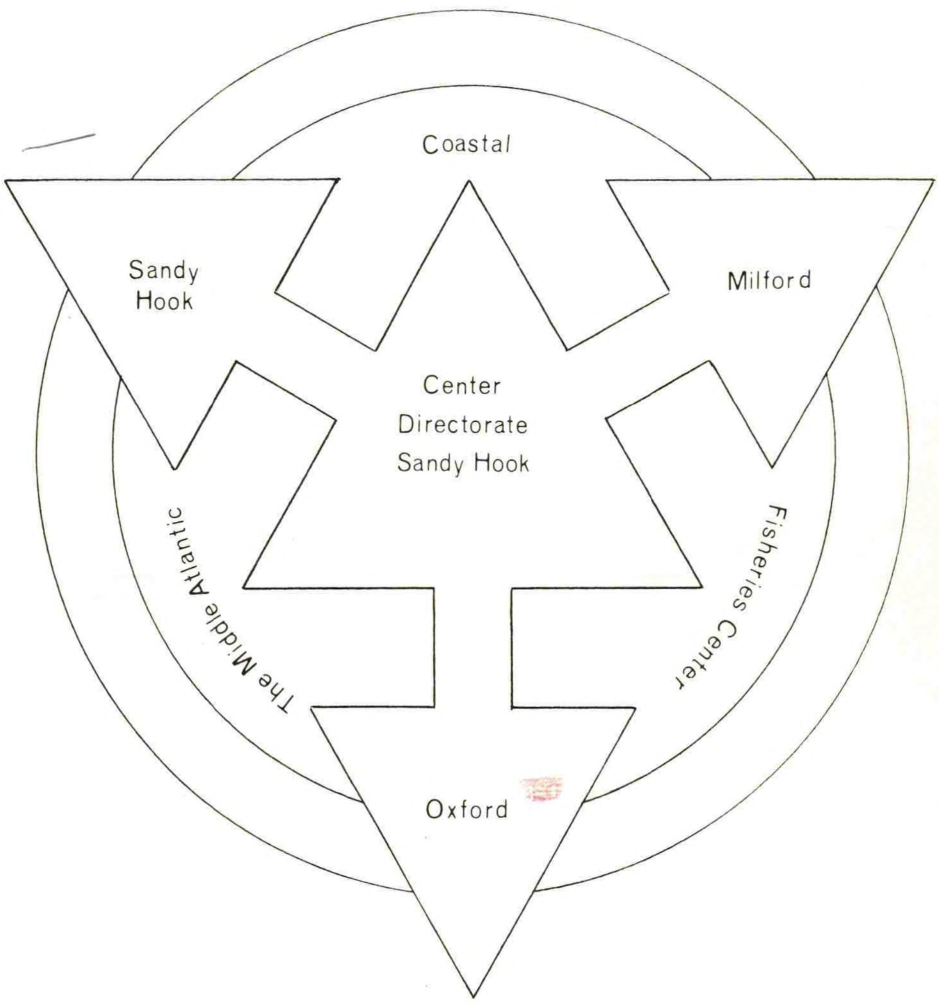
The Effects of Waste Disposal in the New York Bight

Summary Final Report

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region

MIDDLE ATLANTIC COASTAL FISHERIES CENTER



Informal Report no. 2

THE EFFECTS OF WASTE DISPOSAL IN THE NEW YORK BIGHT

SUMMARY FINAL REPORT

Submitted to: The Coastal Engineering Research Center
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THE EFFECTS OF WASTE DISPOSAL IN THE NEW YORK BIGHT

INTRODUCTION: Ocean disposal of sewage sludge and dredging spoils has been an accepted mode of waste disposal in the United States for over a century. When the present study was commissioned only limited information was available as to the consequences of disposal of wastes in the open ocean and in particular in the New York Bight. Buelow (1968) in a report concerned with ocean disposal of waste material stated that the extent and effects of the sludge blanket resulting from the disposal of approximately 12,600 yds^3/day of sludge were unknown. He did recognize, however, that considerable sludge covered the bottom of the New York Bight disposal area. Buelow also referred to the previous studies concerned with hydrographic measurements in the New York Bight (Redfield and Walford, 1951; Miller, 1952; Howe, 1962; and Bumpus, 1965) as well as the study by Redfield and Walford (1951) concerned with the effects of ocean disposal of acid industrial wastes.

Burd (1968) has thoroughly reviewed the general problems associated with sludge handling and disposal. A report by the Tyneside Joint Sewerage Board (1969) considered the disposal of sludge from a specific treatment plant in the United Kingdom. Their report included sections devoted to barging and piping sludge to sea as well as the use of seabed drifters to determine possible movements of suspended solids by water movement. Grigg and Kiwala (1970) recently presented information concerned with the effects on marine life of sewage waste discharged from pipes terminating a short distance offshore.

Saila _et al_. (1968) investigated the effects of dredging spoils resulting from the Providence River and Harbor Improvement Project which were discharged at a designated site in Long Island Sound. An interim report prepared by the Chesapeake Biological Laboratory (1967) considered the gross physical and biological effects of overboard spoils disposal in the Upper Chesapeake Bay.

Very recently, Horne _et al_. (1971) have reviewed the problems associated with the disposal of sewage sludge and dredging spoils in the waters of the New York Bight. Brown and Shenton (1971) have reviewed and evaluated the general problems associated with waste disposal at sea. Based on findings of the BSWM study and Council on Environmental Quality's report they concluded that, "... it is no exaggeration to state that the environmental effects of past and present dumping operations are, with the exception of those dumped in the New York Bight (sewage sludge, waste acid, dredging spoils) and off Cape May, Delaware (waste acid, sewage sludge) not even qualitatively known, much less measured accurately."

Recently, MacKay and Topping (1970) and Shelton (1970) have reported on the effects of sewage sludge dumping in the Firth of Clyde and Thames Estuary, respectively. In their preliminary report, MacKay and Topping indicate that the disposal of 1,000,000 tons of sludge per year in the Firth of Clyde has resulted in "little obvious harm to the environment."

They did, however, report a build-up of organic material and heavy metal residues on the sea bed as well as some indication of qualitative changes in the fauna. It should be considered, however, that the wastes reported on by these authors are disposed of in 300 feet of water and amount to only one-fifth the tonnage of sludge and less than one-tenth of the combined amount of sludge and spoils currently being disposed of in the New York Bight.

The paper by Shelton (1970) is of interest even though it is based on data taken during only one month (April 1970). The author investigated a disposal area at the mouth of the Thames where five million tons of sludge are dumped annually in water 60-70 feet in depth. This is an amount equal to that disposed of in the New York Bight.

In March 1968, a working committee comprised of invited scientists, staff members of the U. S. Army Corps of Engineers, Coastal Engineering Research Center (CERC), and representatives of the Smithsonian Institution met to delineate the problem areas and to design studies which might provide results of value in determining the effects of current waste disposal practices in the New York Bight.

The committee suggested that a two-year program of study could be developed which would answer at least some of the questions posed (Gross and Wallen, 1968, p.4). They also recognized that many questions could not be answered except through a much longer period of study, perhaps up to five years. An interim report was to be made available on or before 1 January 1970 with a final report due in September 1970.

The subjects thought to require consideration in a study of the New York Bight included: 1) biological characteristics; 2) physical and chemical properties of bottom sediments and water-borne particles; 3) physical and chemical properties of the marine environment and 4) sources, dispersal, and movement of waste materials (Gross and Wallen, 1968, p. 6-17). Each of the subjects to be investigated was further broken down into subheadings including appropriate literature surveys, field activities and laboratory studies. Those items of research which were considered important to the basic two-year study were indicated in the committee's recommendations by an asterisk.

In response to the recommendations made by the Smithsonian Institution, the then Sandy Hook Marine Laboratory prepared and submitted to the Smithsonian Institution a proposal, "The Effects of Waste Disposal in the Coastal Waters of New York Harbor." Based on this proposal the Laboratory was awarded a contract by the Corps of Engineers (CERC) to conduct a study within the guidelines set by the Smithsonian Institution's recommendations and our proposal. As was suggested in page 6, paragraph 3 of the recommendations (Gross and Wallen, 1968), we initially limited our biological studies to the benthos (i.e., bottom-dwelling organisms) of the New York Bight, concentrating our efforts in and around the sewage sludge and acid waste disposal areas. Our preliminary work soon indicated, however, that to understand the effects of various wastes on marine biological resources, we would have to study the pelagic and planktonic life in the area as well as the benthos.

We later initiated work in the dredging spoils dumping area to learn how spoil dumping might affect living marine resources. It is important to note that these wastes are being dumped much closer to the shore of Sandy Hook than are the sewage sludges and "acid" wastes.

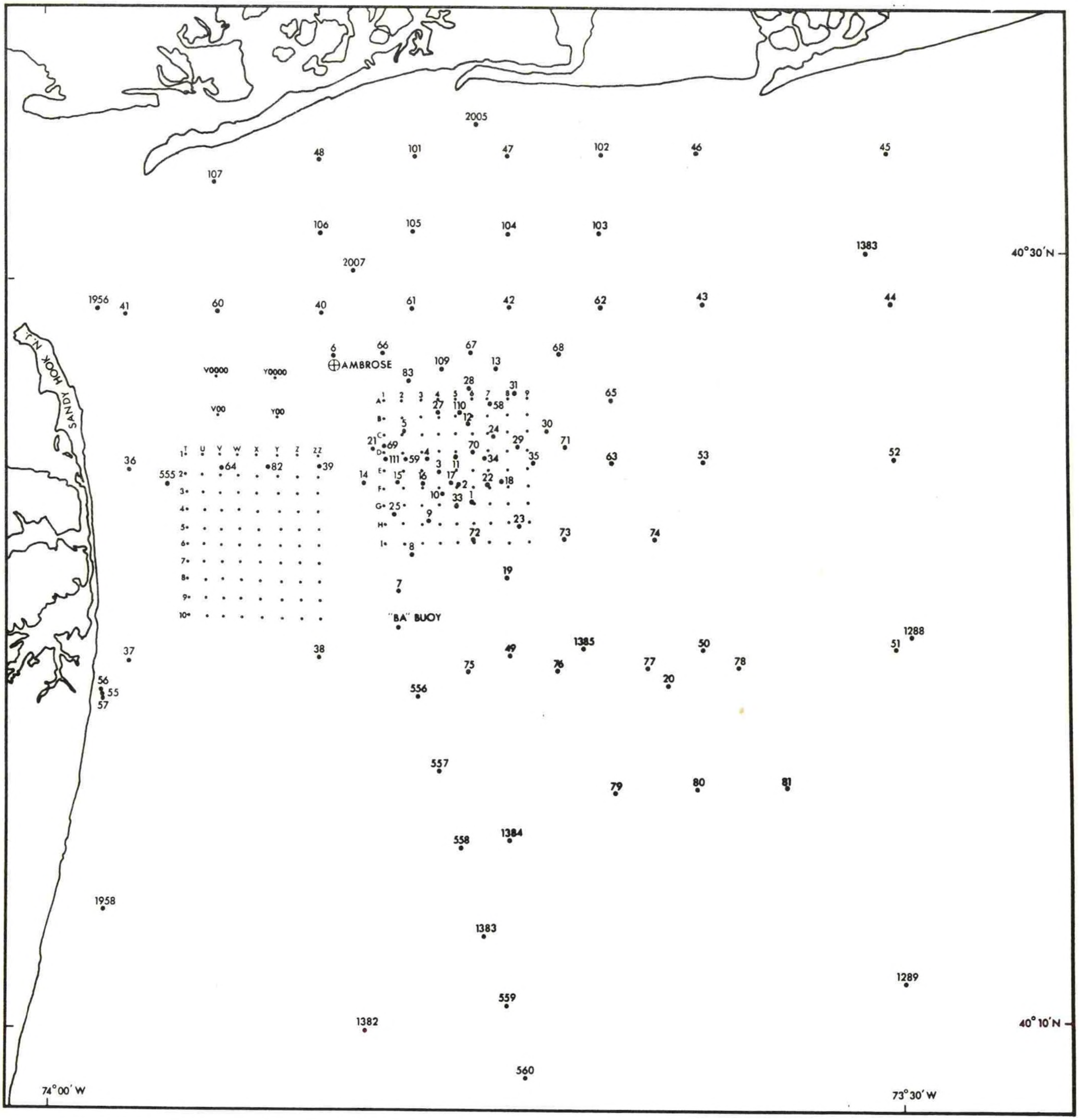
Finally, we expanded an ongoing program of hydrographic research designed to give us information on the movements of water masses in the New York Bight. The collection of field data was undertaken by personnel of the Sandy Hook Laboratory. This data was subsequently analyzed and a report prepared for the Sandy Hook Laboratory by the National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratories, Physical Oceanography Laboratory, Miami, Florida, 33130. This report comprised Section 6 of the complete report.

During the course of this investigation 150 cruises were made to the three principal disposal areas in the New York Bight with a variety of measurements made and samples taken at 307 stations in the Bight and Hudson Canyon (Fig. 1).

