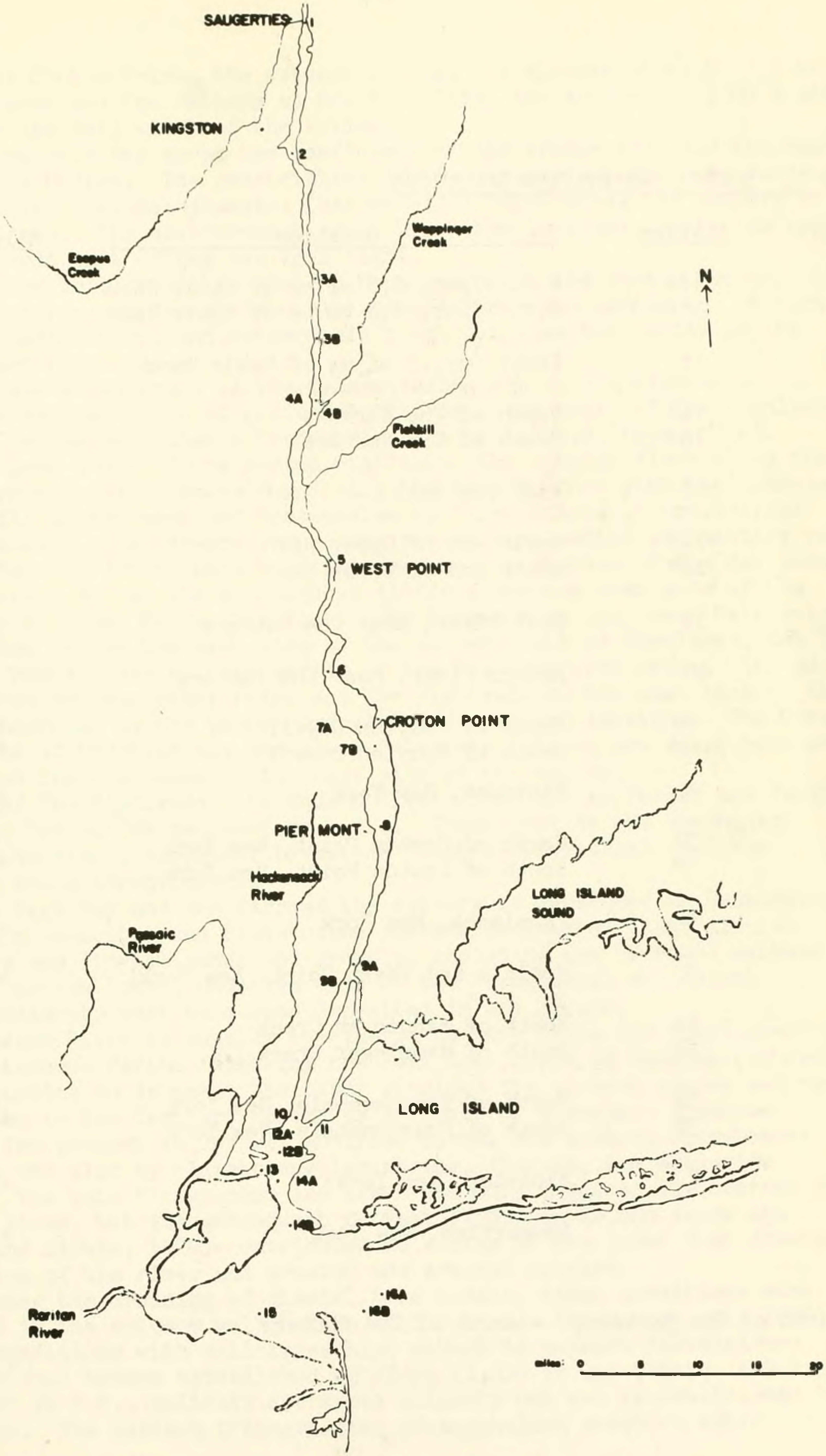

FIGURE 1. MAP OF SAMPLING SITES OF THE HUDSON ESTUARY SURVEY.

Table 1. SECTOR AND STATION LOCATIONS

Sector	Station	Location	Mile Point[*]
16	16A 16B	N.Y. Bight, 6.0 mi ne of Sandy Hook N.Y. Bight, 3.5 mi ne of Sandy Hook	-15
15	15	Lower Bay, 3 mi nw of Sandy Hook	-12
14	14A 14B	North of The Narrows South of The Narrows	- 8
13	13	Kill Van Kull	- 6
12	12A 12B	North end of Upper Bay South end of Upper Bay	- 2
11	11	East River, near The Battery	0
10	10	Hudson River, near The Battery	0
9	9A 9B	North of Spuyten Duyvil South of Spuyten Duyvil	+ 8
8	8	Piermont, New York	+18
7	7A 7B	North of Croton Point, New York South of Croton Point, New York	+25
6	6	Verplanck, New York	+33
5	5	World's End (West Point, New York)	+50
4	4A 4B	North of Wappinger Creek South of Wappinger Creek	+63
3	3A 3B	North of Poughkeepsie, New York South of Poughkeepsie, New York	+71
2	2	Kingston, New York	+88
1	1	Saugerties, New York	+99

[*] + north of The Battery; - south of The Battery

just north of Croton Point, the estuary reaches its maximum width of 5.5 km. Between Piermont and The Battery at New York City, the estuary is 1800 m wide and occupies the full width of the valley.

Upper New York Bay marks the confluence of the Arthur Kill and the East River with the Hudson. The constriction of the estuary's mouth (The Narrows) is caused by the morainal deposits (Harbor Hill) which cross the estuary at its southern end. The southernmost area, Lower New York Bay, marks the apex of the innermost part of the New York Bight.

As seen on this trip (Piermont to Poughkeepsie), the Hudson Estuary lies in a region of Precambrian to late Pleistocene rocks and sediments. A variety of igneous, sedimentary, and metamorphic rocks comprise the valley of the Hudson Estuary (Fig. 2).

The oldest rocks found in the Hudson Valley are in The Highlands. Granites and various kinds of gneiss are the dominant rocks of The Highlands. Radiometric dating indicates a Precambrian age of 1.2 b.y. (Grenville).

In the area south of the Hudson Highlands, the estuary flows along the contact between Triassic rocks comprising the Newark Group with the intruded Palisades Sill on the west and Precambrian to lower Paleozoic crystalline rocks on the east. The Newark Group consists of continental sedimentary rocks (primarily red-beds) that have been intruded by the diabase of the Palisades Sill which crops out as the conspicuous cliffs along the west side of the valley south of Stony Point, New York. The Precambrian and lower Paleozoic rocks cropping out on the east side of the valley south of Verplanck, New York consists of gneiss, schist, and marble of the New York City Group. In addition, the area between Stony Point and The Highlands on the west bank of the valley is underlain by the Cambro-Ordovician Wappinger Limestone. The Cortlandt Complex of Devonian age and lower Paleozoic inliers are found between Verplanck and The Highlands on the east side of the valley.

North of The Highlands, the Hudson River flows across folded and faulted Cambrian and Ordovician sedimentary rocks. These include the Poughquag Quartzite (Cambrian), Wappinger Limestone (Cambro-Ordovician), and the Normanskill Shale (Ordovician).

In New York Bay and The Narrows the estuary is developed on Cretaceous coastal plain deposits, and Pleistocene glacial sediments. Late glacial varved clays and fluvial sands and gravels, including the (former) deltaic deposits of Croton Point, underlie most of the Postglacial and Recent estuarine sediments that have been deposited in the Hudson.

The Hudson River is usually considered to have begun its development during the Cretaceous Period following the Fall Zone cycle of erosion (Johnson, 1931). According to Johnson, the river attained its present course and basic configuration in the Tertiary Period as a result of a series of stream captures. The present valley was modified during the various Pliestocene glaciations and also by Pleistocene lacustrine, fluvial, and estuarine processes. The late Pleistocene ice sheet not only deepened the bedrock channel of the river, but its subsequent retreat 17,000 to 18,000 years ago (Connally and Sirkin, 1970) contributed to a rise of sea level that drowned a major portion of the river and created the present estuary.

Following the draining of glacial Lake Hudson, tidal conditions were established in the estuary well before 12,000 yr ago (Newman *et al.*, 1969). Estuarine conditions with salinities high enough to support foraminifers (approx. 30°/oo) became established by about 11,500 yr ago (Weiss, 1974). About 10,000 yr B.P., salinity decreased slightly but was re-established by 9,000 yr ago. The maximum transgression of mesohaline brackish water

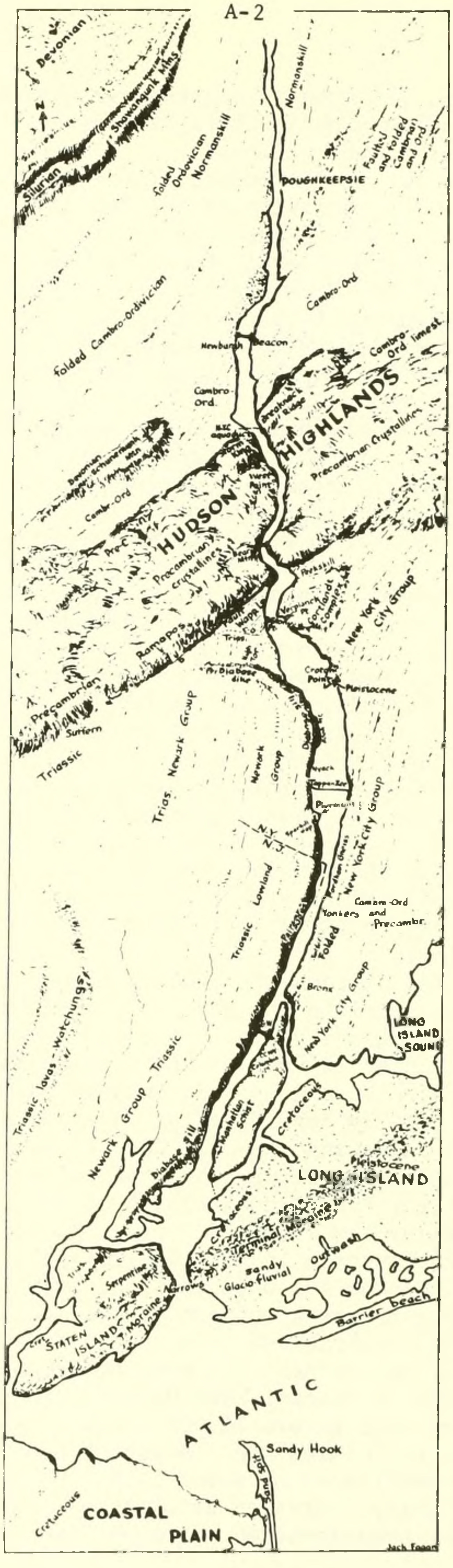

FIGURE 2. PHYSIOGRAPHIC DIAGRAM OF THE LOWER HUDSON RIVER VALLEY

(salinity between 5.0 and $32^{\circ}/oo$) into the estuary during late- and postglacial time occurred about 6,500 yr B.P., as shown by the initial appearance of foraminifers in the Peekskill area of the estuary. This event coincides with the general flooding of the northeastern United States by the Atlantic Ocean. Foraminiferal evidence indicates that the salinity of the estuary has decreased during the past 1,500 to 3,000 years. This appears to be the result of sediment being deposited faster than the rise of sea level or crustal subsidence. Thus, the influence of saltwater within the estuary has been regressing.

