NOAA Technical Memorandum NMFS-F/NEC-55

A Plan for Study: Response of the Habitat and Biota of the Inner New York Bight to Abatement of Sewage Sludge Dumping

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Center
Woods Hole, Massachusetts

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A Plan for Study: Response of the Habitat and Biota of the Inner New York Bight to Abatement of Sewage Sludge Dumping

Environmental Processes Division, Northeast Fisheries Center

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I. INTRODUCTION

Sewage sludge, the portion of sewage which is collected by settling in sewage treatment plants, has been dumped by barges at a site 12 nautical miles (22.2 km) from Sandy Hook in the inner New York Bight since 1924 (Fig. 1). Between March 1986 and December 1987, disposal of sludge is scheduled to be phased out (Fig. 2) in decrements from the 12-mile dumpsite to Deepwater Dumpsite (DWD) 106, at an extra cost estimated at 20 million dollars per year (Leschine and Broadus, 1985). The move was prompted by pressure from politicians, environmental groups, fishermen and government agencies who believed that sludge dumping was degrading the inner Bight.

Based largely on National Oceanic and Atmospheric Administration (NOAA) data, the U.S. Environmental Protection Agency (EPA) has testified that

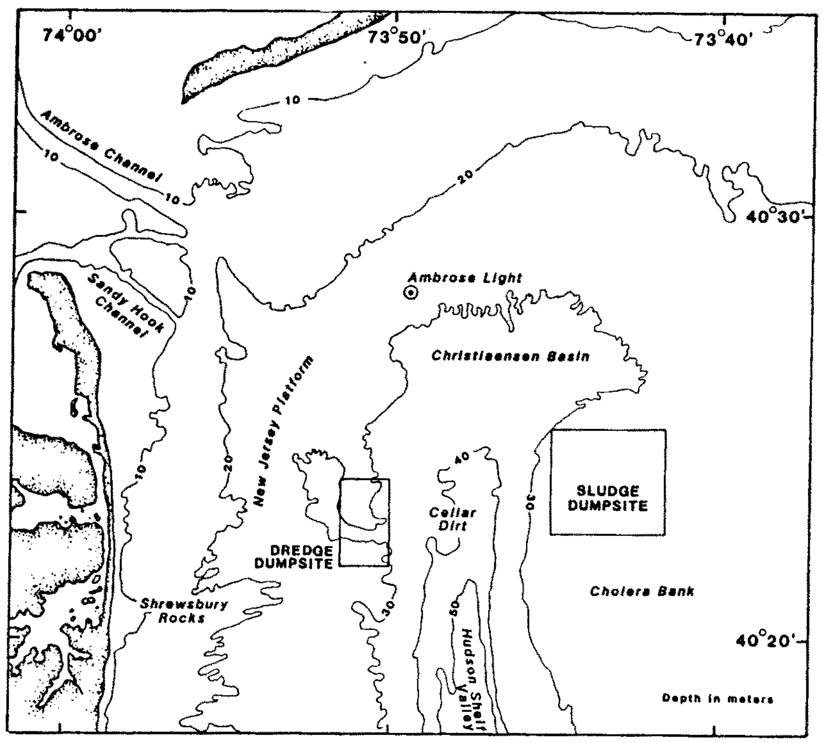

Figure 1. Location of the 12-mile sewage sludge dumpsite and dredge materials dumpsite in the New York Bight.