Figure 1. Stations at which collections were made during the study of the effects of solid waste disposal in the New York Bight. Stations along transects T through ZZ generally delineate the dredging spoils disposal area; stations along transects A through I delineate the sewage sludge disposal area. Samples collected within these areas were characterized by elevated heavy metal concentrations, increased coliform bacteria populations and reduced benthic populations (see Figs. 2-7). Benthic samples were collected at all stations. Zooplankton, finfish and water samples for chemical analyses were collected at the selected stations indicated in the text.

Stations 600-610 are located along the middle of the Hudson Canyon to the 200 meter bathymetric line.

Figure 1



We want to acknowledge the support and interest provided by the U. S. Army Corps of Engineers, Coastal Engineering Research Center, as well as the assistance rendered by the Northeast Technical Services Unit, Food and Drug Administration, Davisville, Rhode Island; Mr. D. Carmody, Westchester College and Columbia University; Dr. J. Graikoski, Chief, Microbiology and Analytical Chemistry Section, National Marine Fisheries Service, Milford, Connecticut; and the Shellfish Research Laboratories, Rutgers University, Monmouth Beach, New Jersey.

RESULTS AND CONCLUSIONS: The complete final data report includes nine sections: 1. Introduction, 2. Benthic Studies, 3. Zooplankton Studies, 4. Finfish Studies, 5. Chemical Studies, 6. Surface and Bottom Water Movement, 7. Conclusions, 8. Literature Cited, and 9. Bibliography. The following paragraphs briefly summarize for the informed reader the observations and data contained in the 762 pages of textual and graphic materials which comprise the nine sections of the final report.

Many marine scientists now recognize that in coastal marine and estuarine environments benthic organisms may be the first forms to be demonstrably affected by pollutants. The Smithsonian committee (Gross and Wallen, 1968; pp. 3 and 6) stated that "... a study of the benthic organisms was thought to be the most fruitful avenue of approach" to evaluate the environmental impact of present waste disposal practices in the New York Bight. It was also the consensus of the committee that there was a dearth of knowledge about marine life in the New York Bight and that this real lack of knowledge was a major limitation on attempts to evaluate the effects of ocean disposal practices (Gross and Wallen, 1968; p. 6). Indeed there have been no major research programs in the New York Bight which considered the benthic populations.

We therefore initiated in August 1968 a series of benthic grab, core, dredge, and trawl collections in the New York Bight. We were particularly interested in the distribution and abundance of certain commercially valuable forms such as the surf clam, the American lobster and the common cancroid or rock crab. The distribution of the ocean quahog was also of importance since it is a potential product for human consumption and the harvesting of it, within six miles of a sewage sludge dump site, is prohibited by the U. S. Public Health Service. Recognizing, however, that these various commercial forms might not be affected by dumping to the same extent as many other taxa, we recorded and considered all benthic species taken by our various sampling gear.

It is well known that the distribution of bottom-dwelling species is related to many factors including sediment type; presence of toxins such as heavy metals; water quality and nutrients; and pathogenic microorganisms. These factors were measured at stations throughout the Bight during the course of the investigation and considered in our conclusions.

Although the Smithsonian committee did not indicate that a study of coliform or pathogenic microorganisms was required in the preliminary, or two-year study, we believed it essential that the sewage sludge and dredging spoils disposal areas be surveyed for coliform bacteria, known indicators of pollution. Although it is often supposed that sea water attenuates or is lethal to coliform bacteria, Greenberg (1956) reported survival of enteric microorganisms in marine muds. Buelow (1968) indicated that pathogenic microorganisms do survive sewage treatment and could possibly infect clams which burrow in a predominantly sewage sludge substrate. In conjunction with the distribution of organic materials, human artifacts and heavy metals, the distribution of coliform bacteria might also aid in circumscribing the impact areas for sewage sludges and dredging spoils. Finally, the survival of coliform bacteria may be indicative of contamination by microorganisms which could be pathogenic to marine life.

Early in the study we collected moribund crabs from the sewage sludge beds. Recognizing that sludge and dredging spoils could possibly be toxic or adversely affect marine organisms, we performed a series of experiments in which sediments collected from the sewage sludge and dredging spoils beds were used as substrata in controlled laboratory experiments. The objective was to approximate in the laboratory the same conditions which were observed in the field and to attempt to detect histological changes which might occur in living organisms exposed to these conditions.

During our investigation of benthic macrofauna, animals larger than 1 mm, we found 81 species which occurred with sufficient frequency in the New York Bight to plot their distribution in relation to bottom sediments and the designated waste disposal sites. The distribution patterns for all these species were given as a series of figures in the final complete data report.

We noted that the areas covered with sewage sludge and dredging spoils were devoid of normal, or are characterized by greatly reduced, benthic macrofaunal populations. These areas or beds generally include those portions of the sewage sludge and dredging spoils disposal areas in which dried sediments consisted of more than 10 percent organic matter. Sediment samples collected from the sewage sludge disposal area were black and had odors characteristic of sewage sludges, hydrogen sulfide, and occasionally, petrochemicals. These samples invariably contain large amounts of debris and artifacts identifiable as having human origin. Sediments contaminated with dredging spoils had similar characteristics although artifacts are not as numerous in samples collected in the dredging spoils disposal area.

During the past decade aquatic biologists have come to recognize the important role which environmental stress plays in species diversity, or the number of species present in a particular community or ecosystem.

Aquatic biologists have for some time recognized that pollution and physical alteration of aquatic environments are among the principal stress factors affecting species diversity in fresh water, estuarine and coastal ecosystems. Wilhm and Dorris (1966, 1968), Wilhm (1967) and Gibson (1966) discuss the use of species diversity as an indicator of stress due to natural physical factors and pollutants. Wilhm and Troy maintain that the use of chemical analyses and indices alone is generally misleading; chemical analyses indicate water quality only at the time of sampling and may give no indication of past contamination or conditions prevailing over extended periods of time. On the other hand, by collecting, observing and analyzing the species diversity of benthic populations, it is often possible to ascertain the severity and, with proper baseline data, the temporal span of contamination. Butcher (1955) indicated that when a multiplicity of pollutants are present the degree of pollution could best be determined by the prevailing biological conditions rather than by chemical standards.

In determining the effects of ocean disposal of sewage sludge, dredging spoils and industrial wastes, we have determined that all of these categories of waste can constitute a stress which might be inimical to marine benthic communities. Several factors, including toxins and reduced dissolved oxygen, might be involved in the diminution of species diversity in the designated waste disposal areas. The totality of the combined effects or synergism, was, however, unknown and for this reason we used changes in the diversity of benthic communities as one of our indices to the effects of waste disposal. It was our final conclusion, however, that the presence of toxic materials and the effects of highly reducing sediments have greatly diminished the diversity of benthic communities in the sewage sludge and dredging spoils disposal areas.

The meiofauna, especially the foraminifera, comprise the most ubiquitous animals in the New York Bight sediments. Even the most polluted stations have occasional representatives of these very small organisms. A study of meiofauna was therefore undertaken as part of an investigation of the effects of waste disposal in the New York Bight. We defined meiofauna as those animals which could pass through a 1.00 mm standard geological screen but are retained on a 63 micron screen. The infaunal meiofauna are of interest for three reasons: 1) they are near the base of the benthic food chain, 2) their small size and general immobility would prevent them from extensive horizontal movement, and they should be indicative of the sediment conditions in which they were found and 3) excluding certain protozoan groups, they are generally the most common ecological group of animals in marine sediments. Communities of meiofauna found at the dumping sites were compared with those of surrounding areas to ascertain the effects of pollution.

We identified 36 common meiofaunal taxa collected from the New York Bight. Twenty-three of these were living foraminiferans. Forms such as cumaceans and phoronids which rarely occurred were not included.

As reported for the macrofauna, meiofaunal species diversity was reduced at stations in the dredging spoils and sewage sludge disposal areas. For instance, at Station 59 we found only nine species of meiofauna present whereas at Station 39, located in the same depth of water between the sewage sludge and dredging spoils disposal area, we found twice this number of species. One sample from Station 82, located at the center of the dredging spoils area, contained nine species and a second contained only two species, the lowest diversity observed in our sampling of meiofaunal communities.

Our observations indicated that the species diversity of meiofaunal communities in similar sediments was affected by waste disposal. Moreover, the numbers of individuals representative of specific taxa were reduced. For instance, we found the nematodes, which are extremely resistant to the effect of reducing conditions, to be diminished in numbers in the waste disposal areas, Stations 82, 59 and 11, relative to the standing crops noted to exist in the uncontaminated portions of the Hudson Canyon, Stations 39, 42 and 2007.

In regard to the larger crustacea, we observed that very few juvenile rock crabs were present in the waste disposal areas compared to noncontaminated areas. We also noted that when adult crabs were found on the sludge and spoils beds they were frequently diseased or moribund. Since the sludge and spoils beds are in the path of crabs and lobsters which seasonally migrate from inshore to offshore water, we concluded that the wastes resulted in mortality of migrating crustaceans.

In laboratory experiments, lobsters and crabs placed in aquaria containing sewage sludge developed ulcers and shell erosions (Pearce, 1969). Also, the gills became fouled with granular material, and a dark brown coating covered the exoskeleton of the filaments. The chitinous covering of the filaments often became eroded and the living tissue developed necrosis. Eroded filaments appeared brittle and on occasion were observed to be broken. We did not observe these effects in crustaceans kept in control aquaria.

The fouling and necrosis of gill tissue which would decrease the respiratory surface area, together with the low oxygen concentrations in the bottom water of the waste disposal areas, may account for the unusual mortality of crabs and lobsters we observed in and around the sewage sludge and dredging spoils disposal areas.

The data collected during our field and laboratory investigations of the New York Bight indicate that both the benthic macrofaunal and meiofaunal organisms have been affected by the disposal of dredging spoils and sewage sludge in the Bight. Sludges and spoils were found to have affected an area of over 20 square miles. The presence of these wastes and their toxic components have significantly reduced the standing crops, or biomass, and diversity of marine benthic communities.

The effects of ocean dumping on benthic environments extend beyond the immediate impact areas which form the sludge and spoils beds. Sediments collected at stations in the Hudson Canyon between the two principal solid waste disposal areas have greatly elevated heavy metal values (Figs. 2-6). These stations, however, do not have completely impoverished benthic communities as have been observed at stations inside the sludge and spoils beds.

We have also noted that heavy metals have been carried to the north of the disposal areas as well as to the south, principally along the southward extension of the Hudson Canyon (Figs. 2-6). Elevated values of heavy metals were measured in Canyon sediments 25 nautical miles south of the station designated for sewage sludge disposal.

The distribution of coliform bacteria in sediments follows the same patterns of distribution as the heavy metals (Fig. 7). Dense populations of bacteria were observed at stations inside the sludge and spoils beds with decreasing populations to the north and south of the disposal area. Sediments collected at stations between the dumping areas and the mouth of Raritan Bay had reduced coliform populations indicating that the source of the bacteria was ocean dumping of solid wastes, not the outflow of contaminated Hudson River or estuarine waters. This conclusion was verified by studies of the distribution of coliform bacteria in surface and bottom waters derived from the Hudson River outflow (Verber, personal communication).

Distributions of bacteria and heavy metals showed little seasonal variation. Mahoney (1972) has established a relationship between the occurrence of coliform bacteria in the waters which surround Sandy Hook

Figures 2-6. Distribution of the heavy metals copper, chromium, lead, nickel and zinc associated with sediments in the New York Bight and Hudson Canyon; based on samples collected in November 1971.