Field Trip Itinerary

The Hudson Estuary field trips (A-2, Friday October 10, 1975; and C-12, Sunday October 12, 1975) will study six sectors of the Hudson, from sector 8, Piermont, New York to sector 3, Poughkeepsie, New York (Fig. 1, Table 1). The vessel will occupy six sampling stations on each trip; sectors 3, 4, 5, 6, 7, and 8. These stations will include sections of the estuary which display the shallow and wide bay areas (sectors 6, 7, 8), the deepest section (sector 5), a major tributary outfall (sector 4), and an area of dense urbanization (sector 3). The following onboard operations will be performed at each station:

1. Precision Depth Recording for depth and topographic profiling.
2. Salinity - Temperature - Dissolved Oxygen - Depth Profile.
3. Phleger core sampling.
4. Peterson grab sampling for bulk sediment and benthic biota.
5. Zooplankton tow primarily for icthyoplankton.

Water samples will be collected if requested by the participants. The significance of these sampling procedures and the results obtained at the stations to be occupied by this field trip are discussed in the accompanying papers in this section of the guidebook.

Trip A - 2 will steam on the R.V. Commonwealth from Piermont, New York at 8:00 A.M. and will arrive at Poughkeepsie, New York at approximately 6:00 P.M. Transportation will be provided from Poughkeepsie to the conference at Great Barrington, Vermont.

Trip C - 12 will depart Great Barrington at 7:30 A.M. and will steam on the R.V. Commonwealth from Poughkeepsie, New York at 9:00 A.M. Sampling operations will be completed at sector 8. From here the ship will proceed to St. George, Staten Island, New York arriving at approximately 10:00 P.M. Public transportation is available from Staten Island.

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A-2

TEMPERATURE AND SALINITY OBSERVATIONS IN THE HUDSON ESTUARY, 1974

J.W. RACHLIN, Department of Biology, Lehman College of C.U.N.Y., Bronx, New York 10468; J. CHUTE, Department of Geology and Geography, Lehman College of C.U.N.Y., Bronx, New York 10468; and E. POS MENTIER, City Institute of Marine and Atmospheric Sciences, Bronx, New York 10468.

Introduction

As part of the City Institute of Marine and Atmospheric Sciences' ongoing multidisciplinary study of the Hudson Estuary, seasonal changes in the temperature-salinity regime of the study area were recorded. This paper reports data from January to November, 1974 measured over a survey track of approximately 115 mi in length, extending from Saugerties, New York on the north, to a southern position, in the apex of the New York Bight, at a point 3.5 mi northeast of Sandy Hook, New Jersey. This survey track included the estuarine section of the Hudson, as well as, freshwater and marine reference stations.

Methods Of Study

A series of 16 sampling sectors (Table 1), containing a total of 23 stations (Fig. 1) was established. Certain stations: 14A and 14B, at each end of The Narrows; 12A and 12B, at each end of Upper New York Bay; 9A and 9B, on either side of the confluence of the Hudson and Harlem Rivers; 7A and 7B, north and south of the mouth of the Croton River; 4A and 4B, north and south of the confluence of the Hudson River and Wappinger Creek; 3A and 3B, north and south of Poughkeepsie, New York, were taken to be tidal stations and were located such that the "A" stations were sampled on the flood tide, while the "B" stations were sampled on the ebb tide. All stations were in or adjacent to the main channel of the river and each sampling sector was occupied at least once per month during the sampling period.

Actual measurements of the Salinity-Temperature-Depth profile at each station was made using a deck lowerable _in situ_ conductivity, salinity, temperature, and depth sensor run concurrently with standard water sampling using Niskin bottles and reversing thermometers. These latter samples were taken as part of a continuing water sampling program including checks of salinity using an on board salinometer.

In order to produce sigma-t (σ_t) curves and gain an understanding of density stratification within the study area, the computer program of Cox _et al._ (1970) was used along with the anticipated and measured temperatures and salinities of the area. While this method does not take into account turbidity related density, it does represent a reasonable first approximation of Temperature-Salinity-Density relationships anticipated in the study area. If the actual Temperature-Salinity profiles of the Estuary are parallel to the generated sigma-t lines of equal density, then there is good presumptive evidence for a condition of at least partial salinity stratification.

This work was jointly sponsored by Lehman College and the City Institute of Marine and Atmospheric Sciences.

Contribution No. 47 of the City Institute of Marine and Atmospheric Sciences.

Results and Discussion

Figure 3 is a graphic representation of equal density profiles generated using the program of Cox et al. (1970), over the salinity-temperature regime of the study area. Figure 4 represents the Temperature-Salinity profiles of representative sectors during the winter (January), spring (April), summer (July), fall (October), and again winter (November) flow periods of the estuary. Comparison of the slopes of these Temperature-Salinity profiles with the sigma-t lines of equal density (Fig. 3) indicate that during all flow regimes of 1974 the estuary was partially stratified with more dense saline water riding below less dense saline water. This is in agreement with the findings of Abood (1974), who described the Hudson Estuary as a partially stratified estuary with a net seaward flow. Further, it will be noticed that the northward progression of high salinity water as a result of tidal forcing during low flow periods is significant and that detectable salinity concentrations were observed north of Haverstraw Bay and even above Verplanck (sector 6), some 35 mi north of The Battery (Fig. 1) in November, 1974.

The observations that the Temperature-Salinity (T/S) profile of station 8 (Piermont) in April is represented by a single point is indicative of total mixing of the water column at that time. Further, the slopes of the T/S profiles of stations 1 to 7 in April and October, and stations 1 to 5 in July and November approach the slope of the sigma-t lines for density (Fig. 3), indicating at least partial mixing of the water column at these stations during these months. The same reasoning and conclusions can be drawn for station 8 in October and stations 6, 7, and 8 during November, 1974.

It will be also observed from figure 4, that the slope of the T/S profile for station 15 during the months of January, October, and July is markedly different from the slopes of stations 9, 12, and 16 during the same months. This can be explained by the fact that during these months station 15 was sampled during an ebbing tide and at this time measurements were for water originating from Raritan Bay, draining from the Raritan River, the Arthur Kill, and Newark Bay, and clearly not water from the Hudson Estuary system. Although not shown in the data, the same observation was made for the waters of stations 11 and 13, which during the ebbing tide are derived from Long Island Sound and Newark Bay (via the Kill Van Kull) respectively, and are clearly not part of the linear tract of the Hudson Estuary system. However, on the flooding tide, as seen in figure 4, for station 15 during April and November sampling, and observed at stations 11 and 13 during the same periods, the T/S profiles "line-up" with the linear T/S representation for the Hudson Estuary. The observations have led to the design of future sampling tracks and time relative to ebb and flow of the tides which will help define the origins and mixing patterns of water types within the Hudson Estuary system and the apex of the New York Bight.

Finally, it will be observed (Fig. 4), from a temperature point of view, that the saltwater end of the survey track had a 13°C range during the sampling period while the freshwater end had a thermal range of 25°C. At any given month during the sampling period the T/S profile of the entire estuary can be approximated by a straight line connecting the saltwater input with the freshwater source, north of station 6, and representing a gradual mixing of these water types. This straight-line property of the Hudson Estuary water mass implies that during the sampling period surface heating, cooling, evaporation, and precipitation did not have significant effects on the properties of the Hudson Estuary water mass.

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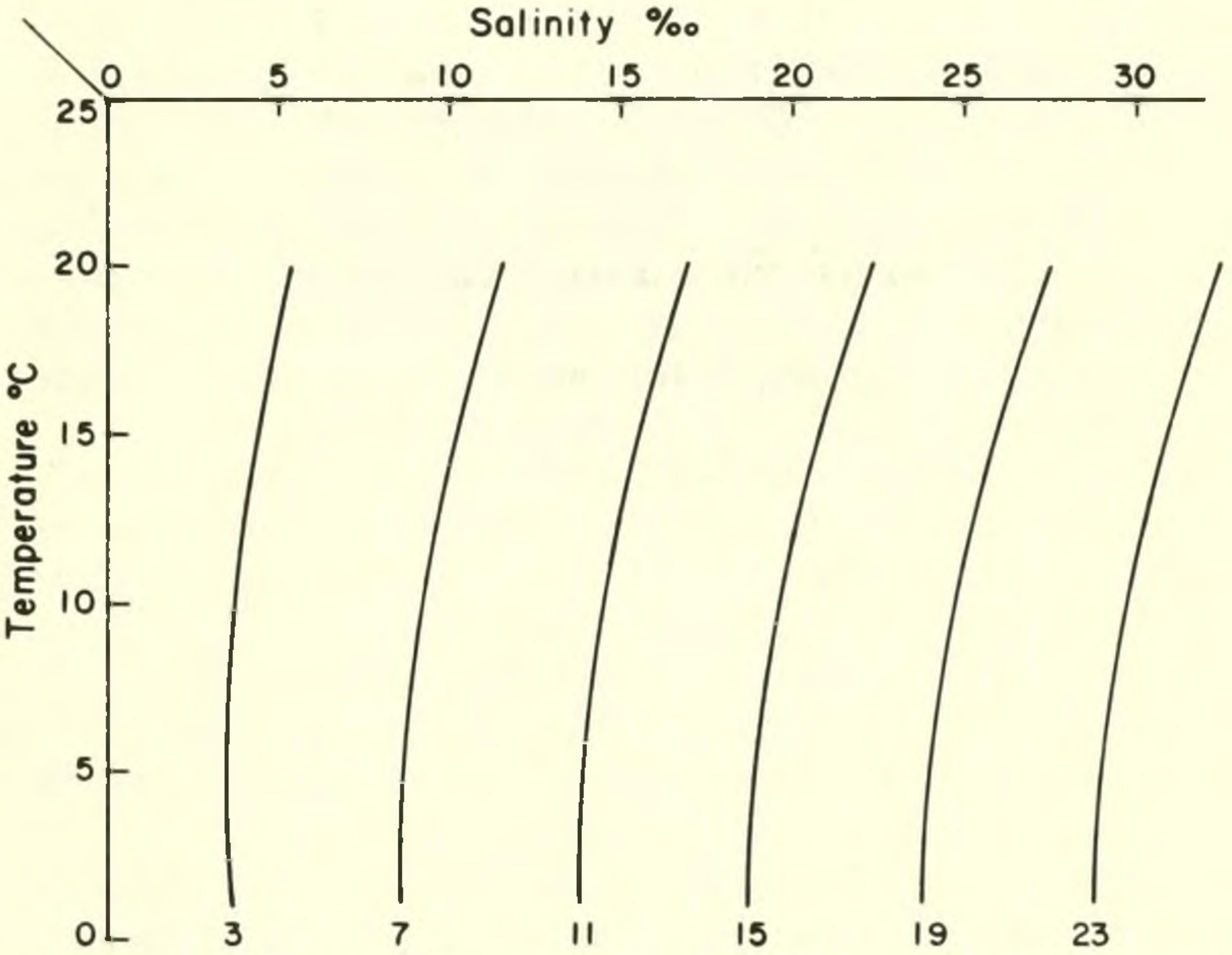