"Ecological effects attributed wholly or in part to the ocean dumping of municipal sludge include: closure of shellfish beds; introduction of viral, bacterial, fungal and protozoan pathogens into the Apex; elevated levels of heavy metals and toxic organic compounds (e.g. PCBs) in bottom sediments; reduced bottom dissolved oxygen levels; reduced catches of bony fishes; alterations in the benthic community, particularly the proliferation of stress-tolerant polychaete worms; observed sublethal effects in organisms, including reduction of reproductive functions, increased incidences of fin rot and black gill, mutation of fish larvae, and decreased survival of offspring; and introduction of carbon and nutrients, which contribute to planktonic blooms and anaerobiosis."[1]

The inner Bight receives organic and contaminant inputs from several major sources besides sewage sludge; the most significant are from the Hudson-Raritan plume and dredged material which is dumped at the western edge of the Christiaensen Basin (Fig. 1; New York City Department of Environmental Protection, 1983). This has made it difficult if not impossible, despite numerous past studies, to quantify and separate contamination and biological effects due to sludge. The lack of pre-dumping baseline information further hinders understanding of sludge effects. The extensive data holdings of the National Marine Fisheries Service (NMFS) and other groups do, however, provide a background against which anticipated changes in inputs and effects can be measured.

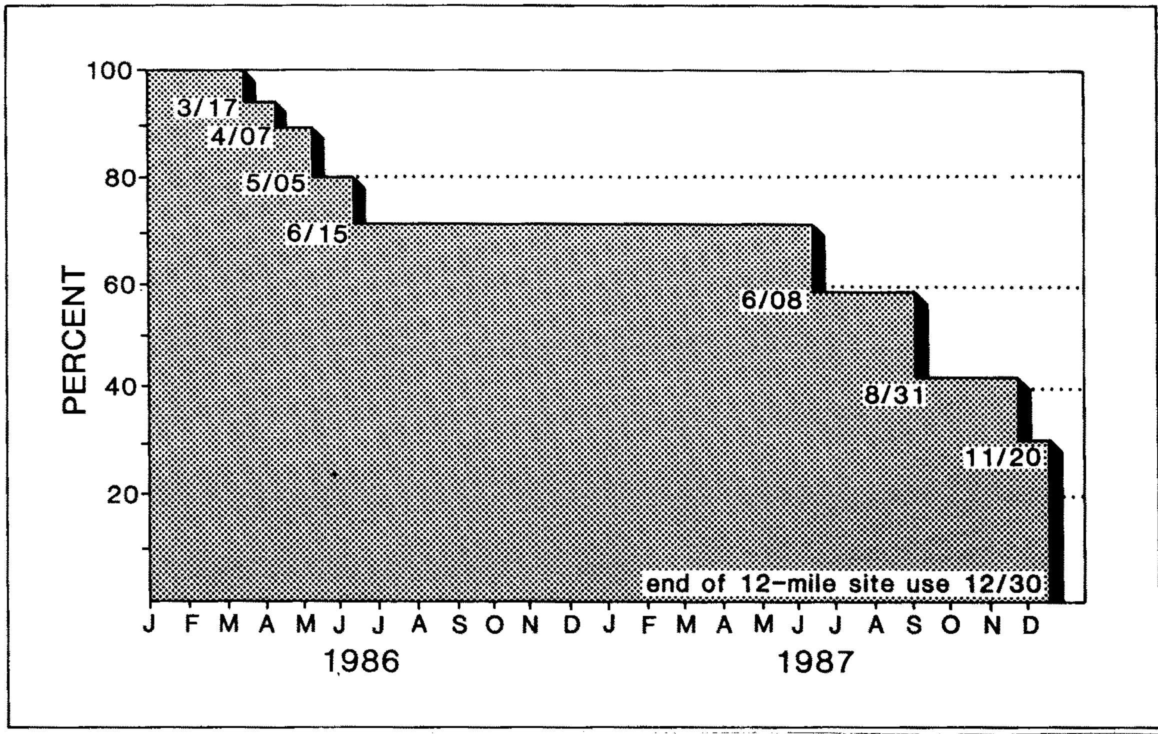

Figure 2. Negotiated phase-out schedules for sewage sludge dumping at the 12-mile site. Modified from Edward Santoro, USEPA Region II, Marine and Wetlands Protection Branch, 26 Federal Plaza, New York, New York 10278 (pers. comm.).