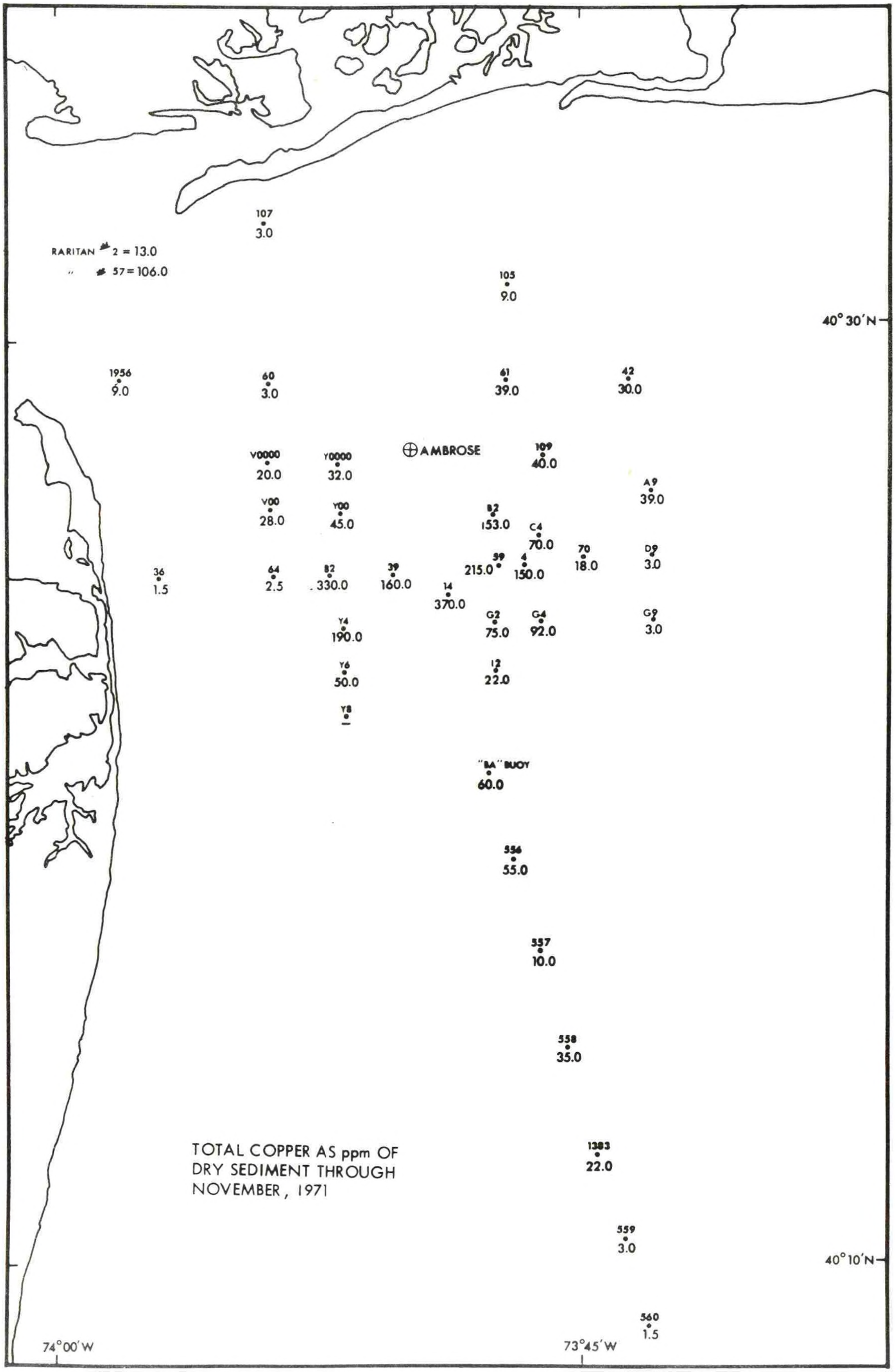
Significantly elevated values were found in sediments at stations as far south of the disposal areas as Station 1383.

Similar values have been measured in sediments collected at the same stations on numerous other sampling dates. Tables providing this data are included in the final complete data report and are available upon written request to Sandy Hook Laboratory.

Heavy metal values for sediments collected at two stations in Raritan Bay are given at the upper left corners of Figs. 2-6. These values are representative of sediments which are located in close proximity to channels maintained by periodic dredging. Spoils from this dredging are disposed of in the dredging spoils disposal area.

Sediments collected from the dredging spoils and sewage sludge disposal areas generally have heavy metal values far in excess of those reported to have deleterious effects on marine life.

Figure 2



107
3.0
RARITAN # 2 = 13.0
" # 57 = 106.0
105
9.0
40° 30′N
1956
9.0
60
3.0
61
39.0
42
30.0
AMBROSE
V0000
20.0
Y0000
32.0
109
40.0
A9
39.0
V00
28.0
Y00
45.0
B2
153.0
C4
70.0
70
18.0
D9
3.0
36
1.5
64
2.5
B2
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39
160.0
59
215.0
4
150.0
14
370.0
G2
75.0
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Y4
190.0
Y6
50.0
12
22.0
Y8
"BA" BUOY
60.0
556
55.0
557
10.0
558
35.0
TOTAL COPPER AS ppm OF
DRY SEDIMENT THROUGH
NOVEMBER, 1971
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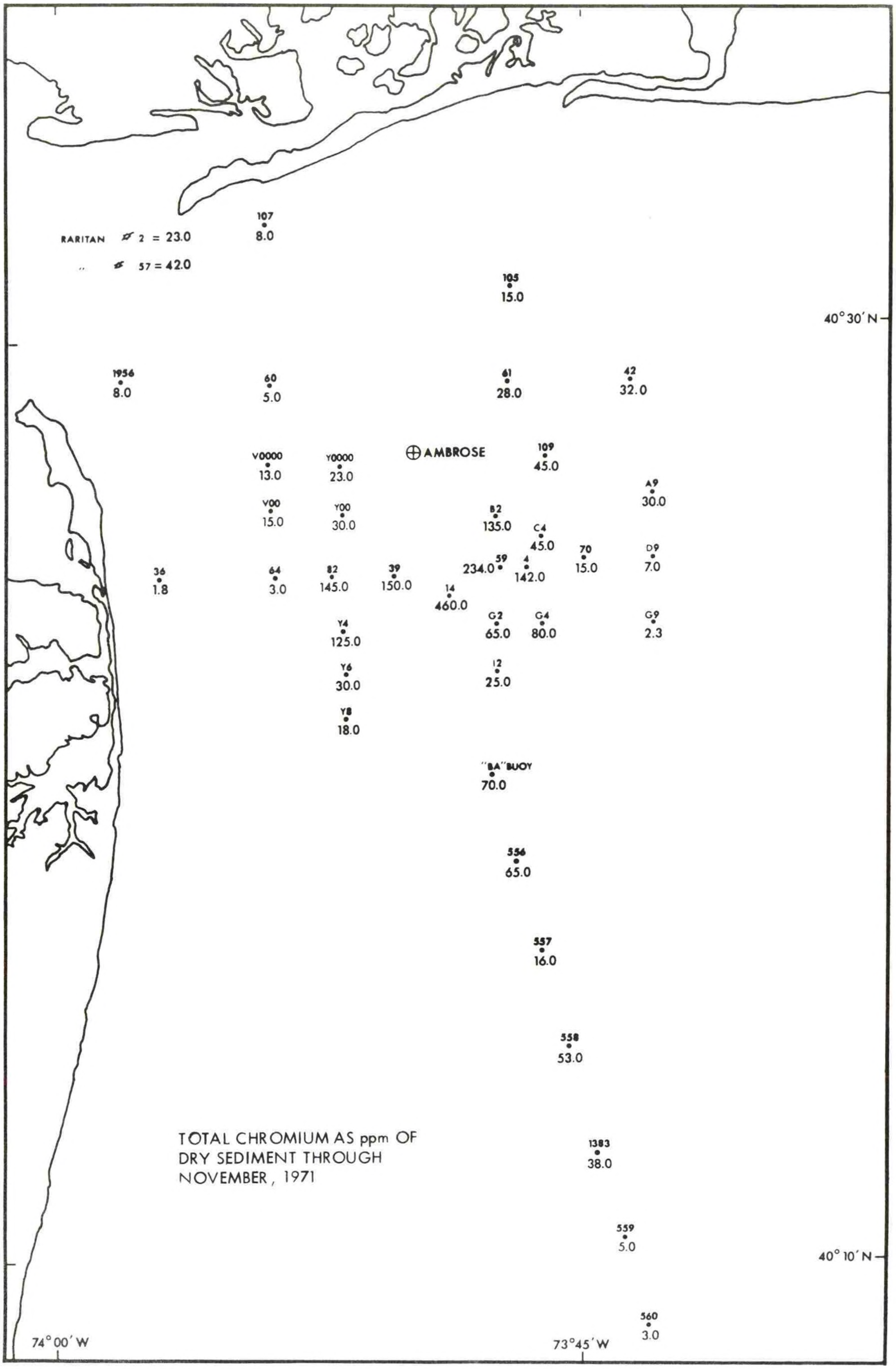
22.0
559
3.0
40° 10′N
560
1.5
74°00′W
73°45′W

Figure 3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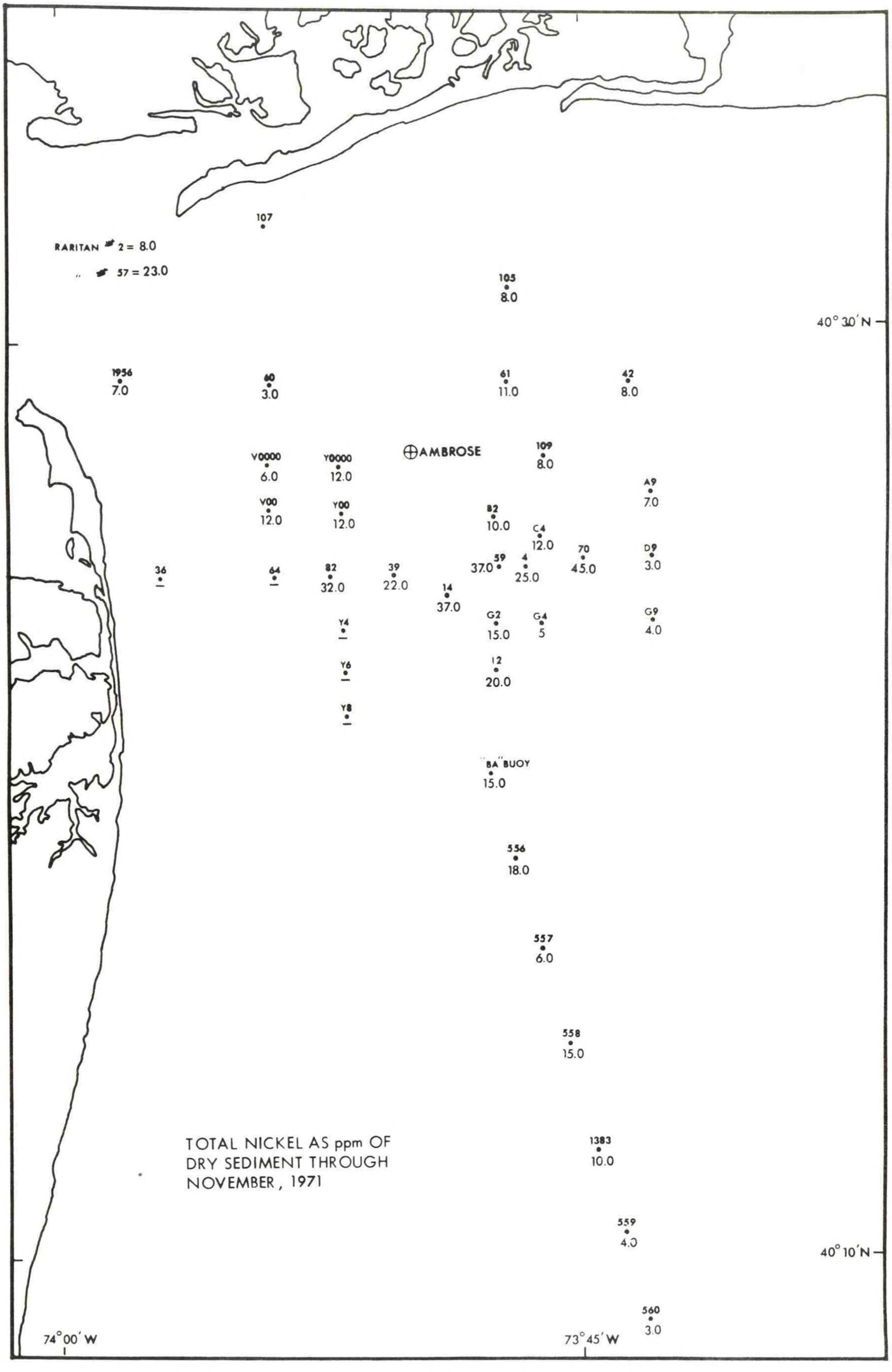
61 28.0
42 32.0
AMBROSE
V0000 13.0
Y0000 23.0
109 45.0
A9 30.0
V00 15.0
Y00 30.0
B2 135.0
C4 45.0
70 15.0
D9 7.0
36 1.8
64 3.0
82 145.0
39 150.0
59 234.0
4 142.0
14 460.0
G2 65.0
G4 80.0
G9 2.3
Y4 125.0
Y6 30.0
12 25.0
Y8 18.0
"BA" BUOY 70.0
556 65.0
557 16.0
558 53.0
TOTAL CHROMIUM AS ppm OF DRY SEDIMENT THROUGH NOVEMBER, 1971
1383 38.0
559 5.0
40°10′N
560 3.0
74°00′W
73°45′W