Fig. 3. σ_T after R.A. Cox, et al. 1970 Deep Sea Research. 17:679-689

$$\sigma_T = \left[\frac{\text{Density of Sea Water at } t°C}{\text{Density of Sea Water at } 4°C} - 1\right] 1000$$

$$\sigma = \sum_i \sum_j a_{i,j} T^i S^j \quad 0 \le i \text{ and } j \le 3 =$$

$$a_{0,0}+a_{1,0}T+a_{0,1}S+a_{2,0}T^2+a_{1,1}ST+a_{0,2}S^2+a_{3,0}T^3+a_{2,1}ST^2+a_{1,2}S^2T+a_{0,3}S^3$$

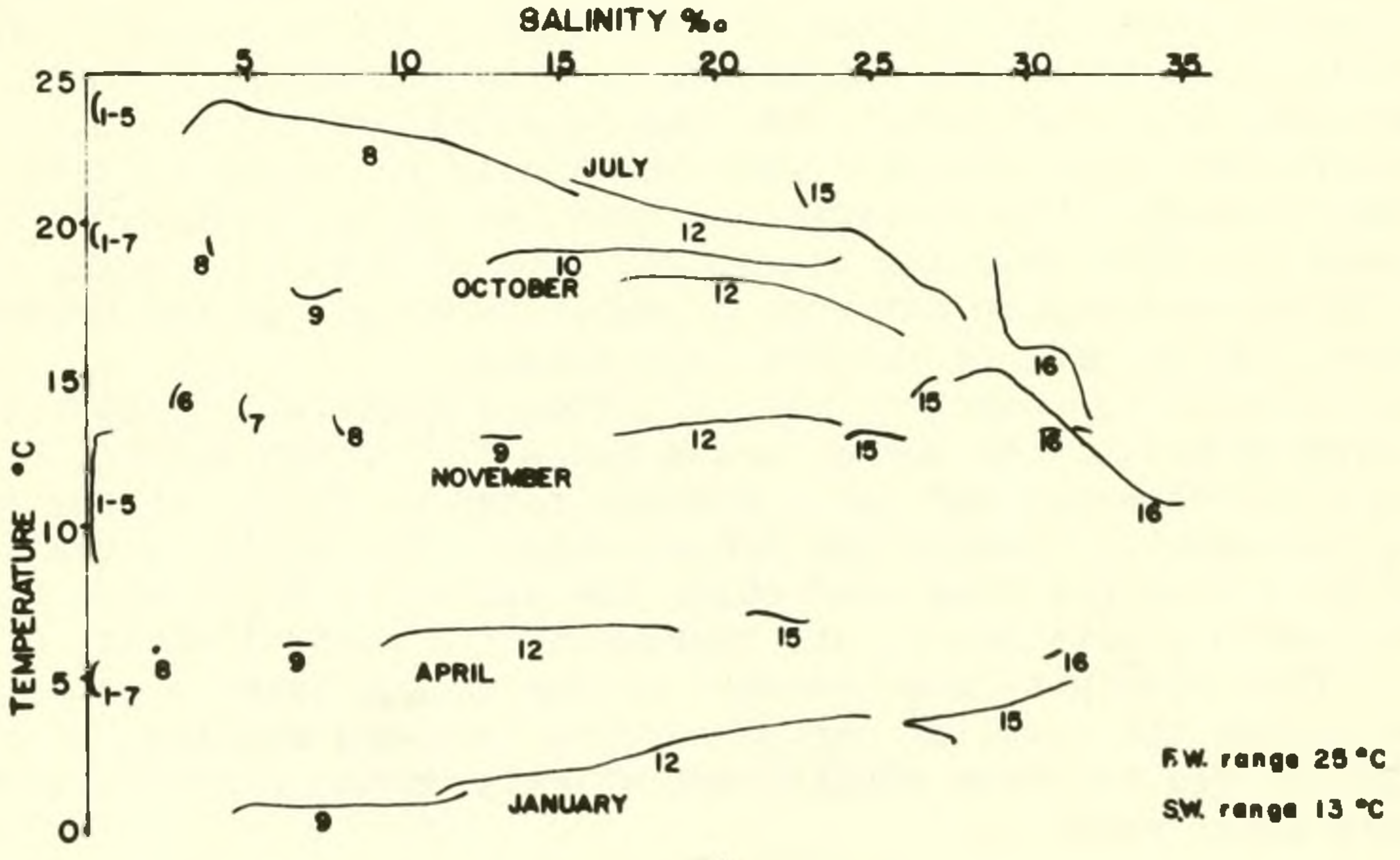

Fig. 4. HUDSON ESTUARY T/S PROFILE

Jan. - Nov. 1974

OBSERVATIONS OF THE TRACE METAL LOAD OF THE HUDSON ESTUARY, 1974

J.W. RACHLIN, and K. RIVLIN, Department of Biology, Lehman College of C.U.N.Y., Bronx, New York 10468.

Introduction

As part of the City Institute of Marine and Atmospheric Sciences' Hudson Estuary study, soluble trace metal determinations were made from surface and bottom waters at each of the stations listed in Figure 1 and Table 1. The object was to record the changes, on a month to month basis, of the soluble trace metal load of the system and to observe the movements of these metals with respect to the tidal movement of the estuary.

Methods of Study

Surface and bottom water was collected in 8-liter Niskin (PVC) bottles at each station and a 500 ml sample from each bottle was filtered through a 0.45 micron Millipore filter to remove particulates. The filtered water was stored in acid washed polypropylene bottles and acidified to pH 2 using trace metal free concentrated HCl. These acidified filtered water samples were sent to the laboratory where they were analyzed for their lead, copper, and cadmium content. The analysis procedure involved triplicate runs using the technique of standard additions and was accomplished by the polarographic method, using an Environmental Sciences Associates, Inc. Anodic Stripping Voltammeter. This technique employes a mercury-graphite electrode for uniform geometry and requires that the samples be buffered to pH 5 using a sodium acetate buffer. The theory of this procedure and its application to aquatic environments has been documented by Allen, Matson, and Mancy (1970) and has the advantage of high sensitivity in the nanogram range.

Results and Discussion

Figure 5 presents the soluble trace metal data (Cu, Pb, Cd) for the months of March, May, August, and November, 1974. These months are representative of the spring, summer, and winter flow regimes of the estuary. It will be observed from the figure that the trace metal range over the whole water column and extent of the sampling track was as follows:

Month	Cadmium	Lead	Copper
March	0 - 3.45 ppb	0.2 - 6.9 ppb	2.0 - 26.0 ppb
May	1.0 - 7.6 ppb	1.0 - 4.0 ppb	3.2 - 13.2 ppb
August	0 - 0.8 ppb	1.3 - 3.4 ppb	5.3 - 15.0 ppb
November	0.3 - 1.1 ppb	1.1 - 4.0 ppb	5.1 - 13.4 ppb

Further, one can see that the metals occur in the water column such that the concentration sequence is Cu > Pb > Cd.

This work was jointly supported by Lehman College and the City Institute of Marine and Atmospheric Sciences.

Contribution No. 48 of the City Institute of Marine and Atmospheric Sciences.

By understanding the state of the tide at the time of sampling at each station one can speculate that metal inputs into the system occur at station 13, the Kill Van Kull (which is observed as metal peaks at station 12); between stations 9A and 9B (Harlem River); between stations 7A and 7B (Croton River); between stations 3A and 3B (Poughkeepsie); and station 1 (Saugerties). This is particularly evident by the peak Cu values at stations 12, 9, 7, 3, and 1 for all months, and peak Pb values at station 12 in March and November, as well as, the peak Cu, Pb, and Cd values at station 3 during May. There also appears to have been a Pb input into the system at Saugerties during the months of March and May.