[1]Statement of Dr. Peter Anderson (USEPA) for the Public Hearing on the Tentative Denial to Redesignate the 12-mile Sewage Sludge Dumpsite. Monmouth College, West Long Branch, New Jersey, June 18, 1984.

The abatement of sludge dumping thus offers a rare opportunity - an "experiment" or case study approach which may permit determination of ecosystem response to removal of a major waste input. The NOAA/EPA 1986 Federal Action Plan for Ocean-Dumping Research and Monitoring (National Oceanic and Atmospheric Administration, 1986) ranks case studies of former (and new) dump sites highest among the 39 research activities recommended in the Plan. The only existing information of this nature is from surveys made by NMFS, EPA and the Food and Drug Administration (FDA) before and after the 1980 closure of the Philadelphia sewage sludge dumpsite (Devine and Simpson, 1985). These surveys indicated that approximately 4 years were needed for microbial contamination to return to background levels. However, the Philadelphia site differed from the New York site in that it was more dispersive, with no good evidence of sludge accumulation or benthic community alterations (Lear and O'Malley, 1983).

Given the uncertainty as to whether cessation of dumping at the 12-mile site will eventually result in significant changes in water and sediment chemistry, benthic community structure, utilization by fishery resources, body burdens of organic contaminants, and reopening of shellfish beds for commercial harvesting, the Environmental Processes Division (EPD) of the Northeast Fisheries Center (NEC) of NMFS has begun an interdisciplinary study of effects of abatement of sludge dumping on contaminant concentrations and biological effects in the inner New York Bight. Findings from the 3-year study, during which dumping will be phased out, should permit better management decisions as to whether increased costs of barging sludge to offshore sites will be justified. Presently, the Northeast Regional Office (NER) of NMFS anticipates several future requests for dumping in shelf areas. Furthermore, findings from this study may be extrapolated to other areas (e.g., Boston Harbor) which are presently faced with managing large anthropogenic inputs from sewage and other sources. Documenting the spatial and temporal changes in contaminant fates and effects in this "controlled" type of field experiment can lead to the development of a model of predictive capability for future risk analysis.

II. PURPOSE

The overall purpose of this study is to document changes in living marine resources and their habitats during and following the period in which sewage sludge dumping is phased out at the 12-mile site. Choice of monitoring variables was based on two considerations: (1) relevance to fisheries of the inner Bight, both directly, in terms of abundance, distribution and contamination of resource species and indirectly, as indicated by quality of their habitats, and (2) predictive value in detecting changes with abatement. Biological, chemical, and physical oceanographic approaches have been integrated to provide comprehensive and statistically valid work plans.

III. STUDY DESIGN

A. Background

Sludge has been dumped at the site since 1924 and no historical data exist which characterize the site in a "clean" state. In the past, NOAA's Marine Ecosystem Analysis Project (MESA) (for review see Gross, 1976; Mayer, 1982) and the Northeast Monitoring Program (NEMP) surveys (Reid et al., 1987) have attempted to characterize the effects of sludge dumping on the sediment and benthic infauna. These surveys had certain inherent drawbacks. First, because there had been long-term inputs of sludge, dredged and riverborne materials, it was difficult to separate the effects of sludge from other anthropogenic or natural effects. By post-sample stratification based on sediment contaminants, "clean" sites with characteristic faunal assemblages could be identified for use as controls. However, it is not provable that niches occurring at control stations are identical with those occurring at "contaminated" stations. Second, recent preliminary evidence has indicated that reducing conditions in the sediment, which occur episodically during the summer in the highly organically contaminated area of the Bight, can markedly influence the structure of the benthic community. Since the data necessary to characterize this event were not collected for the historical surveys conducted during the summer, variances in the benthic community cannot be partitioned between annual variation and seasonal redox-related effects. Consequently, the sensitivity and precision of these surveys are decreased. Finally, in these past surveys, a full suite of environmental and biological variables was not measured systematically at appropriate sampling frequencies.