Figure 4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105
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1956
7.0
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3.0
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11.0
42
8.0
AMBROSE
109
8.0
V0000
6.0
Y0000
12.0
A9
7.0
V00
12.0
Y00
12.0
82
10.0
C4
12.0
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45.0
D9
3.0
36
64
82
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22.0
59
37.0
4
25.0
14
37.0
G2
15.0
G4
5
G9
4.0
Y4
Y6
12
20.0
Y8
"BA" BUOY
15.0
556
18.0
557
6.0
558
15.0
TOTAL NICKEL AS ppm OF
DRY SEDIMENT THROUGH
NOVEMBER, 1971
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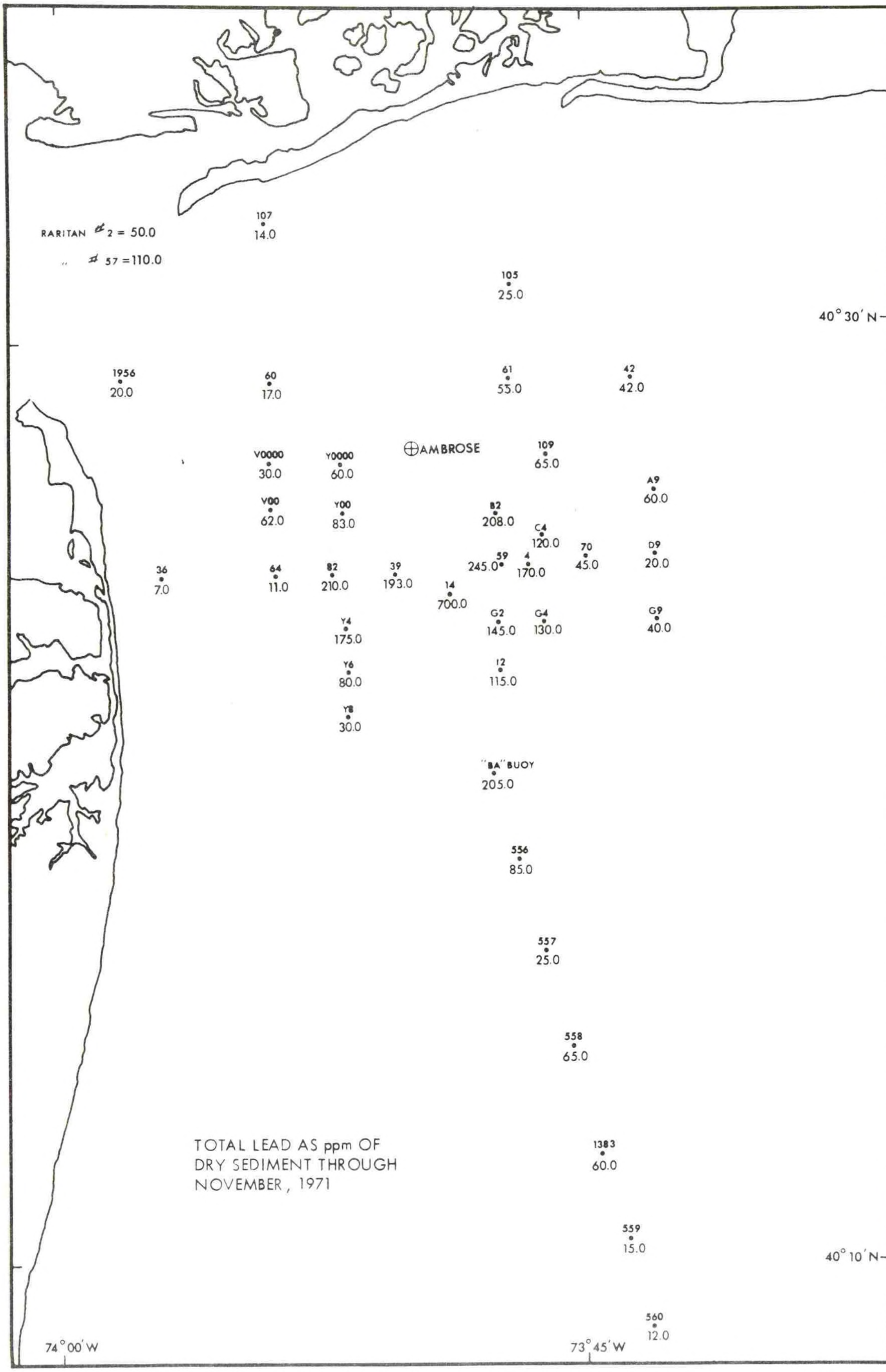
10.0
559
4.0
40° 10′ N
560
3.0
74° 00′ W
73° 45′ W

Figure 5



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Y0000 60.0
109 65.0
A9 60.0
V00 62.0
Y00 83.0
B2 208.0
C4 120.0
70 45.0
D9 20.0
59 245.0
4 170.0
36 7.0
64 11.0
82 210.0
39 193.0
14 700.0
G2 145.0
G4 130.0
G9 40.0
Y4 175.0
Y6 80.0
12 115.0
Y8 30.0
"BA" BUOY 205.0
556 85.0
557 25.0
558 65.0
TOTAL LEAD AS ppm OF
DRY SEDIMENT THROUGH
NOVEMBER, 1971
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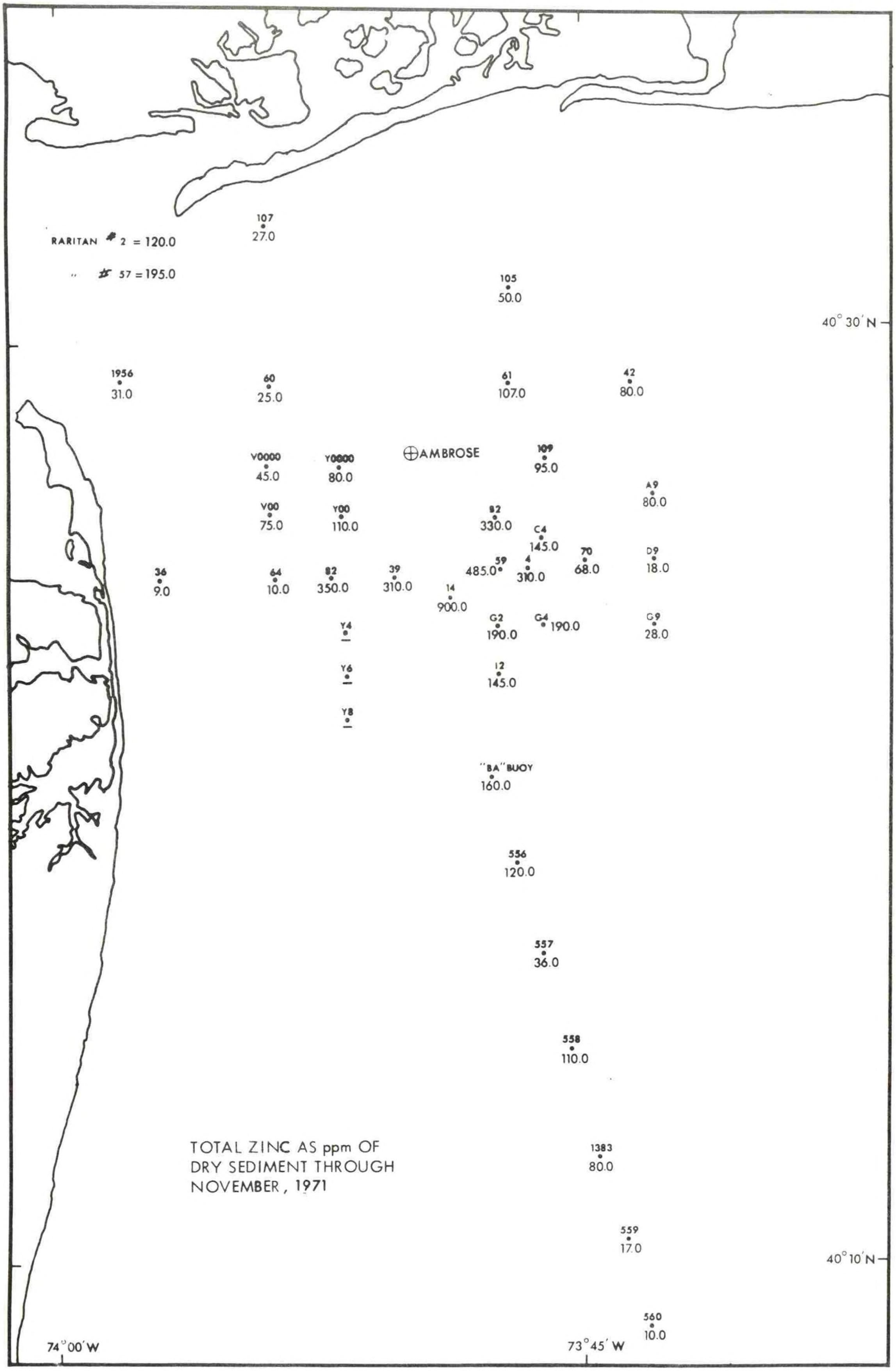
40° 10′ N
560 12.0
74° 00′ W
73° 45′ W

Figure 6

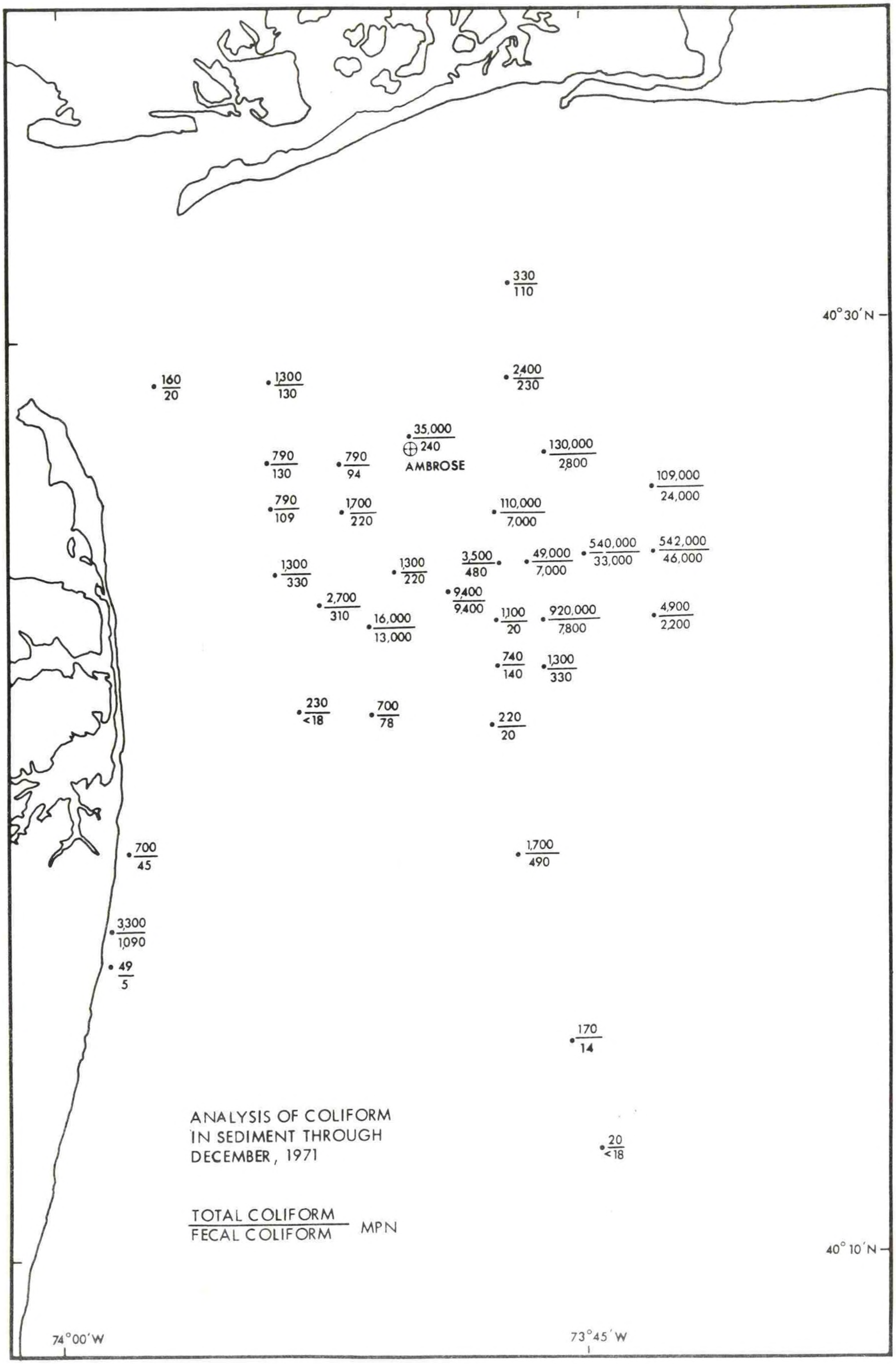


TOTAL ZINC AS ppm OF DRY SEDIMENT THROUGH NOVEMBER, 1971

Figure 7. Distribution of coliform bacteria in sediments collected at stations in New York Bight and Hudson Canyon; based on samples collected in December 1971.

The general pattern of distribution of coliform bacteria conforms to the patterns of distribution noted for several heavy metals (Figs. 2-6).

Figure 7


330/110
40°30′N
160/20
1300/130
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35,000/240
AMBROSE
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1700/220
110,000/7,000
1300/330
1300/220
3,500/480
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740/140
1300/330
230/<18
700/78
220/20
700/45
1,700/490
3300/1090
49/5
170/14
ANALYSIS OF COLIFORM
IN SEDIMENT THROUGH
DECEMBER, 1971
20/<18
TOTAL COLIFORM / FECAL COLIFORM MPN
40°10′N
74°00′W
73°45′W

and three genera of bacteria which apparently are facultative pathogens involved in the etiology of a fin rot disease prevalent in the waters of the New York Bight. If the same relationship between the presence of coliforms and facultative pathogens requiring elevated nutrient levels proves to be true for waters receiving dredging spoils and sewage sludge, it is likely that the causative agents of the disease syndrome are being spread into uncontaminated and ecologically important areas.