References

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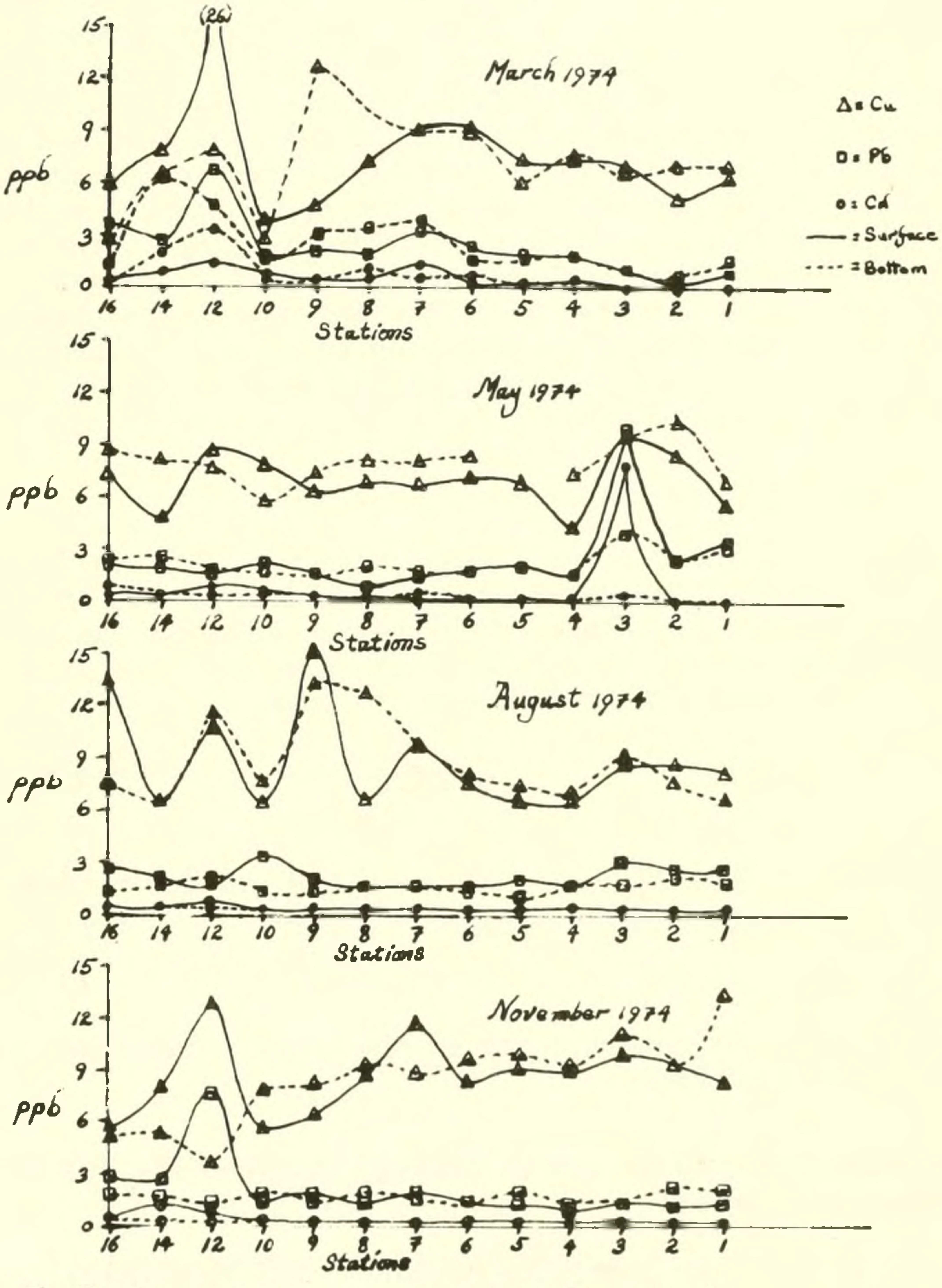

Fig. 5. Hudson Estuary Survey. Soluble Trace Metals

THE DISSOLVED OXYGEN IN THE HUDSON RIVER ESTUARY

B.P. MOFFITT, Department of Biology, Lehman College of C.U.N.Y.,
Bronx, New York 10468.

The dissolved oxygen present in a body of water is one indicator of the potential of that water to serve as a healthy biological environment. Many factors, such as the oxidative breakdown of organic materials present, respiratory activities of heterotrophic organisms and surface films of oil or detergents will reduce the total dissolved oxygen, which has entered the water by diffusion, or been produced there by photosynthetic organisms. The distribution of the dissolved oxygen throughout the water column can also serve as an indicator of hydrodynamic processes taking place.

Dissolved oxygen (D.O.) levels in the Hudson River estuary were determined at approximately monthly intervals at seventeen stations located between Saugerties to the north, and the apex of the New York Bight, 3.5 mi northeast of Sandy Hook to the south. The D.O. was measured by using an oxygen electrode and/or the Azide modification of the Winkler method (A.P.H.A., 1971).

Data obtained in March, July, October, November, and December of 1974 are plotted in figures 6 and 7. Data for the stations at the East River (11), Kill Van Kull (13), and lower New York Bay (15) are given separately in table 2, as these three samples come from different water masses (Chute, Rachlin, and Postmentier, 1975; Postmentier, Rachlin, and Chute, 1975), and so cannot be included in figures 6 and 7.

Inspection of figures 6 and 7 reveals some general trends which are similar from month to month. In the freshwater reaches of the river, the D.O. was higher than in the brackish or salt water regions. The D.O. declined slightly from Saugerties to Piermont, where the water was usually slightly brackish. Between Spuyten Duyvil and The Narrows the D.O. decreased, reaching a minimum in the New York Harbor, before rising again at the New York Bight station (16) in the Ambrose Channel. These trends are seen in both the surface (1.5 m below the surface) and bottom (2 m above the bottom) D.O.

In absolute terms, in the freshwater regions of the river both the surface and bottom D.O. were lowest in July when water temperature was 20°C and highest in December when it was 1°C. The difference in temperature accounted only in part for the differences in D.O. however, for in July the water was from 70 to 80% saturated with oxygen, and in December it was 85 to 93% saturated. It seems reasonable to assume that the increased water temperature in July led to increased metabolic activities of the poikilothermic heterotrophs in the river, and that this resulted in increased oxygen utilization and therefore depletion of D.O.

With the exception of July, the surface and bottom D.O. are very similar in the freshwater regions. This would suggest good vertical mixing of the waters, which may vary in depth from about 10 m at Piermont to 50 m at the World's End, but being mostly about 15 m deep. Temperature data would support this point of view.

South of Piermont the surface and bottom D.O. decreased in value, with the minimum values each month obtained in the New York Harbor between The Battery and The Narrows. Dissolved oxygen levels in the Ambrose Channel were always higher than those in the Harbor.

In New York Harbor, the lowest D.O. levels were observed in October and November, when about 4 ppm oxygen were present. At this time the water was

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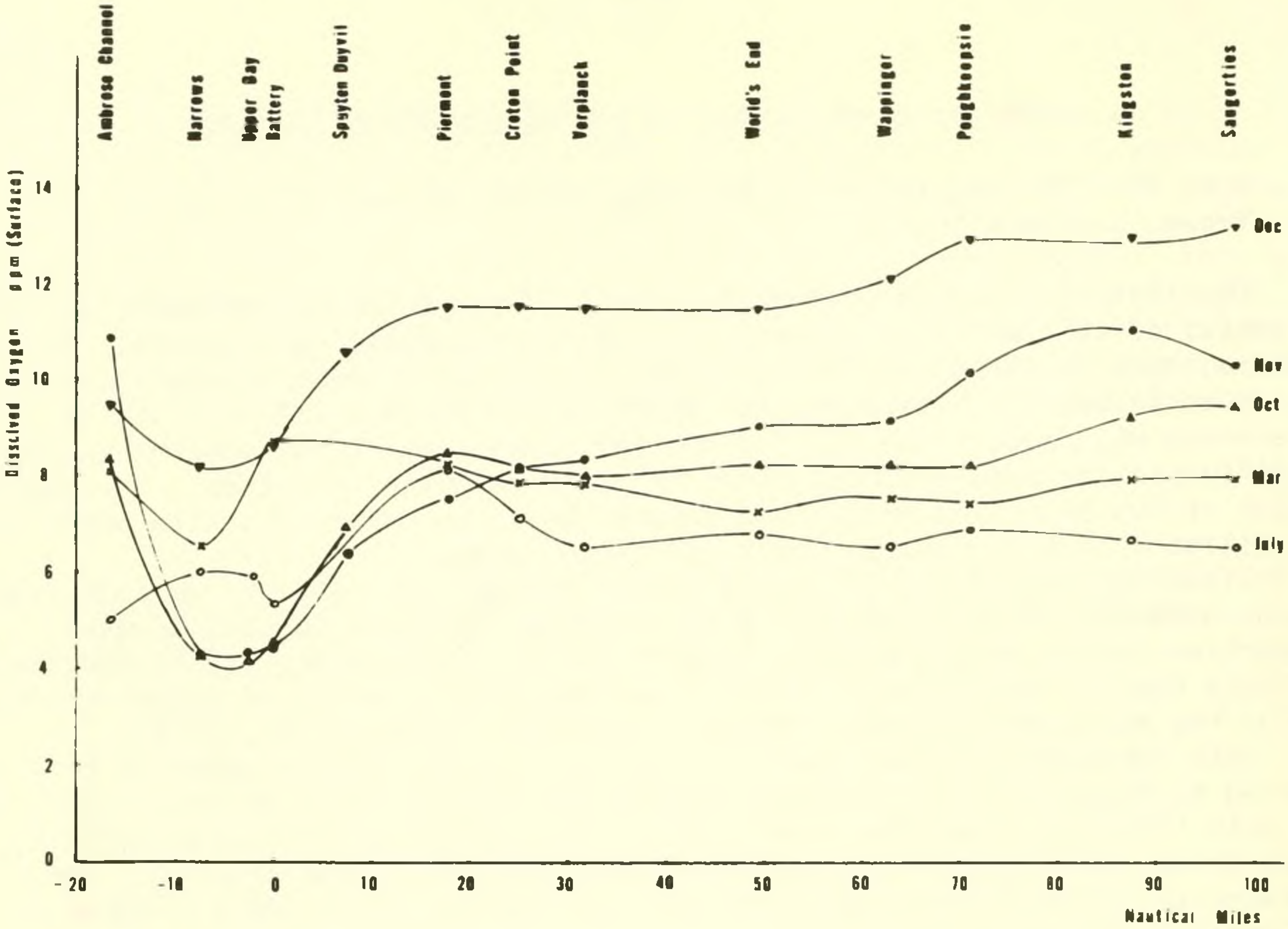

FIGURE 6. SURFACE DISSOLVED OXYGEN IN THE HUDSON ESTUARY BETWEEN SAUGERTIES AND THE AMBROSE CHANNEL FOR FIVE MONTHS IN 1974.