By conducting synoptic surveys and taking advantage of the cessation of dumping, it is possible to understand better the effects of sewage sludge dumping on environmental and biological measures and the interactions and relationships among them.

B. Survey design

Ideally, replicate measurements of a complete suite of variables should be collected at all sample locations so that the areas of polluted and adjacent cleaner sites would be sufficiently characterized over space and time. However, replicated sampling is costly and labor intensive and to this end, the overall survey design is a compromise consisting of two complementary sampling surveys which will be termed "replicate" and "broadscale" surveys.

(1) Replicate survey

This survey is based on the assumption that changes in sediment chemistry which can affect fish and shellfish occur on the order of weeks, and sampling to detect these changes and possible effects must be made frequently, especially in summer when the most stressful combinations of high temperature, low oxygen and sulfide are likely to occur. Therefore, intensive sampling will be conducted at "replicate" stations (Fig. 3) which have been chosen to represent a gradient of sewage sludge concentrations and effects. The data collected will be used for hypothesis testing in which treatment effects (enrichment and contaminant level) are examined (Appendix A).

(2) Broadscale survey

The second portion of the design is a complementary "broadscale" survey. Sampling will consist of a single, non-replicated suite of measurements taken at 25 stations (Fig. 3) covering much of the inner Bight and chosen to include all major habitat types that could be affected by changes in sludge input, as well as reference areas. Data from this portion of the survey will be used to display graphically, via contours, the geographical extent of the fates and effects of sewage sludge contaminants. Additionally, they will be used to examine the relationships and interactions between variables via correlative analyses (e.g., regression, discriminant, principle component, and canonical correlations) since the full range of gradients in the study area will be sampled. Finally, the data can also be used for post-stratification hypothesis testing.