During a recent study of oil degrading bacteria, Atlas (1972) found the existence of a large population of unidentified bacteria in surface waters at Station 82, the center of dredging spoils disposal. He had collected water samples for oil degrading microorganisms along a line extending from Arthur Kill, past Sandy Hook to the dumping area. Despite the fact that Raritan and Lower Bays are heavily polluted by local sewage and industrial outfalls his highest counts were found at stations in the spoils disposal area. This indicates that the transport of dredging spoils, heavily contaminated with bacteria, act to introduce bacteria in an environment far removed from the source of bacteria. Hlavka (1971) suggested that at the Hyperion outfall in southern California "the survival of coliform bacteria associated with floating particulates may differ substantially from that generally reported for coliforms in sea water." Because we have noted extensive surface accumulations of floating particulates in both dumping areas (Fig. 9) we believe there may be significant accumulations of bacteria at the water-air interface and in the water column as the particulates sink.

It is of significance that of several hundred marine teleosts recently collected in the New York Bight and analyzed for the presence of mercury, weakfish (Cynoscion regalis) with fin rot disease had the greatest amount of mercury in their tissues. Apparently healthy weakfish collected at a control site off Chincoteague, Virginia had an average of 0.31 ppm of mercury in their muscle tissue and 0.14 ppm in liver tissue. Diseased fish collected from the New York Bight had an average of 0.62 ppm mercury in muscle tissue and 0.54 ppm in their liver. In view of the report by Pippy and Hare (1969), that certain metals might predispose fish to disease, our preliminary findings are important and should be considered at this time.

The presence of elevated values of organic materials associated with sediments correlates well with observed patterns of distribution of coliform bacteria and heavy metals. We found that organic materials derived from solid wastes disposal have been carried north of the sewage sludge dumping areas where they settled upon sediments which are not directly affected by dumping.

It is important to note that certain species of invertebrates have apparently extended their range into areas impinged upon by organic debris. We do not, at present, know if the spread of organic

Figure 8. Artifacts found in a single grab sample (surface area collected, 0.1 m^2); these materials are characteristic of the items found in sediments collected from the sewage sludge disposal area and include band aids, cigarette filters, matches and a variety of seeds.

These items are characteristic of materials washed through garbage disposal units and toilet bowls.

The distribution of these materials is correlated with the distribution of coliform bacteria, heavy metals and organic matter in the New York Bight.


Figure 8

materials has resulted in an increased biomass at stations within this possibly enriched area. Also, we do not know if the heavy metals and other toxic elements known to be associated with these organic materials have had an effect on species which habituate the affected areas. There is some indication that forms collected at the edges of the sludge and spoils beds do have elevated values of heavy metals in their tissues.

It is also apparent that ocean disposal of sludges and spoils drastically altered the simple physical structure of the sediments impinged upon by these wastes. This, in itself, is sufficient to markedly change patterns of distribution and species diversity. Finally, it has been recognized that sludge and spoils disposal can effectively bury many benthic organisms.

Because of the vast difference in amounts and composition of solid waste being disposed of, and differences in water depth and hydrography, it is difficult to compare the results of similar studies completed in other areas. Several aspects of these different studies do, however, appear to be similar. Heavy metals have apparently accumulated in areas used for dumping or discharge of sludge and sewage in the Thames River Estuary, England (Shelton, 1971); Firth of Clyde, Scotland (MacKay, Halcrow and Thornton, 1972); coastal waters of California (Hlavka, 1971); and the New York Bight as indicated in the present report.

As we have noted in collections made in the New York Bight (Fig. 8), Shelton (1971) reported finding sediments in the Thames Estuary contaminated with objects recognizable as having their origin in sewage. As suggested by Pearce (1971), Shelton used tomato seeds associated with sediments as an indication of contamination by sludge. MacKay, Halcrow and Thornton (1972) did not report the presence of individual recognizable objects such as seeds, cigarette filters and band-aids but they did indicate that the highest values of organic carbon were associated with the center of the Clyde Estuary sludge disposal area. In addition to finding seeds, Shelton (1971) also reported buildups of organic matter in the Thames disposal area although he suggested that this could be the result of "... settlement of the normal traction load of organic matter which is present in the River Thames." We do not believe this to be the situation in the New York Bight where observations indicate that the Hudson River, and its entrained organic matter and microorganisms, does not generally flow to the disposal areas. Gross (1970) reported that ocean dumping constitutes the largest single source of solids entering the New York Bight.

During the past year we have studied intensively the Delaware Bay sludge dumping area. We have been doing this on a comparative basis with the New York Bight and a control site located off Barnegat Bay Inlet, New Jersey. To date, using the same collecting techniques and methodology, we have been unable to find any adverse effects resulting from dumping at the Delaware Bay site. Heavy metals were not observed to have accumulated because of dumping, and no accumulations of sludge were evident in over one hundred grab samples collected at the designated point for solid waste disposal. Again this indicates that the effects of solid waste disposal cannot be predicted on the basis of a study of one single area. Differences in water depth, topography, currents and amounts and composition of wastes will undoubtedly result in different distributions and accumulations of solid wastes.

In a review of the problems associated with the disposal of sewage sludge and dredging spoils in the New York Bight by personnel of the Woods Hole Oceanographic Institution (Horne, Mahler and Rossello, 1971), it was concluded that the bearing capacity of the center of the sewage sludge dump has been exceeded; this conclusion is similar to ours except that we recognized comparable damage to the dredging spoils disposal area.

One of the questions most frequently asked in connection with ocean disposal is: what is the rate at which the effects of ocean disposal are expanding outward from the designated points of dumping? Our data indicate the conditions which prevailed from late 1968 through January 1972. Certain data suggest that during the period of study heavy metals have increased at specific stations. Conclusions in regard to these particular data are, however, highly speculative and the observed increases may only reflect recent dumps of sludge having

Figure 9. Floating debris associated with a recent discharge by a sewage sludge barge. Photograph was taken from a height of six feet to the water surface. Similar materials were observed in slicks covering square miles of ocean surface.

Figure 9

a higher metal content. Observed changes in the distribution of organic matter and benthic communities may also only indicate "short dumping" and movement of recent dumps by water currents. Our present baselines do, however, allow for future studies, particularly the shoreward distributions of organic matter and heavy metals as well as changes in the distribution of benthic organisms and coliform bacteria and heavy metals within the Hudson Canyon.

Two papers in the literature do indicate that the effects on benthic communities of pollution spread with time. Grigg and Kiwala (1970) reported that the effects of effluents from the Los Angeles (California) Sewer Outfall at White Point spread from 3/4 to two miles in 1954 to six miles in 1969, a three-fold increase in 15 years. The effects included the almost complete disappearance of certain seaweeds and a reduction in benthic animals. Finally, Beyer (1968) noted significant changes in the fish fauna and fisheries of the Oslofjord since the turn of the century. These changes are correlated with change in sediments and reduction in dissolved oxygen. The changes include the complete elimination of fauna in certain areas of the Oslo-fjord and the presence of certain species known to be indicators of polluted environments.

Both of these studies indicate that marine environments can deteriorate within years or decades following initial pollution or physical alteration. While the two marine environments considered are quite different from the New York Bight and, as mentioned earlier, it is difficult to make direct comparisons between different studies conducted in dissimilar environments, the results of these earlier studies should be given consideration in any evaluation of the rate of spread of the effects of point source pollution.

Another question frequently posed in connection with solid waste disposal in the New York Bight is whether or not the existing sludge and spoils beds will recover or return to their natural state if dumping were to cease. Obviously this question can be answered only after dumping ceases or the practice is markedly altered. There is, however, some historical evidence which suggests that heavily polluted marine environments do not return to their pristine state. Based on preliminary findings, Hlavka (1971) reported that heavily polluted environments around the old Orange County, California outfall had not recovered biologically once pollution abatement was initiated there. He did report, however, that levels of hydrogen sulfide and organic carbon diminished with pollution abatement. McNulty (1970), in an extensive paper entitled, "Effects of abatement of domestic sewage pollution on the benthos, volumes of zooplankton, and the fouling organisms of Biscayne Bay, Florida," concluded that: "There was no evidence of improved commercial and sport fishing following abatement; this is interpreted to mean that long-lasting detrimental effects have resulted from pollution and dredging."

Dean and Haskin (1964) reported on benthic repopulation of the Raritan River estuary following pollution abatement. They noted that following pollution abatement in the upper Raritan River there was a rapid repopulation of the estuary. Their data seem to indicate, however, that it was principally the fresh water forms in the upper river which repopulated formerly depleted environments. Recent benthic surveys by this laboratory in western Raritan Bay indicate a highly impoverished benthic environment not indicative of significant recovery following pollution abatement.

Based on these few studies we can only conclude that the return of the New York Bight sludge and spoil grounds to their former level of productivity may require years or possibly decades. Much of the water depth over the dumping area is sufficiently deep to avoid normal wave action. There are, however, word-of-mouth reports that sludge has been carried to the shores of Long Island following particularly severe storms. If this is true the sludge and spoil beds might eventually be moved and dissipated by wave and current action.

Fortunately the present study, as well as those by Gross et al. (1971), provide us with a reasonable baseline against which we can compare future changes in the benthic biota and physical conditions in the New York Bight.

Zooplankton studies were undertaken as part of the overall investigation of the effects of offshore waste disposal on the waters of the New York Bight. The main emphasis of the zooplankton studies has been on copepods, small shrimp-like animals important in the food chain, because they occur in this area the year-round and are usually a principal constituent of the zooplankton. Forms that occasionally outnumber the copepods include temporary zooplankters (meroplankton) such as larvae of bivalves, polychaetes and echinoderms or seasonal visitors such as siphonophores and salps. Although these forms are important in the zooplankton community, when they are present, the seasonality of their occurrence limits their value for our purposes. The meroplankton forms, however, are useful in predicting the potential benthic community.

The study was designed to compare the zooplankton constituents in the disposal areas with those in nearby waters. Ideally, field stations in unpolluted waters should have the same physical and chemical characteristics as those in the disposal sites except for the added waste material. The geography and hydrography of the Bight, however, make such an ideal system impossible. For example, salinity increases as one moves southeast from the Lower Bay area and temperature and nutrient gradients, suspected at the beginning of the study, were later verified by chemical and hydrographic observations. The zooplankton sampling stations were located in a grid of stations in and outside the sewage sludge and industrial acid waste disposal areas. This sampling pattern enabled us to exclude most variations that might be due to factors other than waste disposal.

The zooplankton serve as the link between the phytoplankton (primary producers) and the larger organisms of the sea. Any major disruption in zooplankton production affects the fish and other larger organisms that use zooplankton as a food source. Their mode of life, i.e., drifting with the currents, makes it difficult to assess the effect of a particular material added at a single point. However, the frequency and quantity of acid wastes and sewage sludge disposal are constant enough to be considered as continuous point sources. Industrial acid waste is dumped twice daily at the rate of 220,000 cubic feet per day, and the sewage sludge is dumped at an average rate of 500,000 cubic feet per day. This dumping results in two areas that are receiving material regularly and even though the currents are moving water past the dumping points, we have assumed a steady state of waste concentrations dependent on major wind and current forces, to exist in the dump areas.

To trace the movement of sewage sludge and industrial acid wastes, chemical analyses of water samples for total iron, nitrate and three species of phosphate were made in conjunction with the zooplankton samples. The sewage sludge was expected to have high phosphate and nitrate content and the industrial acid wastes are known to contain about 10 percent $FeSO_4$ (Redfield and Walford, 1951). We, therefore, used phosphate and total iron concentrations as indicators of water contaminated with wastes.

Zooplankton samples were collected at surface, mid- and bottom depths at 15 stations within and outside areas affected by dumping during daylight hours from January 1969 to April 1970. Sampling was done semimonthly at Stations 69, 70, 71, 75, 76S and 78 and monthly at Stations 66, 67, 68, 72, 73, 74, 79, 80 and 81. Samples were collected by towing simultaneously at three depths for 5 to 10 minutes three nets of 1/2-meter diameter #8 mesh (.203 mm aperture) Nitex netting with a flow meter mounted in the throat. Samples were preserved in 4% buffered formaldehyde. Animals were later counted and identified.

For this report the copepods were grouped by genus and other organisms classified to major taxonomic groups. Appendix 3-1 of the complete final report (available on request) is a listing of the data associated with each sample analyzed with station listing preceded by a coding key to transform the digital codes to taxonomic groups. The raw data included numbers of organisms counted and identified from each sample and the calculated data were recorded as numbers per cubic meter.

Samples collected from January 1969 to April 1970 at six stations have been analyzed. There is a general increase in total number of copepods from January until late June, then a decrease from July until October, after which the numbers again increase. Plots of the total number of copepods per cubic meter for each station and depth over the sampling period were included in the complete final report. The average number per cubic meter ranged from a high of 41,000 to a low of 700. The largest number found was 87,000 copepods/m^3 and the lowest 100 copepods/m^3 with most counts between 1,000 and 10,000/m^3. The number of copepods/m^3 found in the study area was within the ranges reported for other middle Atlantic coastal waters. Numbers reported by other workers vary greatly depending on the area, season and size of mesh net used for collection. Direct, quantitative, comparisons between different studies are not justified unless the same mesh net has been used and numbers have been reported quantitatively.