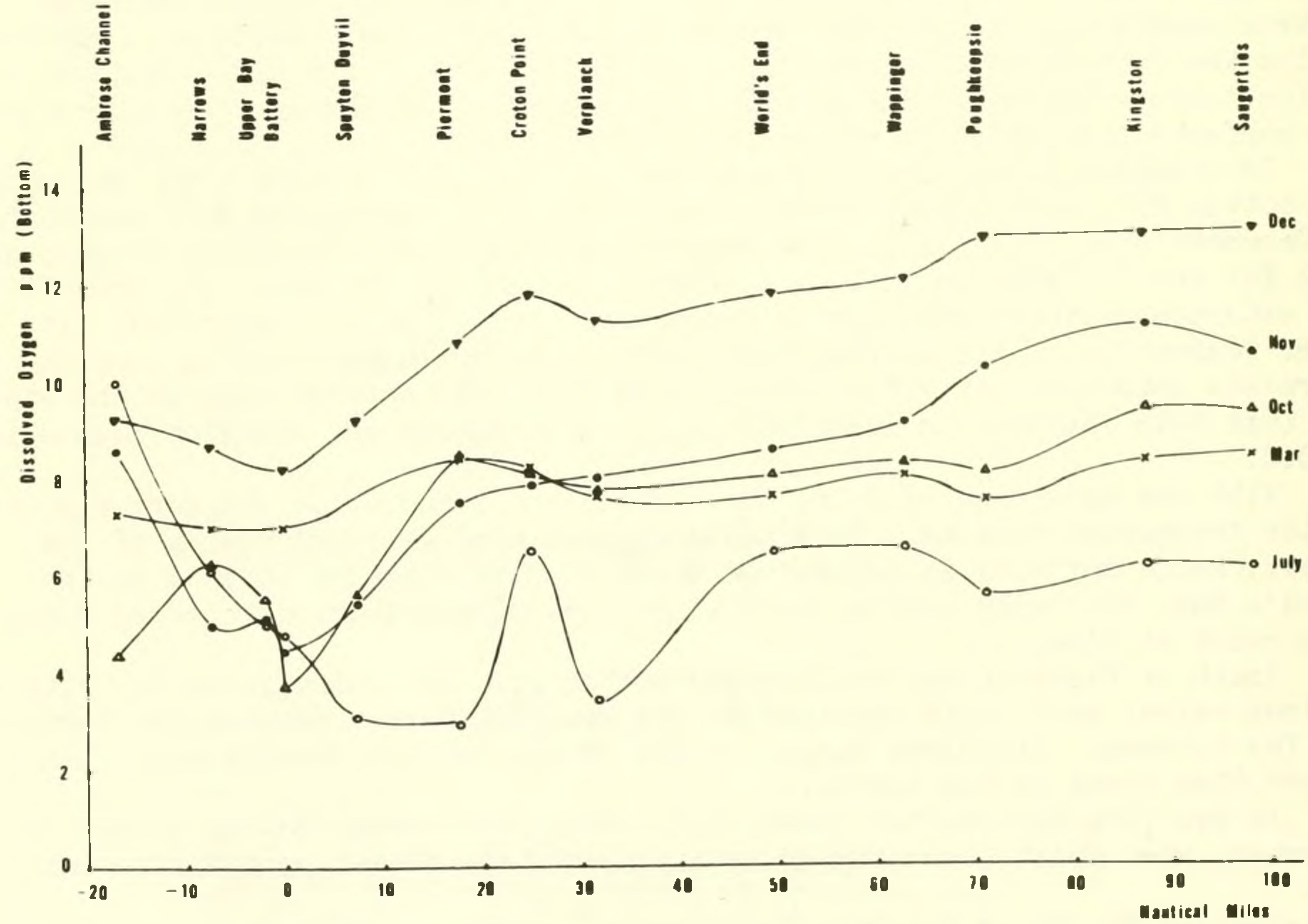

FIGURE 7. BOTTOM DISSOLVED OXYGEN IN THE HUDSON ESTUARY BETWEEN SAUGERTIES AND THE AMBROSE CHANNEL FOR FIVE MONTHS IN 1974.

about 40 to 55% saturated with oxygen. In March, July, and December, when the D.O. was higher, the percentage saturation was 55 to 70%. The depletion of oxygen found in the Harbor, as compared with the freshwater parts of the river, can not be attributed solely to the increased salinity of the harbor waters. In the absence of any studies to ascertain the processes involved (such studies are planned) it is only possible to speculate. The heavy use of the harbor by shipping of various types, and the increased sewage load carried by the water would seem to be the most obvious sources responsible for the additional oxygen depletion.

During the period under study, the D.O. of the freshwater section of the river did not fall below 6 ppm, except for two bottom samples in July. On this basis it can be concluded that there is sufficient dissolved oxygen in the Hudson River north of Piermont to provide a healthy biological environment, from the oxygen point of view, for the aquatic fauna. Even the low D.O. values found in the New York Harbor are sufficient for survival of aquatic organisms (Kinne and Kinne, 1962; Rao, 1968; Tarzwell, 1958).

It should be pointed out that, as far as the Hudson River is concerned, 1974 was not a typical year, it being much wetter than usual, thus increasing the freshwater flow rate of the river. So, while during 1974 the river had sufficient D.O. to support the life of aquatic fauna, it is quite possible that in years of lower rainfall, such favorable conditions, from the oxygen point of view might not exist.

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		Dissolved Oxygen (ppm)			
		Mar.	July	Oct.	Nov.
East River	S	12.8	5.10	3.26	3.85
	B	6.2	4.56	3.08	3.63
Kill Van Kull	S	-	5.90	3.95	4.34
	B	-	4.36	3.40	4.15
Lower Bay	S	8.1	9.13	7.12	6.43
	B	7.6	8.17	7.16	6.53

Table 2. Surface and bottom dissolved oxygen at the East River, Kill Van Kull, and Lower Bay stations for four months in 1974.

PRELIMINARY ANALYSIS OF PHYSICAL PROPERTIES OF HUDSON RIVER SEDIMENTS

N.K. COCH, D. MALOUTA, and N. EICHENBERGER, Department of Earth and Environmental Sciences, Queens College of C.U.N.Y., Flushing, New York 11367.

Introduction

Previous studies of the surficial sediments of the Hudson Estuary (McCrone, 1967) have provided data based on single samples taken at different locations over a period of time. This sediment study differs from the previous investigation in being part of an interdisciplinary City Institute of Marine and Atmospheric Sciences' research project aimed at both determining and interrelating the monthly parameters at the same series of stations within the Hudson Estuary.

Sample stations (Fig. 1) extend from Saugerties, New York southward to the inner New York Bight south of The Narrows. Stations were chosen to evaluate the contribution of rivers, and sources of effluents, and also to provide uniform geographic coverage over the area of study. The Hudson Estuary survey team attempted to obtain Phleger cores from each station on each monthly cruise but were often not possible due to weather, tidal current velocities, and bottom conditions.

Laboratory Analysis

The Phleger cores taken on each cruise were frozen on board ship and transferred to the laboratory in insulated containers. In the laboratory, the top 10 cm of each core was extruded, split longitudinally, described, and sampled over the entire 10 cm length. A 10 to 15 gm subsample was taken for moisture content determination and a 20 gm subsample was removed for size analysis. The 20 gm subsample was wet sieved into sand, and silt plus clay fractions. The sand fraction size distribution was determined in a set of $\frac{1}{2}$ Ø interval sonic sieves. The silt and clay fractions were dispersed in sodium hexametaphosphate with an ultrasonic probe and size analyses were made using the pipette method. Cumulative frequency curves were constructed from which the size frequency parameters of Folk and Ward (1957) were calculated.

Analysis of Data

In discussing the data presented in this paper (Table 3) it should be emphasized that only preliminary interpretations can be made on this limited data and that these interpretations will probably be considerably modified as our work progresses. Since the data presented is representative of the whole 10 cm interval, it does not accurately record the present sedimentation in the estuary but an average over the time span represented by the 10 cm of sediment accumulation.

The data for each station exhibit different degrees of variability. Many factors probably contribute to this spread of values such as small numbers of samples, vessel re-positioning errors on subsequent cruises, differential thawing of frozen cores enroute to the laboratory, and operator variation in the laboratory. In addition, natural causes in the estuary may account for

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some of this variability. Examples of these kinds of changes include artificial input resulting from channel dredging and changes in estuary currents causing erosion and deposition. Present and future research cruises are attempting to define the variability and its causes by making a series of coring traverses across the axis of the estuary.

Areal Variation in Grain Size

Mean grain sizes do not seem to show steady decreases or increases up or down the estuary but seem to be related to input from local streams. Relatively coarse sediments (fine to very fine sands) are found at station 1 (Saugerties) adjacent to the mouth of Esopus Creek and at station 2 (Kingston) adjacent to the mouth of Rondout Creek. Sediments from Poughkeepsie (stations 3A and 3B) south to Verplanck (station 6) are generally characterized by finer grain sizes (fine to very fine silt and coarse clay) with the finest material occurring at station 5 within the Hudson Gorge (World's End). Constriction of the channel at this point might be expected to result in scour and coarser sediment but the opposite seems the case. Perhaps the high cohesiveness of this material and its low bed roughness inhibits erosion once the material has been deposited from suspension.

From Verplanck (station 6) southward to the Kill Van Kull (station 13) the sediments are primarily medium to fine silts. Within this length of the estuary several interesting changes are noted. Samples taken at station 7A, which is located north of Croton Point, have finer mean grain sizes (6.5 Ø) than those on the south side of Croton Point at station 7B (5.4 Ø). This may possibly be the result of sediment input from the Croton River between the two stations. A similar difference, though not as marked, is seen on either side of the confluence of the Hudson River and the Harlem River at Spuyten Duyvil. Samples from station 9A on the north side of the confluence have a mean grain size of 6.1 Ø, whereas those from station 9B on the south side have a mean grain size of 5.93 Ø.

A distinct change in grain size occurs in the area between stations 14A (north of The Narrows) and 14B (south of The Narrows) where the average grain size is in the fine sand range in sharp contrast to the area to the north within the upper New York Bay. This may represent the effects of tidal scour due to channel constriction or the input of sand into this area by the Long Island and New Jersey littoral drift systems. Another sharp change occurs at station 15 in the lower New York Bay where the sediment is in the very fine silt to coarse clay range. Such accumulation of fines would be expected in such a wide bay away from the influx of coarser sediment.