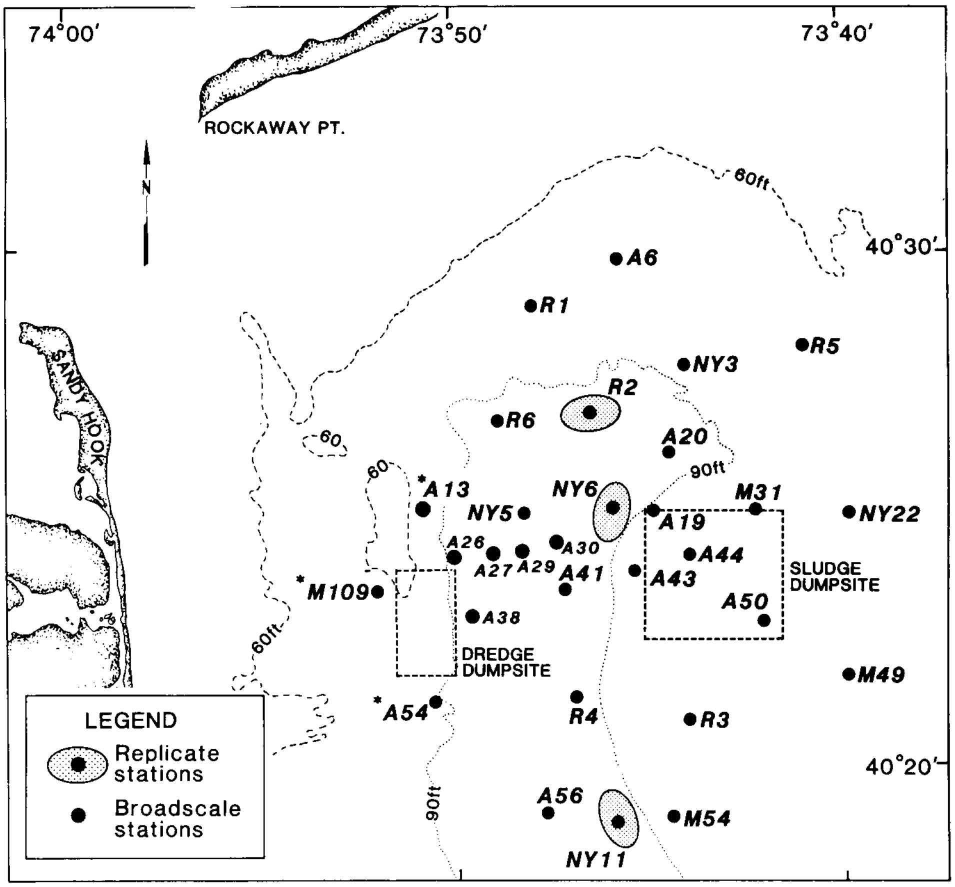

Figure 3. Locations of stations sampled on the replicate and broadscale surveys during the 12-mile dumpsite recovery study.

C. Site selection

(1) Replicate survey

Three stations (Fig. 3) were selected for intensive sampling because they are similar with respect to depth and sediment type, are presumably not affected by dredge spoil dumping, and are thought to be sharply differentiated with respect to sewage sludge presence and effects. In addition, data from past benthic surveys are available for these stations (Appendix B).

(a) Station NY6. This is located at a depth of ~31 m, near the eastern margin of the Christiaensen Basin and about 1.6 km "downslope" from the point at which most sludge dumping occurs, at the northwest corner of the designated dump site. This station is apparently the most polluted and is characterized by the greatest accumulation of sludge and associated contaminants, as well as the most altered benthic macrofauna, indicated by the dominance of the polychaete *Capitella*, a classic indicator of organic enrichment and other disturbances. This station also is located near the center of the major sulfide-generating area in the Basin. Although information is not available for certain years, baseline data for this station are available for sediments, sediment contaminants, seabed oxygen consumption and benthic macrofauna from 1973 to the present. Some of the benthic sampling dates back to 1969. Sediment and near-bottom water sampling has been conducted monthly since 1983, while fish, fish guts, and benthic macrofauna have been sampled monthly since 1984.

(b) Station R2. This station is located at a depth of ~28.5 m, near the north edge of the Basin, 3.4 km NNW of the center of dumping. This area is characterized by an "enriched" benthic community with high biomasses of several tolerant, though not necessarily pollution-indicator, species. Bottom water is occasionally sulfidic. Water and sediment chemistry, including sediment metals, have been sampled monthly since May 1983, while benthic macrofauna have been sampled approximately monthly since April 1984.

(c) Station NY11. This station is located at a depth of ~29 m, on the eastern shoulder of the upper Hudson Shelf Valley, 9.9 km S of most dumping. This area probably is subjected to little or no sludge influence, based on low concentrations of sediment contaminants. Sulfide presence in bottom waters is improbable. The benthic community is typical of upper Shelf Valley sediments. Contaminants, seabed oxygen consumption and benthos were sampled in 1973-75, and all but seabed oxygen consumption have been sampled annually since 1980.

At each of these three stations a suite of observations is replicated eight times. Three complete sets of measurements are made at a central point and the remaining five replicates are taken within an ellipse about each point with the major axis of each ellipse oriented to cover the same depth stratum represented by the point. The purposes of the ellipses are to 1) spread sampling to reduce the likelihood that the sampling is influencing the variables of interest; 2) permit extrapolation of results to slightly larger areas; and 3) assess small-scale variability in the vicinity of each replicate station.

(2) Broadscale survey

Station locations for the broadscale survey were determined subjectively according to the following criteria:

1. Standardize effort with the replicate survey, i.e., collect approximately 24 samples per cycle.

2. Provide fairly regular coverage of the study area (area of apparent impact plus immediate environs) to facilitate contouring.

3. Provide as complete as possible coverage of the niche gradients in the study area to legitimize correlative analyses.

4. Correspond with historical station locations when possible.

D. <u>Sampling schedule</u>

The plan is to conduct the replicate and broadscale surveys in alternate months, year-round. However, it is believed that replicate sampling should be monthly during the periods (July-September) when hypoxia and sulfide accummulation are most likely. Therefore, both replicate and broadscale surveys will be conducted each August. Sampling of the full suite of measurements began with a replicate survey in July 1986 and will continue through the summer of 1989 which will be 21 months after the end of sludge dumping (Table 1).