Sampling for zooplankton was done at the designated point for sewage sludge disposal, Station 70, biweekly from April 1969 to March 1970. Although it is the designated point for release of sludge, Station 70 lies at the eastern periphery of the sewage sludge beds characterized by a limited benthic fauna and high levels of heavy metals, coliform bacteria and organic matter. No attempt was made to tow the 1/2-meter nets through a fresh dump because of the floating and suspended debris and organic material which resulted from the dumping of sewage sludge (Fig. 9). Sixteen samples contained large amounts of paper fibers and carbon-rich aggregate particles (Fig. 10) even though the surface water was free of sludge residue. These samples did not have copepod counts that were significantly different from clean samples. Throughout the year the numbers of copepods per cubic meter at Station 70 were significantly different (P = .001) only 5 times. Two of these times the counts were higher than expected and three times they were lower. Station 67, which lies 2.5 miles north of Station 70, also varied significantly from the expected count five times. Three of these were higher than expected and two were lower. The rest of the 93 samples analyzed from these two stations fell within the expected range.

The original sampling design included a station located at the winter acid disposal site (Station 76) and one at the summer disposal site (Station 77). Because of the naturally varying position of the acid dumping site, subsequent sampling was done in the ferric hydroxide stain, which results from industrial acid waste disposal, and the samples recorded as taken at Station 76S. In this section, therefore, all zooplankton collections taken in ferric hydroxide stain are listed under Station 76S.

The stratified distribution of copepods that occurred at the five stations did not exist at Station 76S. Copepods normally migrate vertically, occurring in deep water during the daylight hours and

Figure 10. Photomicrograph of debris associated with zooplankton samples. The fibrous materials were identified as paper fibers. Personnel of the Woods Hole Oceanographic Institution have reported that such materials make the waters of the New York Bight among the most turbid coastal waters of the eastern coastline.

The copepod is approximately two millimeters in length.

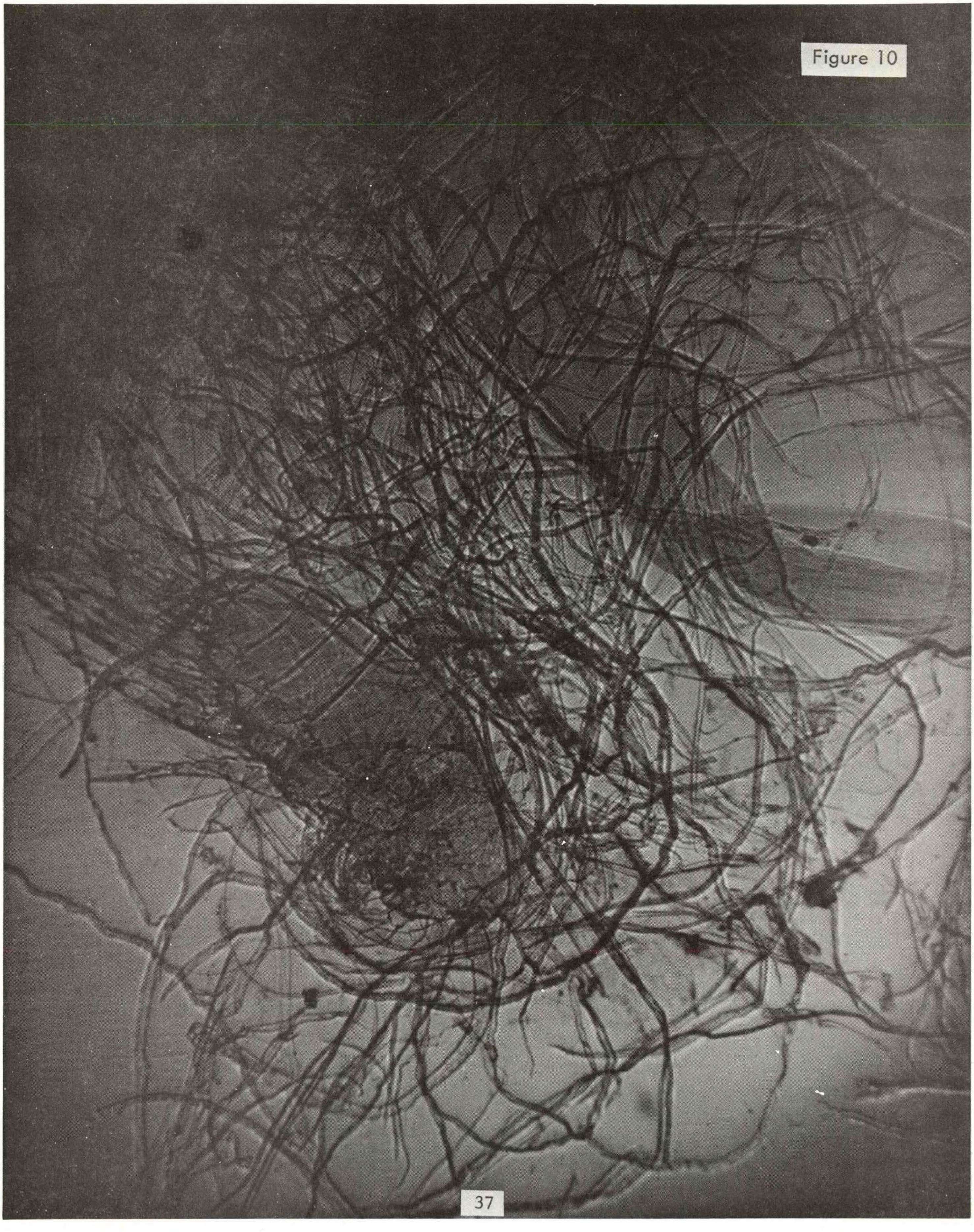


Figure 10

rising to the surface waters at night (Cushing, 1951; Bogorov, 1958; Banse, 1964). The daily vertical migration is generally thought to be controlled by light intensity (Herman, 1963; Segal, 1970). The acid wastes, when mixed with sea water, produce a ferric hydroxide floc that results in turbid, stained waters. This stain apparently changes the light conditions enough to disrupt the normal vertical distribution of the copepods in the area. The total numbers for the stain area, however, are not significantly different from those of the other five areas analyzed.

Changes in the environment often cause changes in the composition and seasonal distribution of local zooplankters. Jeffries (1959) related a large increase in the Pseudodiaptomus sp. population of Raritan Bay to the removal of a sewage effluent. Unfortunately no quantitative information on the zooplankton of the study area prior to dumping was available. We have information, however, for the nearby Block Island Sound area and the waters off Delaware Bay. Their physical characteristics are similar enough to those of the study area to make reasonable comparisons of the seasonal availability of zooplankters. Generally, we found the composition and seasonal distributions to be similar to those reported by other investigators.

Zooplankters other than copepods that commonly occurred in significant numbers were chaetognaths, polychaete larvae, bivalve larvae, and pelagic gastropods. Seasonal zooplankters that occurred in abundance were cladocerans, nauplii and cyprid stages of barnacles, siphonophores, salps and echinoderm larvae. The seasonal abundances of bivalve and polychaete larvae were indicated in numerous figures in the complete final report.

Bivalve larvae were abundant from January to April and from August through November in 1969. In January through March of 1970, they were not as abundant as the previous year. The highest concentration, 8,400/m^3, was from a bottom sample from Station 76S taken in late September 1969. As many bivalve larvae were taken at Station 70, the designated point for sewage sludge disposal, as at the other stations. Our benthic data, however, show a small adult population in the area suggesting that something inhibits settlement or kills the young before they grow to a size detectable in our benthic samples.

The polychaete larvae were less abundant than the bivalve larvae and were found in densities up to 600/m^3. Their highest concentration was in samples taken near the bottom. January to early June and late August to December were the periods of peak abundance. The numbers/m^3 collected in water samples at stations over the sewage sludge disposal area were no different from those at other stations, indicating that some larvae are able to live in waters over this area but apparently unable to survive after settling onto the bottom sediments.

Three genera of cladocera, small crustaceans, were present, _Evadne_ sp., _Penilia_ sp. and _Podon_ sp. _Evadne_ was the commonest of the three and was present in densities of 50 to 7,000/m^3 from the middle of May until October. _Penilia_ and _Podon_ were less frequent in appearance but occasionally dominated the zooplankton in July and August. The largest catch of _Podon_ was 23,941 individuals/m^3 at Station 70 in July and for _Penilia_ was 62,570/m^3 in August. Although the cladocera can be abundant their infrequent occurrence and small size make them minor elements of the total zooplankton fauna.

Chaetognatha, an important member of the zooplankton community because of size and predatory habits, were present in the study area throughout the year. Arrow worms were most abundant in the bottom waters and peak numbers occurred from May to July. The highest number taken per m^3 was 714 from the bottom water at Station 78. There was no significant difference in occurrence or abundance among the six stations.

The pelagic gastropod, _Limnacia_ sp., was present in the study area throughout the year. Its numbers per cubic meter ranged up to 1,780 individuals. The peak number occurred in October 1969 with peaks also in August 1969 and February 1970. Salps, siphonophores and echinoderm larvae were abundant from August to October. Organisms taken sporadically in small numbers included larvae of crabs, shrimp, phoronids, barnacles, bryozoans and fish as well as mature forms of amphipods, mysids, pelagic polychaetes, tunicates and hydromedusae.

Based on our field and laboratory studies of zooplankton we have concluded that the present practice of industrial acid waste dumping killed copepods in the immediate area of disposal. The volume of sea water affected was calculated to be 900,000,000 gallons or 3,400,000 m^3 per barge load of wastes. This is a maximum value and in this area would contain approximately two cubic meters (displacement volume) of zooplankton biomass. It appeared that the number of zooplankton affected was small in relation to the total population of the New York Bight area as a whole and was not discernible in our field sampling.

We also concluded that the ferric hydroxide floc which results from acid dumping is not directly toxic to copepods but does change their vertical distribution pattern. It is, however, important to note that Kinne and Rosenthal (1967) indicated that acid wastes they worked with posed a danger to fish eggs up to a dilution of 1:32,000 and, furthermore, precipitates which formed as a result of ocean dumping of acid wastes might interfere with gaseous exchange in fish eggs.

We found that sewage sludge had no discernible effect on the zooplankton and did not affect its species composition or distribution in the study area. Again, however, preliminary work by Barber and Krieger (1970) indicated that waters contaminated by sewage sludge might interfere with growth of phytoplankton.

Finally, we observed that the zooplankton species composition, density and seasonal distribution in the New York Bight are similar to those of Block Island Sound and the waters off Delaware Bay.

To determine the effects of ocean disposal of sewage sludge on demersal or bottom-dwelling finfishes, we trawled at frequent intervals in and outside the area immediately affected by sludge dumping. Sampling stations were selected for comparability of depth to Station 70, the designated point for sewage sludge disposal.

Station 70 lies at the eastern edge of the sewage sludge beds. We could not sample the extensive sludge beds located west of Station 70 because of trawling restrictions due to the presence of submerged World War II mines. Our sampling of the sludge area was therefore confined to an area that is at times heavily polluted and at other times only marginally so. In all trawl samples taken at Station 70 large quantities of artifacts such as mammalian hair, paper, foil, tampons and cigarette filters were found, indicating that we were collecting in an area contaminated by sewage sludge.

In addition to Station 70, samples were collected regularly from May 1969 through August 1970 at Stations 65, 67 and 72. Other stations sampled were I-1, 78, 76-77, BA buoy, 38 and 75.

Otter trawls were towed for fifteen minutes at 3 nautical miles per hour except on two cruises when sampling time was ten minutes. Captured fish were sorted to species, counted and a subsample measured for total length. When captured, samples of 10 to 20 yellowtail flounder (Limanda ferruginea), winter flounder (Pseudopleuronectes americanus), ling (Urophycis chuss), and whiting (Merluccius bilinearis), each were preserved for analysis of stomach contents. Stomachs were removed in the laboratory and stored in buffered 4% formalin in individual jars with labels indicating sampling location, date collected, species and total length. Identifiable contents were later enumerated by species whenever possible. Whole fish were frozen and sent to several laboratories for analyses for the presence of heavy metals and pesticides.

We collected 31 species of fish in and around the sewage sludge disposal area. Twenty-two of these were collected from Station 70, the designated sewage sludge dumping area. Three Stations, 65, 67 and 70 were sampled often enough to provide a representative picture of the fish population at each. At these three stations, whiting (Merluccius bilinearis), ling (Urophycis chuss), winter flounder (Pseudopleuronectes americanus), yellowtail flounder (Limanda ferruginea), windowpane (Scophthalmus aquosus), and longhorn sculpin (Myoxocephalus octodecemspinosus) occurred the most frequently. The remaining species of fishes occurred sporadically in samples and usually in low numbers. Occasionally large numbers of fish such as Atlantic mackerel (Scomber scombrus), porgy (Stenotomus chrysops) and various herring were taken in the trawl.