Areal Variation in Other Physical Parameters

Standard deviation (sorting) shows no particular patterns. All of the samples are fair to poorly sorted (1.20 to 3.95 Ø). Skewness values (0.01 to 0.65) are consistently positive suggesting an excess amount of fine sediment in the size distribution. The relatively low standard deviation of the skewness values (0.07 to 0.44) relative to the standard deviation of the other parameters suggests a strongly developed trend. Perhaps this results from either greater sedimentation than erosion or from erosion and redeposition of suspended material of finer size without the development of a coarse lag between the two events.

Moisture contents (24.6 to 64.6 weight percent) show the greatest spread of values at each station of all parameters measured. This variability may be the result of field and laboratory operations in which water was lost or moved within the core due to inadvertent defrosting of the cores in transport. A general trend of increasing water content with decreasing grain size can be seen in a plot of mean grain size versus water content.

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PRELIMINARY MINERALOGIC DATA OF HUDSON ESTUARY BOTTOM SEDIMENTS

J. BOWMAN, Department of Geology and Geography, Lehman College of C.U.N.Y., Bronx, New York 10468.

Clay Mineralogy

X-ray diffraction analysis of the clay fraction of Hudson Estuary bottom sediments is difficult. These sediments, for the most part, are not simple muds but organic-rich sludges. In order to obtain valid identification of clay mineral components, it is necessary to remove these organic constitutents without changing the original clay mineral structures. A number of standard techniques, alone and in combination, have been tried. As a result, preliminary data indicate that illite is the dominant clay mineral in samples obtained from Verplanck, New York and adjacent to 64th Street in New York City.

Heavy Mineralogy

Optical analysis of heavy mineral suites have been completed for two selected localities (Saugerties, station 1 and Spuyten Duyvil, station 9). In both cases data was obtained for the fine sand grade size (1/4 to 1/8 mm). Heavy mineral analysis indicate that garnet and hornblende are abundant at Saugerties, whereas at Spuyten Duyvil, there is less garnet and hornblende, and more pyroxene (notably hypersthene). The apparent variation in abundance of black opaques (mostly ilmenite) is not yet understood. Tourmaline distribution, especially the red-blue variety, may prove important relative to the definition of dispersal patterns. The study of zircons in the finer size grades may reveal significant varietal distributions.

Table 3. CORE TOP DESCRIPTIONS (upper 10 cm)

Sta. No.	Location	Wet Color Range*	Avg. Lab. Description
1	Saugerties	10Yr 3/1	Sandy silt to silty sand
2	Kingston	2.5Y 3/2-5Y 3/2 very dark grayish brown to dark olive brown	Sandy silt, thin laminae of organic material
3A	Poughkeepsie N.	5Y 3/2-5Y 4/2	Uniform silt and clay with some sand
3B	Poughkeepsie S.	2.5Y 4/2-5Y 3/1 dark grayish brown to very dark gray	Silt and clay, occasional layers of coarse material and shell fragments
4A	Wappinger Creek N.	5Y 3/2-5Y 2/2 dark olive gray to black	Uniform silt and clay, occasional small shell and wood fragments
4B	Wappinger Creek N.	5Y 3/2 dark olive gray	Uniform sandy silt and clay, occasional small pebble gravel
5	World's End	5Y 4/2-5Y 3/1 olive gray to very dark gray	Uniform silt and clay, occasional small pebble gravel
6	Verplanck	2.5 3/2-5Y 2/1 very dark grayish brown to black	Uniform silt and clay, some coarse and angular sand
7A	Croton Point N.	5Y 4/2-5Y 2/1 olive gray to black	Silt and clay, scattered angular shell fragments and shells
7B	Croton Point S.	5Y 3/1-5Y 3/2 olive gray to very dark gray	Sandy silty clay with shell fragments and pebble gravel
8	Piermont	5Y 3/1-5Y 2/1 very dark gray to black	Uniform silt and clay, scattered shell fragments, coarse sand and pebble gravel

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*Munsell Color Designations

Table 3 (con't.). CORE TOP DESCRIPTIONS (upper 10 cm)

Sta. No.	Location	Wet Color Range*	Avg. Lab. Description
9A	Spuyten Duyvil N.	5Y 2/2-5Y 2/1 black	Uniform dark silt and clay, coarse sand, pebble gravel and shell in patches at top of core
9B	Spuyten Duyvil S.	5Y 5/2-5Y 3/1 olive gray to very dark gray	Sandy silt, shell fragments, medium sand, and shells concentrated near top
10	The Battery	5Y 4/2-5Y 3/1 olive gray to very dark gray	Dark silt and clay, with shell fragments and shells
11	East River	5Y 3/1 very dark gray	Uniform sandy silty clay with shell fragments more abundant in upper portion
12A	Upper Bay E.	5Y 3/1-5Y 2/1 very dark gray to black	Sandy shelly silt to shelly sand
12B	Upper Bay W.	5Y 2.5/1-5Y 2/1 black	Oily and organic silt and clay, shell fragments
13	Kill Van Kull	5Y 2.5/1-5Y 2/1 black	Uniform silt and clay, oily and organic, shell fragments
14A	The Narrows N.	2.5Y 3/2-5.5Y N 3/0 very dark gray brown to dark gray	Sandy silt, worm tubes running vertically through core
14B	The Narrows S.	2.5Y N 2/0 black	Uniform silt and clay, oily sand and shell fragments near top
15	Lower Bay	5Y 2/1	Plastic silt and clay, oily and organic, trace of fine sand

*Munsell Color Designations

A-2

FORAMINIFERAL ASSEMBLAGES IN THE HUDSON ESTUARY

D. WEISS, Department of Earth and Planetary Sciences, The City College of New York of C.U.N.Y., New York, New York 10031; and J. KRASOVSKY, Department of Biology, The City College of New York of C.U.N.Y., New York; New York 10031.

Within the study area of the Hudson Estuary survey of the City Institute of Marine and Atmospheric Sciences, foraminifers have been found south of Verplanck, New York (Fig. 8). Samples for foraminiferal analysis have been collected at stations 6 to 10, 12, 14 to 16 (Fig. 1). Most stations were occupied monthly from December, 1973 to December, 1974 to determine if temporal changes occurred with respect to foraminiferal distributions. Samples were taken using a Phleger gravity corer from which the upper cm of sediment (approximately 25 cm^3) was removed for foraminiferal analysis. All sediment samples collected were treated with rose bengal stain dissolved in methanol. The stain solution served as a preservative and as a means to distinguish living (stained) from dead (unstained) foraminifers. Environmental data (*i.e.*, salinity, temperature, dissolved oxygen, turbidity) were recorded for each sampling station. In the laboratory, samples were washed onto sieves with mesh openings of 125 and 63 microns. Foraminifers were then separated from the bulk of the sediment trapped on the 125 micron screening by the carbon tetrachloride flotation method. A binocular microscope was used to identify the foraminifers present in each sample.

Foraminifers representing 15 genera and 20 species have been identified (Table 4). Total numbers of foraminifers per sample ranged from zero to over 2500. Specimen representing live foraminifers were not found in all samples or representative of every species identified.

Three distinct assemblages of foraminifers have been identified to date (Fig. 8, Table 4). The assemblages are as follows:

1. *Ammobaculites assemblage.* The assemblage is dominated by agglutinized (arenaceous) foraminifers. *Ammobaculites* and *Ammomarginulina* are the dominant forms present followed by lesser amounts of *Trochammina* and *Miliammina*. In addition, an occasional specimen of *Elphidium* and *Ammonia* have been found. This assemblage is found in an area from station 6 (Verplanck) on the north to station 9 (Spuyten Duyvil) on the south (Figs. 1, 8). The salinity for this section of the estuary during the period of study averaged about 6°/oo and ranged from 0.4 to 15°/oo. The northernmost limit of the *Ammobaculites* assemblage is indicative of the maximum penetration of foraminifers into the Hudson Estuary. In addition, this uppermost limit can serve as a marker for the boundary between oligohaline and mesohaline waters at a salinity of 5°/oo.
2. *Elphidium - Ammonia assemblage.* The *Elphidium* - *Ammonia* assemblage is characterized by species of *Elphidium*, especially *E. clavatum - incertum* complex, and lesser amounts of *A. beccarii*. In addition, agglutinized foraminifers such as *Ammobaculites* have also been found in this assemblage. The *Elphidium* - *Ammonia* assemblage has been identified at stations 9 (Sputen Duyvil), 10 (The Battery), 12 (Upper New York Bay), and 15 (Lower New York Bay) in waters with bottom salinities ranging from 11.2 to 26.1°/oo, and averaging 20°/oo (Figs. 1, 8). This assemblage occupies a transitional position between the lower salinity

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indicative *Ammobaculites* assemblage and the higher salinity, more open water, *Elphidium* - *Quinqueloculina* assemblage. It overlaps the former on the north and the latter on the south (Fig. 8).

3. *Elphidium - Quinqueloculina assemblage.* *Elphidium clavatum - incertum* complex and *Quinqueloculina seminula* are indicative of the third foraminiferal assemblage. Species assignable to the *E. clavatum - incertum* complex are found in great abundance. Specimen of *Buccella frigida*, *Ammonia beccarii*, *Discorbis squamata*, and *Cibicides lobatulus* were also found. Relatively small numbers of agglutinized foraminifers have also been found in this assemblage along with individual species characteristic of the waters of the inner New York Bight and western Long Island Sound. This assemblage is found at stations 14 (The Narrows) and 16 (New York Bight). Bottom water salinities during the study period in the area of occurrence of this assemblage averaged 29.0°/oo and ranged from 25.7 to 32.4°/oo.

The examination of foraminiferal samples on a monthly basis indicates that the distribution of the assemblages described above is apparently controlled by the salinity of the estuary. During the high salinity months of July to November, the assemblages display their most northerly distribution in the estuary. The boundaries between the assemblages, along with the maximum limit of foramifers, shifts as much as 20 mi to the south during December to June, the low salinity phase in the estuary.

Table 4. FORAMINIFERAL ASSEMBLAGES. Species listed in descending abundance.

AMMOBACULITES ASSEMBLAGE

Ammobaculites sp.
Ammomarginulina sp.
Trochammina sp.
Miliammina fusca
Elphidium clavatum - incertum complex
Ammonia beccarii

ELPHIDIUM - AMMONIA ASSEMBLAGE

Elphidium clavatum - incertum complex
Ammonia beccarii
E. subarcticum
Ammobaculites sp.
Ammomarginulina sp.
Buccella frigida
Quinqueloculina seminula

ELPHIDIUM - QUINQUELOCULINA ASSEMBLAGE

Elphidium clavatum - incertum complex
Ammonia beccarii
Quinqueloculina seminula
E. subarcticum
Buccella frigida
Discorbis squamata
Nonionella atlantica
Pseudopolymorphina novangliae
Q. seminula var. jugosa
Q. subrotundra
Cibicides lobatulus
Triloculina trihedra
Nonionella auricola
Discorbis columbiensis
Trochammina sp.
Ammobaculites sp.

DIATOM DISTRIBUTION IN THE HUDSON ESTUARY

K. GEITZENAUER, Department of Geology and Geography, Lehman College of C.U.N.Y., Bronx, New York 10468.

Diatoms are important members of most aquatic communities and often the major primary producers. Weaver (1970), in a year long study of phytoplankton in the Hudson River at Indian Point, found species of the diatom genus Melosira to be the dominant phytoplankter, with the diatom Asterionella also occurring in high numbers. Whereas Weaver used plankton nets with a mesh size of 76 microns, this study has invovled the analysis of diatom assemblages in bottom sediments. Thus, live cells and empty frustules are being examined. In addition, diatoms as small as 5 microns are being studied.

The Hudson River and Estuary system has an abundant and diverse diatom flora. In a count of 350 individuals it is not uncommon to have as many as 55 to 60 species, although most of them occur in low numbers and only a few reach frequencies as high as 10%. In sediment samples Stephanodiscus astrea (sensu lato) is the dominant form from Poughkeepsie, New York (station 3) to Upper New York Bay (station 12). Weaver (1970) did not find the planktonic Stephanodiscus to be an abundant genus. It is generally much smaller than 76 microns and thus was not trapped in her plankton tows. Melosira sulcata is dominant in the Upper New York Bay (station 12), and Anorthoneis hyalina is dominant at the New York Bight station (16A).

On the basis of selected diatom distributions (Fig. 9), the study area can be divided into four zones as follows:

Zone 1: marine - high salinity brackish; inner New York Bight to The Battery (samples 16A to 10).
Zone 2: brackish; Spuyten Duyvil to Tarrytown (samples 9A to T10C).
Zone 3: brackish - very low salinity; Tarrytown to West Point (samples T12C to 5).
Zone 4: freshwater; Newburgh to Saugerties (samples 4B to 1).

These divisions are based primarily on the distribution of marine and brackish water species as the freshwater species tend to have their distribution extended by downstream transport of frustules. This is especially evident in the distribution of the diatom species Stephanodiscus astrea (Fig. 9).

References

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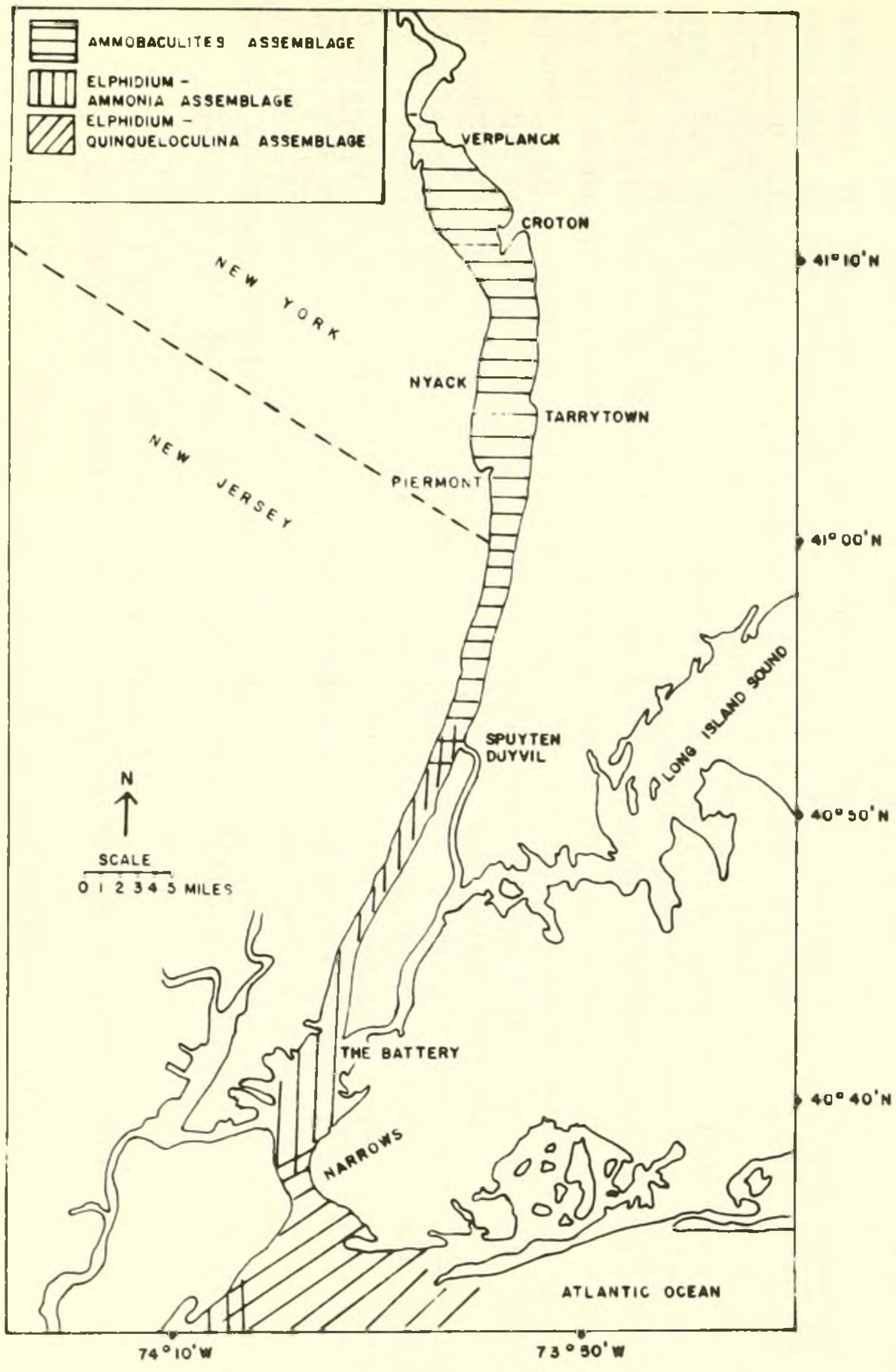

FIGURE 8. DISTRIBUTION OF FORAMINIFERAL ASSEMBLAGES IN THE HUDSON ESTUARY.

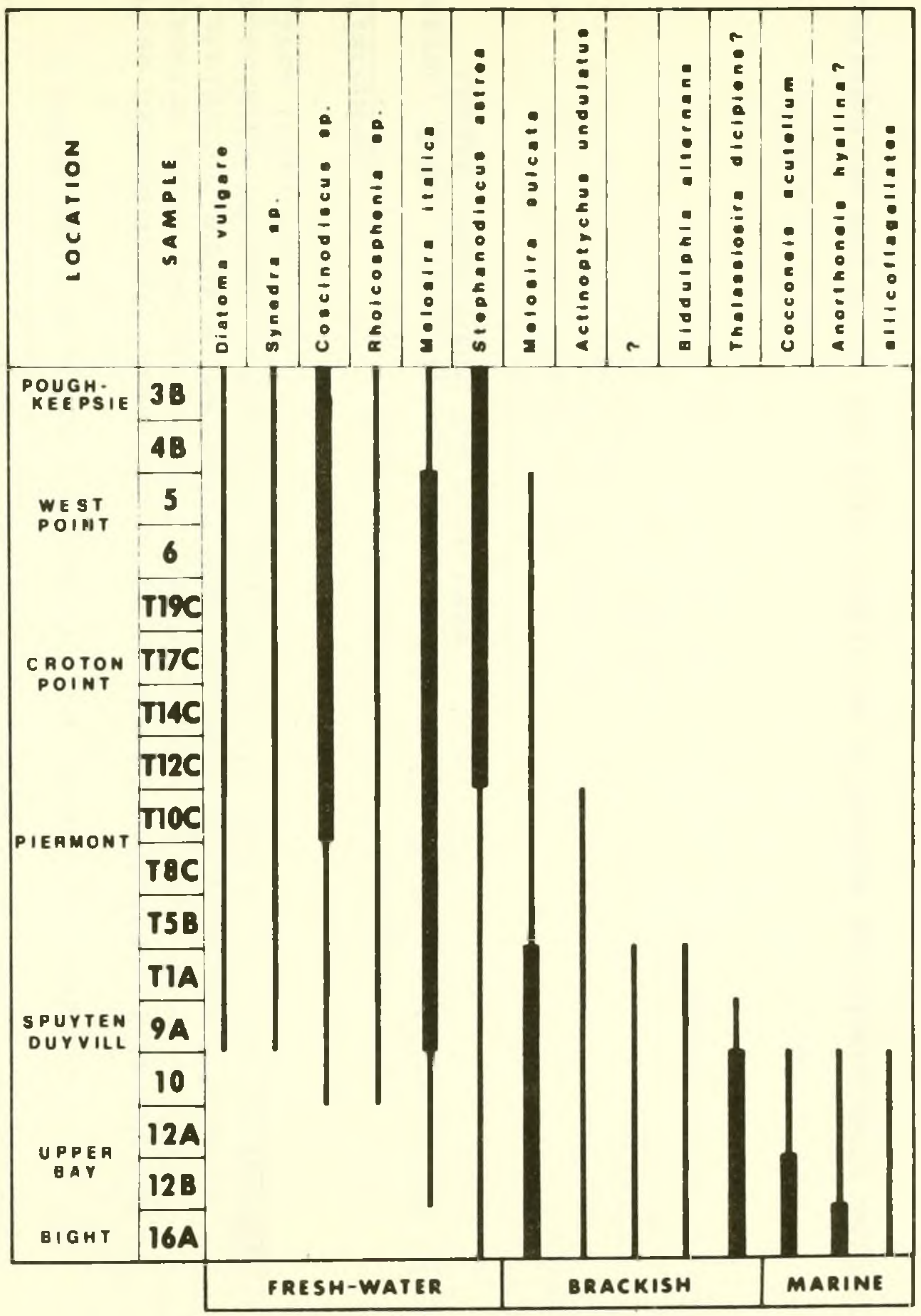

FIGURE 9. DISTRIBUTION OF IMPORTANT DIATOM SPECIES. The width of each line representing specie's range indicates the area in which that species occurs most abundantly.