A special series of collections was made to sample demersal fishes along a transect across the Hudson Canyon. These collections were made on 21 May 1970 at Stations 38, BA buoy and 75 (Fig. 1). Stations 38 and 75 are located on either side of the gorge while Station BA buoy is in the center of it. Twelve of the 13 species collected occurred at all three stations, at Station BA buoy 1,416 fish were taken, compared with 207 fish at Station 38 and 484 fish at Station 75. The significantly higher number of fish taken at Station BA buoy suggests that the Canyon is an important area to local fish populations. We do not know the reason for their increased numbers in that location or whether the difference exists throughout the year. Importance and function of the Canyon as a habitat should be more thoroughly investigated since the sewage sludge disposal site lies at the head of it and we have observed that heavy metals and coliform bacteria extend southward from the disposal area into the Canyon. If, as has been suggested, it serves as a principal migration route for organisms entering and leaving the shallow areas of the New York Bight the addition of wastes to it could adversely affect this important environment and interfere with normal patterns of movement.

The results of the stomach content analysis indicated that yellowtail flounder, winter flounder and ling ingest mainly benthic organisms such as polychaete worms, amphipods and bivalves as well as sewage sludge artifacts such as mammalian hair, band-aids, seeds and cigarette filters. Whiting appear to feed mainly on epibenthic and swimming organisms such as mysids, sand shrimp and fish.

Some flounder collected from the sludge area had blackened gills. When two winter flounder were kept in aquaria, one containing a substrate of sludge and the other a substrate of clean sand, a blackening of the gills occurred in the fish held in the aquarium with the sludge substrate (Fig. 11).

The trawl samples and stomach analyses indicate that the local groundfishes use the area peripheral to the sewage sludge beds for habitat and feeding. We found their numbers at Station 70 and three miles north (Station 67) to be greater than those found on a clear sand bottom three miles east of the dump site (Station 65). Because we have on occasion observed commercial trawlers working near Stations 65, 67 and 70, we believe fish from the area are being commercially harvested and marketed. Numerous reports from sport fishermen indicate that foul smelling fish, which are unsatisfactory from an aesthetic point of view, have been caught in the sludge disposal area.

Figure 11. Winter flounder that were held in aquaria with (A) clean sand substrata and (B) sediments contaminated with sewage sludge. The photo was copied from a color slide and suffers from loss of resolution. The gills of fish (A) were pink in the living fish and the gills of fish (B) were black.


Figure 11
A
B

Our conclusion as to how the sewage sludge affects the distribution of the fish at the head of the Canyon would be better if we had been able to trawl west of Station 70. Unfortunately, this area has a rugged bottom and, as previously mentioned, a large section is closed to trawling because old mines are known to exist there. Attempts to sample at Stations 59 and 39 resulted in extensively damaged and lost trawling gear.

Analyses of stomach contents indicate that fish are actively feeding in the periphery of the disposal area and are ingesting materials associated with sewage sludge, carbon-rich aggregate particles, band-aids, hair and cigarette filter tips. Whether the fish ingest the material selectively or accidentally during feeding on normal food items is unknown. The fact that they are ingesting some of these items opens up the question as to what, if any, of the harmful materials including heavy metals and pathogenic microorganisms are ingested by the fish. The fate of such material is of concern because of its potential effects to finfish and ultimately man.

Our data on levels of heavy metals found in fish suggest that a concentration of metals may have taken place in some of the fish examined. The levels of nickel, chromium and lead in several fish examined exceed those amounts listed by the Federal Water Pollution Control Administration (1968) as normal for marine animals. Far more basic research will be necessary, however, to determine what constitutes a dangerous level of heavy metal in marine organisms. This laboratory, in conjunction with other facilities of the National Marine Fisheries Service, has initiated an intensive comparative study of New York Bight and Delaware Bay to ascertain the distribution of heavy metals and their role in marine food chains.

Certain chemical analyses were undertaken to determine the distribution and fate of sewage sludge, dredging spoils and the "acid wastes" disposed of in the New York Bight and to relate these findings to concurrent biological and hydrographical investigations.

Previous studies of the chemistry and hydrography of the New York Bight (Ketchum, Redfield and Ayers, 1951; Redfield and Walford, 1951) described the distribution of salinity, temperature, dissolved oxygen and iron on seven cruises between February 1948 and January 1950. Disposal of the "acid wastes" began in April 1948, during the tenure of these studies. In 1956, Corwin and Ketchum sampled sediments in and northeast of the disposal area and reported on the iron content of the sediments. Ketchum, Yentsch and Corwin (1958) reported on the salinity temperature, total phosphorus, total iron and chlorophyll-a measured during three cruises in the Bight.

Studies of non-ferrous metals are more recent. Buelow, Pringle and Verber (1968) took sediment samples at three stations near the sewage sludge disposal grounds and analyzed the water extracts for copper, zinc, chromium and lead. Gross *et al.* (1971) used optical emission spectroscopy to estimate copper, lead, silver and chromium content of surficial sediment deposits.

The present study was carried on in conjunction with our zooplankton investigation principally to relate any differences found in zooplankton populations to properties of the water column. Samples were collected on 27 cruises to the disposal areas located south and east of Ambrose Light Tower in 23 to 27 meters of water from late January 1969 to mid-July 1970. Initially, stations on east-west transects through the sewage sludge and acid waste disposal areas were sampled bimonthly. These included Stations 69, 70, 71, 75, 76, 77 and 78 (Fig. 1). Stations located on transects to the north, south and between the above stations were sampled monthly. This scheme included Stations 66, 67, 68, 72, 73, 74, 79, 80 and 81. The chemical studies were continued after the zooplankton collections ended.

Determinations were made of the concentrations of phosphorus (ortho, organic, meta and total), nitrate, total iron, dissolved oxygen, and chlorophyll-a in water samples and temperature, salinity, turbidity and pH were measured.

Sediment samples were analyzed for heavy metals, petrochemicals, pesticide metabolites and redox potential to discover whether the distribution of benthic organisms might be correlated with these parameters. The findings in regard to heavy metals were reported previously in this paper.

The acid wastes disposed of at sea by National Lead Company are a solution of 8.5 percent H_2SO_4 and 10 percent $FeSO_4$ in water. They are discharged at a point about 12 nautical miles east of New Jersey and 15 nautical miles south of New York. The acid is reported to be rapidly neutralized (Redfield and Walford, 1951) while the ferrous sulphate is oxidized to the ferric state, precipitating as the hydroxide, the dispersion of which can readily be traced. We found it to be the dominant source of iron in the area; there are, however, occasional contributions of iron from river water introduced in the northeastern portion of the study area.

Primary and secondary sewage sludge from communities in the New York metropolitan area have been disposed of for over four decades at Station 70 (Fig. 1), a site approximately 10 nautical miles equidistant from New York and New Jersey. At present, this amounts to more than 5 million yd^3 per year. Dredging spoils from New York metropolitan harbor areas (6 million yd^3 per year) are dumped at Station 82, 3.5 nautical miles southwest of Ambrose Light and 5 nautical miles east of Sandy Hook. The sludges are rich in certain nutrients. Routine measurement of one of the nutrients, phosphorus, was undertaken not only because of its role as an essential nutrient in aquatic food chains and its abundance in sewage sludge, but because of its value as a tracer material to follow the movement of contaminated water.

Jones and Folkard (1971), working in the Irish Sea, considered their finding of more than 2 ug-at/l orthophosphorus in the surface waters extraordinary; an upper limit of 2.8 ug-at/l for an unpolluted nearshore water has been suggested (Ketchum, 1969). In the present study we found concentrations of orthophosphorus of up to 5.64 ug-at/l. While this concentration for inorganic phosphorus exceeds that in the Irish Sea, where elevated levels were attributed to a chemical plant effluent, it does not reach the proportions observed in Moriches Bay, Long Island, where pollution from duck farms resulted in concentrations of 7.0 ug-at/l inorganic phosphorus (Ryther and Dunstan, 1971).

We found that the disposal of acid wastes results in an area of turbid iron-rich water which is almost constantly present and which appears to have increased in magnitude over the last 20 years. The acid waste tends to remain in a distinct pattern after disposal; the mass sinks and is moved along the bottom by currents, generally to the northeast. The dumping of sewage sludge results in areas of turbid, phosphorus-rich water containing particulate matter; the heavier portions of the sludge sink, leaving soluble nutrients behind. We found no demonstrable increase in primary productivity in the disposal area as a result of this nutrification. As observed with the acid wastes, the slowly settling sludge generally moves northeastward, resulting in the deposition of organic material for some distance to the north and northeast of the designated disposal area.

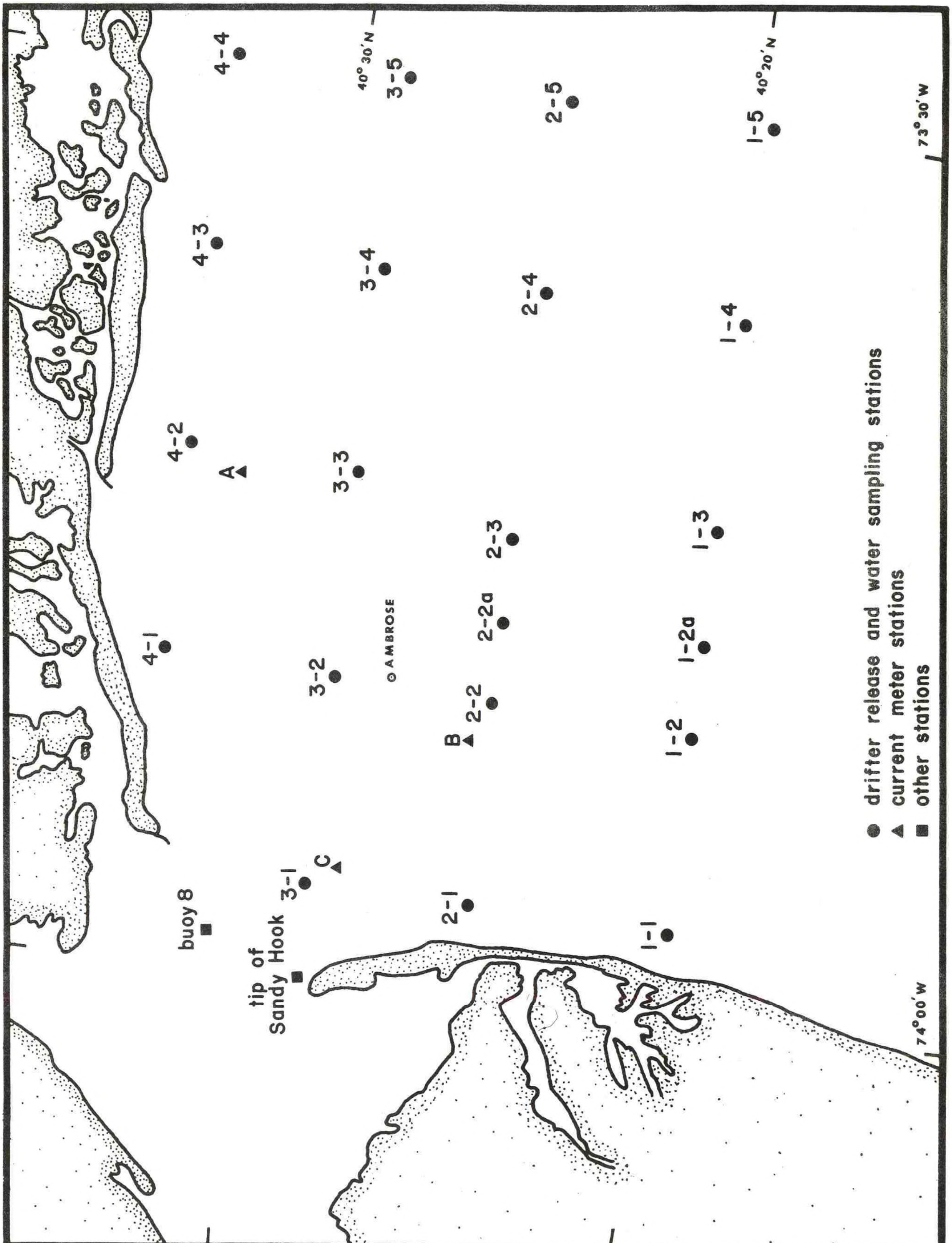
Our data on dissolved oxygen suggests that bacteriological activity in the sludge beds periodically depletes the overlying waters of oxygen to levels insufficient to support life. We found that sediment samples collected from the dredging spoil beds contained amounts of petroleum sufficient to injure or cause death to bottom-dwelling organisms. Heavy metals, including copper, chromium, lead, nickel and zinc, which originated in the sewage sludge and dredging spoils and were found in water, sediments and the tissues of organisms, exist in concentrations which exceed levels known to be toxic to many marine organisms.

For several years, the Sandy Hook Laboratory has collected data on temperature and salinity between Cape Cod and southern Florida to learn how these features of the marine environment affect distribution of marine organisms. This long-range study was continued when, in 1968, the U. S. Army Corps of Engineers provided additional support to augment these observations in a part of the New York Bight extending from Jones Inlet, N. Y., to Monmouth Beach, N. J. The extended study was made to provide details of the nearshore water circulation as it might relate to the movement and dispersal of sewage sludge and dredging spoils deposited in the area.