A-2

DISTRIBUTION OF SHELLED MACROINVERTEBRATE BENTHOS IN THE HUDSON ESTUARY

F.C. SHAW, Department of Geology and Geography, Lehman College
of C.U.N.Y., Bronx, New York 10468.

Shelled benthos (primarily molluscs, bryozoans, and barnacles) have been sieved from one liter bottom grab samples. Samples have been taken on a random monthly basis for one year at the 16 stations of the City Institute of Marine and Atmospheric Sciences' Hudson Estuary survey, and are located in or near the main ship channel from the inner New York Bight (station 16) to Saugerties, New York (station 1). The number of live individuals, disarticulated valves, fragments, and preliminary size measurements have been recorded. Three assemblages, characterized by nominate bivalve genera and consisting largely of bivalves are proposed:

1. Elliptio assemblage: an essentially freshwater fauna present from Peekskill to Saugerties.
2. Mytilopsis assemblage: occupying the area between Yonkers and northern Haverstraw Bay, showing low species diversity in bottom salinities which may vary as much as 15°/oo in the southern Tappan Zee. Salinities over this entire reach range from 1 to 15°/oo.
3. Mulina - Mya assemblage: essentially marine in generic composition and diversity, present as far north as Riverdale in salinities which may drop as low as 10°/oo.

A typical monthly sample of these assemblages is shown in figure 10 and compared to other proposed estuary classifications in figure 11.

Bottom salinity and temperature appear to be the controlling factors for these assemblages. Dissolved oxygen is judged adequate for molluscs at all stations over the sampling area. Bottom sediments in the study are have not been fully analyzed. There does appear to be little difference in the genera at stations 10, 12, and 13 in spite of major differences in sediment.

A finer grid lateral to the main channel is being sampled at present to fully clarify the local factors controlling the distribution of shelled macroinvertebrate benthos.

Several questions may now be raised on the basis of this new information. First, do local distruptions in this assemblage pattern, such as the very scanty faunas in the south Yonkers - Riverdale area and the demise of the shell fish industry in the Tappan Zee, represent human interference or natural changes in the Estuary? Secondly, can the distribution and individual growth characteristics of bivalves be used as part of a natural monitoring system in the Estuary?

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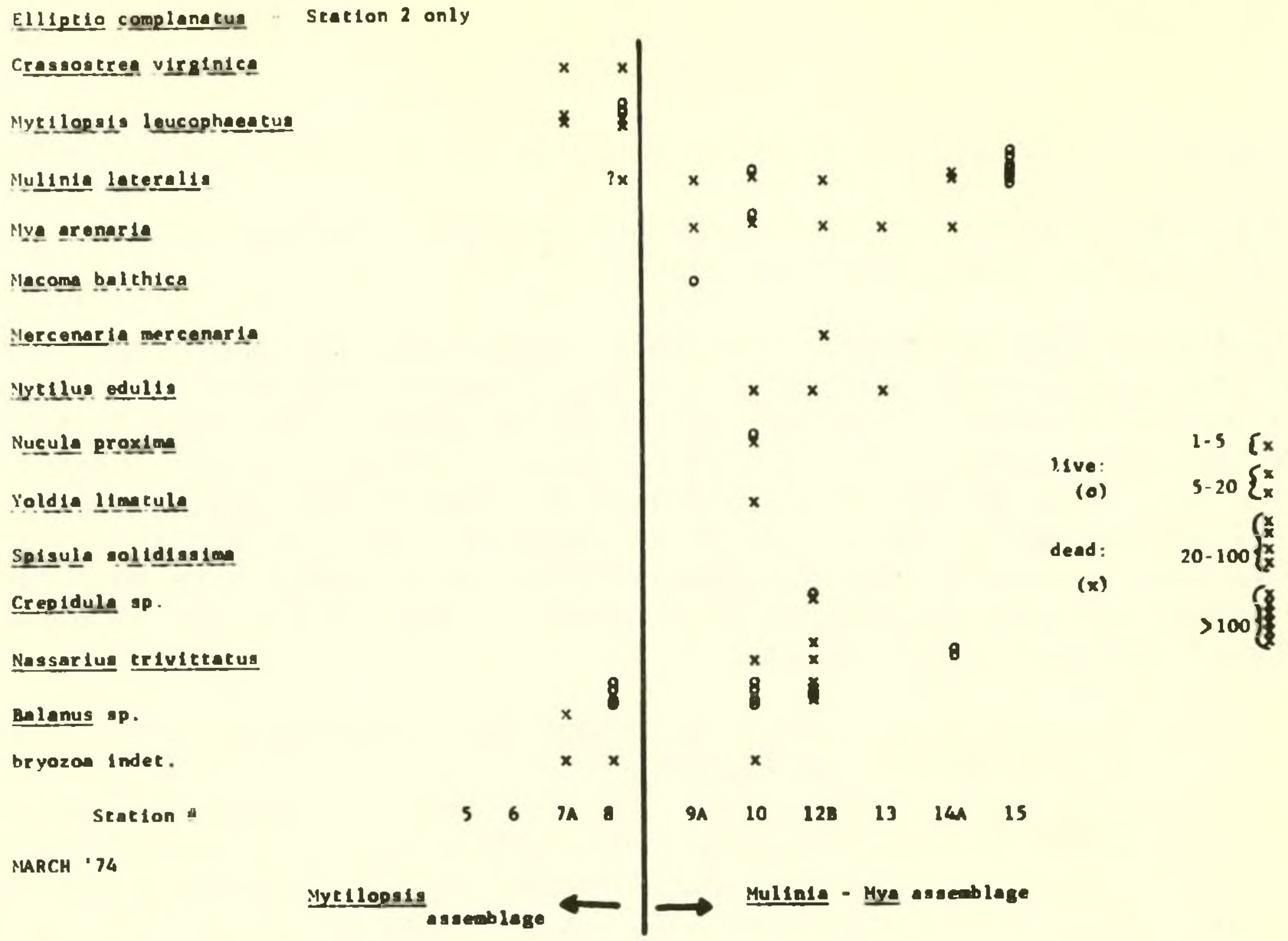

FIGURE 10. SELECTED TALLY OF HUDSON RIVER BENTHIC SPECIES. Numbers refer to survey stations. 5 is to the north.

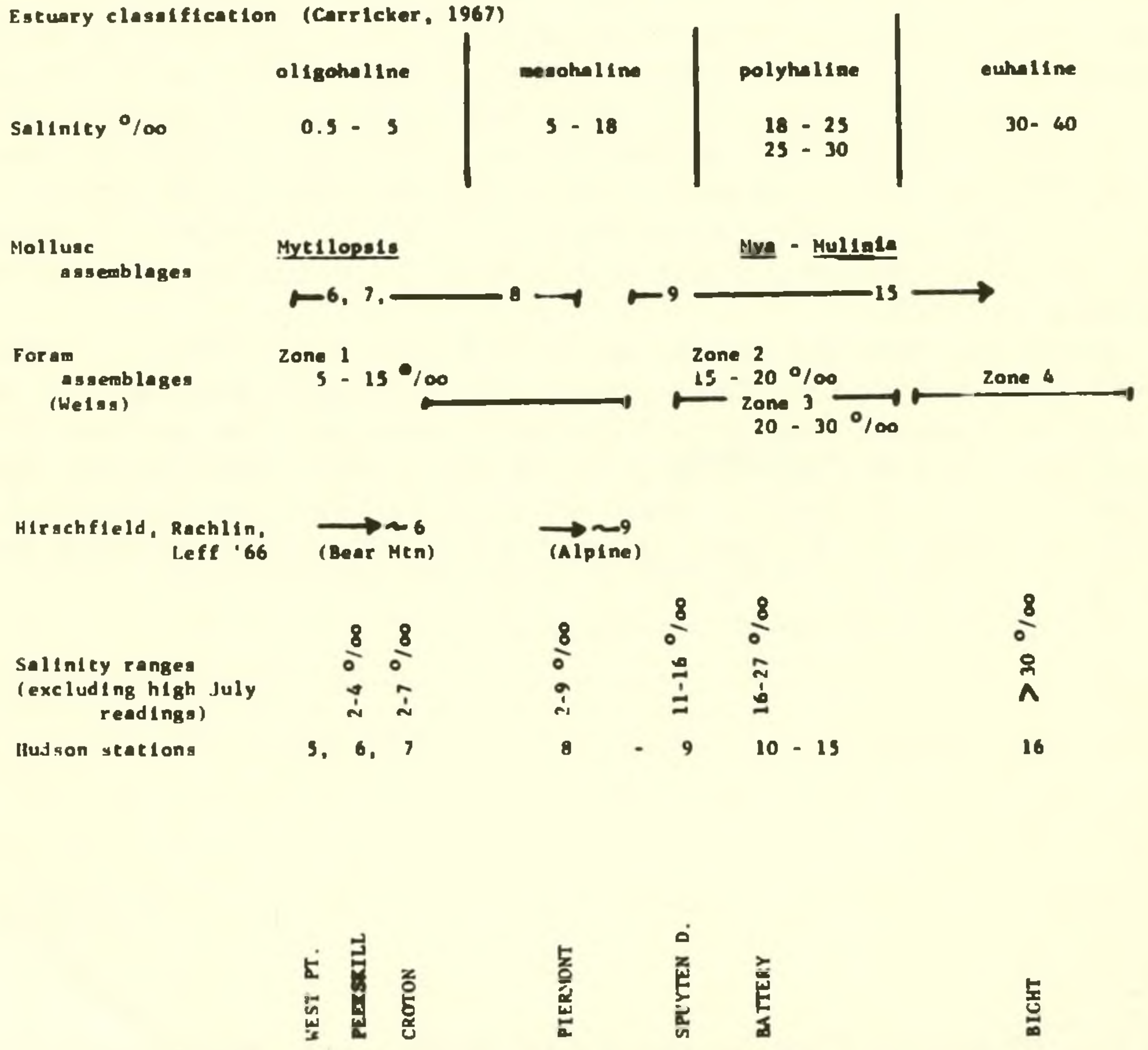

FIGURE 11. COMPARISON OF MULLUSCAN ASSEMBLAGE DISTRIBUTIONS TO FORAMINIFERAL DISTRIBUTIONS OF WEISS AND STANDARD ESTUARY CLASSIFICATION OF CARRICKER.