To meet these objectives a sampling grid of 23 stations was established in a part of the Bight (Fig. 12). Periodic measurements were made at these stations to determine values for temperature and

Figure 12. Stations in the New York Bight at which hydrographic measurements were taken and bottom and surface drifters released.

Figure 12


40°30'N
40°20'N
73°30'W
74°00'W
AMBROSE
buoy 8
tip of Sandy Hook
A
B
C
1-1
1-2
1-2a
1-3
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1-5
2-1
2-2
2-2a
2-3
2-4
2-5
3-1
3-2
3-3
3-4
3-5
4-1
4-2
4-3
4-4
drifter release and water sampling stations
current meter stations
other stations

salinity at depth intervals of four meters, and for dissolved oxygen near the bottom. In addition, several attempts at direct measurement of currents and particulate transports were made. Current meters were placed at four fixed stations within the study area to measure current speed and direction near the bottom and at approximately 40 feet above the bottom.

Estimates of surface and bottom particulate transport were made with the use of seabed and surface drifters. These drifters were released at 21 of the fixed grid stations on each of the regular cruises. The seabed drifter we used is a positively buoyant plastic saucer (diameter 18 cm) fastened to a small diameter stem 54 cm long. The free end of this stem is weighted so that the whole drifter has slight negative buoyancy. Surface drifters were small bottles, ballasted to float vertically and yet present a low above-surface profile to minimize unwanted wind effects. Details of construction and operation of these drifters can be found in Bumpus (1965), or Harrison et al. (1967).

Reaction of the drifters to water movement closely approximates that of other small movable objects at the surface and near the seabed. Their behavior thus provides the best estimate of the effect of water movement on the transport and dispersal of sewage sludge and dredging spoils. This study relied on the public to return information on the time and location for each drifter found. Thus, positive results are obtained only when drifters move into areas accessible to the public. This may be an important consideration in New York Harbor where there are limited areas for drifters to wash up on a beach. Response to the drifter program was, however, high. Of 1,886 surface drifters released, 497 or 26% were returned. Of 2,190 seabed drifters released in 1969, 710 or 32% were recovered. These rates of return are exceptionally high for this type of investigation and are attributable to a combination of vigorous onshore transport mechanisms and the intensity of traffic on the adjacent beaches. Results of our analysis reported here are based primarily on spatial and temporal patterns in return of those drifters released during 1969.

Several studies using seabed drifters have been made on the continental shelf in the middle Atlantic Bight area. The study by Bumpus (1965) indicates that nearshore, the tendency for flow is westerly or southerly with a component toward the coast; but the onshore-offshore component is difficult to distinguish from more or less isotropic dispersion because only those drifters carried onshore yield any information. His study, like that of Harrison et al. (1967), indicates that there is definite residual bottom drift towards the mouths of estuaries. Such inflow to the Hudson Estuary mouth is expected as a normal consequence of estuarine circulation driven by fresh water outflow and has been observed in a wide variety of situations (Conomos et al., 1970; Gross, Morse and Barnes, 1969). Data from the present study tend to show the same pattern as described by Bumpus.

Information reported in the final data report tends to support four major conclusions in regard to water circulation in the New York Bight: First, there is substantial shoreward migration of drifters deposited at the surface or on the bottom. Over 29% of all drifters released found their way to shore. Second, the data suggest a strong flow at the bottom along the axis of the Hudson-Ambrose Channel into the mouth of the Hudson Estuary. Few drifters were recovered in the bay; this low return may be due to public inaccessibility, reduced drifter buoyancy or other forms of drifter entrapment. Third, there is some indication of a general clockwise circulation in the Bight which may be associated with a bifurcation in the head of the Hudson Channel. Finally, while surface drift patterns suggest strong seasonality, there is only mild seasonal variation in the bottom returns. During winter, surface flow seems to be predominantly southeast out of the study area. At other times flow tended northward onto Long Island.

These results indicate a transport mechanism which can account for the patterns of distribution of organic material, coliform bacteria and heavy metals found in the New York Bight. As wastes are disposed of offshore those portions of the waste which remain temporarily suspended are carried towards shore, eventually settling between the dump sites and the shoreline.

From the foregoing we conclude that disposal of dredging spoils and sewage sludges has had a significant, and often deleterious effect on the living resources of the New York Bight.

We found that heavy metals have accumulated in sediments directly receiving the sludges and spoils. Heavy metal values in sediments collected from spoils and sludge beds were often 100 times the background values found in apparently uncontaminated sediments collected at stations surrounding the disposal areas, off Barnegat Bay Inlet and in Delaware Bay. We found no evidence that the observed buildup of metals has any origin other than ocean disposal of solid wastes.

More important than the actual presence of these metals is their spread outward from the designated points of disposal. Heavy metals were found at stations north of both dumping sites as well as south along the length of the Hudson Canyon. Heavy metal concentrations apparently higher than normal were measured at stations 25 nautical miles south of the site designated for sludge disposal.

We found that coliform bacteria were also present in high concentrations throughout the areas receiving dredging spoils and sewage sludges. As in the case of heavy metals, coliform bacteria have been transported outside the actual dumping areas; their pattern of distribution generally follows that found for heavy metals and organic materials.

The anomalous concentrations of heavy metals, microorganisms and organic materials were correlated with reduced species diversity and generally impoverished benthic populations within the disposal areas.

In our field studies we were unable to detect any effect of sewage sludge on the species composition or distribution of zooplankton. Barber and Krieger (1970) reported, however, an inhibition by sewage sludge on the growth of phytoplankton. Unless their preliminary results are not positively confirmed, we should continue to regard sewage sludge to be a material possibly toxic to phytoplankton. Costlow (personal communication) has noted that water contaminated with sewage sludge caused anomalies in growth and development of brach [illegible] an crab larvae. Although these findings are preliminary, they should certainly be considered in an objective evaluation of the effects of sewage sludge on the development and survival of adult and larval planktonic animals.

During an intensive literature review, included as a bibliography in the final data report, we found that there have been very few studies concerned with solid waste disposal in offshore coastal waters. Furthermore, it is difficult to compare the results of these studies since the hydrography, water depth, sediment types and indigenous fauna at each study site are markedly different. In spite of these differences, review and comparison of the studies by Grigg and Kiwala (1970); Hlavka (1971); MacKay, Halerow and Thornton (1972); Shelton

(1971); Saila, Polgars and Rodgers (1968); and the present investigators show that certain characteristic effects do result from ocean dumping of sludges and spoils. In all of these studies a buildup of organic material has been observed in the areas receiving the wastes. Indications of accumulation of heavy metals have also been noted in the reports by Shelton; MacKay _et al._; Hlavka; and the present investigators. The paper by Saila _et al._ indicates that dredging spoils disposed of in Long Island Sound were contaminated with hexane extractible petro-chemicals. We have also observed this about dredging spoils disposed of in the New York Bight. Saila _et al._, suggested "... that efforts be made to minimize the discharge of sediments with a high organic and/or oil content during the summer season." They also called for the recognition of the probably adverse effects of petroleum products and organic materials associated with dredging spoils.

The report by Grigg and Kiwala (1970) indicated a reduction in species diversity and numbers of individuals at sewage outfalls along the southern California coastline. Results of the present study indicate a marked reduction in species diversity and total numbers of individuals. Samples collected at stations located throughout a 20 square mile area have been found to be largely devoid of normal benthic fauna. Shelton (1971) was unable to detect a significant effect of ocean disposal of sludge on benthic organisms. He does state, however, that "... the benthos of the outer Thames, as is to be expected of an area where tidal currents are strong, is relatively poor." It may be that where tidal currents are strong sludge is rapidly diluted and winnowed out over a large area. If, in addition to the physical dilution of sludge, the fauna is poor then changes in the fauna would not be conspicuous or easily measured.

In the Clyde Estuary, MacKay, Halcrow and Thornton (1972) reported that sediments are quite uniform; this is reflected by the uniformity of faunal assemblages throughout the area. The only marked departure observed was in the dumping ground which was subjected to high levels of organic pollution. They found a distinct transition from a molluscan/echinoderm assemblage at stations outside the dumping area to a primarily polychaete assemblage inside the disposal area. They did not find any of their sampling stations to be devoid of fauna, though they did find the variation in species composition already mentioned. They also found an increase in standing crop, as biomass, in the organic and rich sediments of the Clyde Estuary dumping ground. They emphasized, however, that the increase in productivity was of questionable value, since none of the infaunal species which comprise the increased biomass were used as food by finfish. They did find that clam-like species such as Abra and Nucula, known to be used as forage by plaice and whiting, "were absent from the centre of the deposit ground." We found a larger area in the Bight decimated by ocean disposal of sewage sludge and dredging spoils. Again, this more extensive damage to the environment may have resulted from: 1) the much larger amounts of waste disposed of in the New York Bight, 2) the generally shallower receiving waters in the Bight, and 3) the possibly unique circulation of water in the Bight. Only one million tons of waste per year are dumped in the Clyde Estuary whereas approximately five million tons of sewage sludge and six million tons of dredging spoils are being disposed of annually in the New York Bight. These larger amounts of waste are dumped in waters averaging 30 meters in depth whereas the receiving sediments in the Clyde Estuary are in waters 100 meters deep. In greater depths of water there is increased opportunity for these highly organic wastes to be incorporated into the food web or be carried away from a centralized area. Thus, far less material is available to impinge upon bottom sediments and marine benthic organisms, but even under these circumstances involving less expected impact on the environment, MacKay, Halcrow and Thornton (1972) report significant change.

A thorough comparison of studies concerned with ocean disposal of solid wastes does indicate certain similarities in all cases. The amount of change and the total effect varies from area to area. It is difficult to determine the rate of change although we do know that the damage observed in the New York Bight has occurred during a period of only four decades. Dumping in the Clyde Estuary has been carried out over the past 60 years. In both instances the volume of sludge has increased several fold in recent decades. The present Thames River Estuary dumping ground (Barrow Deep) has been recently used only since 1967. Prior to that, another area, Black Deep, was used from 1915 to 1967. Barrow Deep was previously used from 1887 until 1915. The amount of sewage sludge being dumped in the Thames River Estuary is similar to the quantity disposed of in the New York Bight; since 1920 no dredging spoils have been disposed of in the sewage sludge disposal areas. In spite of the similar amounts of sludge being dumped in the Thames River Estuary, the effects are somewhat different. Shelton (1971) suggests that this is because of the strong current, regularly over 2 knots, which prevails in the Thames Estuary.

Finally, as noted earlier, Grigg and Kiwala (1970) indicate that between 1954 and 1969 the effects of disposal of sewage from a California outfall pipe extended from an original length of between 3/4 to two miles of coastline to six miles. This was accompanied by "... large scale ecological changes... in this area."

Although it is difficult to determine quantitatively the rate of change in environments receiving solid wastes and sewage, it is even more difficult to predict the rate at which recovery would proceed following pollution abatement. We previously discussed the few studies which are concerned with the changes that occur following abatement of pollution. Based on these few studies we concluded that recovery of impoverished areas is slow and waters which have been heavily polluted cannot be expected to return to their former condition or productivity. This suggests that authorities responsible for disposal of solid wastes should objectively consider all evidence before commencing to despoil new areas or before moving existing inshore disposal activities further offshore. The present study, and others, have provided evidence that ocean disposal of sewage sludges and dredging spoils has had deleterious effects in a number of different marine environments. MacKay, Halcrow and Thornton (1972) present evidence that dumping of sludges in marine waters 100 meters in depth has had demonstrable effects on the quality of benthic communities. Scientists can only guess the possible effects of dumping solid wastes in waters off the continental shelf.

Present disposal practices have: 1) degraded the marine benthic communities of the New York Bight, 2) produced large amounts of floatable materials, and 3) resulted in generally deteriorated waters and marine sediments. We believe, however, that it would be imprudent to shift ocean dumping further offshore unless it is done with considerable caution and supervision. We know little about the fate of highly organic or toxic wastes in deep offshore waters. Jannasch et al. (1971) recently reported on the unexpected fate of organic materials (including fruit, bread and meat) sunk at a depth of 1,500 m for almost three months. They found very little microbial degradation of these materials suggesting the possibility of damage to benthic nonmicrobial fauna if extensive deep-sea dumping were to occur. Until sewage sludges and dredging spoils can be effectively recycled on land, development of experimental disposal areas over the relatively unproductive continental shelf areas 25 to 30 miles from the New Jersey and Long Island shorelines would be far preferable to deep water, off the shelf disposal practices. If industrial wastes and other toxic materials were eliminated from domestic sewage, the sludges could be spread over large areas and perhaps would act to augment biological productivity rather than to deteriorate close inshore water quality. Contaminated dredging spoils constitute a separate problem and their disposal is more difficult. There is little likelihood that these materials can be effectively recycled on land although they might be used for fill and other, as yet undefined, purposes. Based on the study by Saila, Polgar and Rodgers (1968) and the present study there is no doubt that certain categories of dredging spoils do reduce the quality of the marine environment when disposed of in inshore waters. A high priority should be given to developing new modes of disposal of contaminated dredging spoils.

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