Table 1. Survey schedule of the 12-mile dumpsite.

	86						87-88												89								
	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Replicate	x	x	x		x		x		x		x		x	x	x		x		x		x		x		x	x	x
Broadscale		x		x		x		x		x		x		x		x		x		x		x		x		x	
Seabed metabolism		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Hydrographic surveys (with EPA)											x												x				
Seabed and water column rates, hydrographic surveys with EPA, NJ DEP, and others														x												x	

If sludge and effects are still evident after 1989, we anticipate continued sampling of selected variables at reduced frequencies where sampling is adjusted on the basis of rate of change of the variables.

The sequence of sampling in the broadscale surveys is straightforward. A single trawl, bottom water sample and grab sample for sediment chemistry and biology are taken at each station. Factors determining the trawl track include the presence of fair ground and the need to maintain homogeneity of bottom type. The order in which stations are sampled depends on weather, vessel "piggybacking" needs and timing in relation to the replicate surveys.

Five stations (A26, A27, A29, A30, A38) between the dredge and sludge dump sites (Fig. 3) will be sampled less frequently to monitor changes in contaminant concentrations due to anticipated increased disposal of dredge material.

Scheduling within a replicate survey is more complex. If all eight replicates were to be completed at one station before occupying another, enough time could elapse to introduce substantial bias into the results. There are also daily biases (e.g., location, feeding) related to photoperiod. A "balanced" sampling design was therefore devised which controls these potential biases by partially alternating the station sampling order (Appendix A).

E. Variables

A range of variables has been selected relevant to fishery resources and their habitats and/or as accepted indicators for detecting environmental changes (Table 2).

Table 2. Variables measured during the 12-mile dumpsite study.

Habitat		
Water	**Sediments**	**Biota**
° Bottom water Dissolved oxygen (R,B) Temperature (R,B) Salinity (R,B) pH (R,B) Sulfide (R,B) Nutrients (R,B) Turbidity (R,B)	° Chemistry Heavy metals (R,B) Organic contaminants (R,B) Sulfide, pH profiles (R) Redox potential (R,B) Sediment BOD (R) Chlorophyll pigments (R) Total organic carbon (R,B)	• Resource species Distribution/abundance (R,B) Diet (R) winter flounder red hake silver hake lobster Gross pathology (R,B) Tissue organics (R) winter flounder lobster Migration (tagging) (B) winter flounder
° Water column Temperature Salinity (CTD) Oxygen Current measurements (moored meters)	° Characteristics Grain size (R,B) Erodibility ° Rates Seabed oxygen consumption Sedimentation	° Benthos Macrofauna abundance/ diversity (R,B) Meiofauna abundance/ diversity (R,B)
		° Bacteria - sediments Fecal and total coliform (R) C. *perfringens* (R) *Vibrio* spp. (R) Total count (R)
R = Replicate Survey B = Broadscale Survey		° Bacteria - shellfish

This section summarizes sampling methods and the biological, chemical and physical measurements taken during replicate (R) and broadscale (B) surveys. Details for each set of variables to be measured are provided in Appendix C.

(1) Distribution and abundance of fish and megainvertebrates (R, B)

Collections are made by 15-min bottom trawls. All specimens of fish and invertebrates are separated and identified to species and total weight recorded by species. All specimens of each species are counted and individually measured (subsamples used in exceptionally large catches). In addition, interviews are being conducted with lobstermen to assess effects of sludge disposal on catches, conditions of pots and lobsters, and changes with abatement.

Rationale: Determination of changes in abundance, distribution, and species size composition may indicate how utilization of these habitats has been affected by sludge.

(2) Diets of winter flounder, red hake, silver hake, and lobster (R)

Volumetric determinations are made of gut fullness and prey identified to lowest taxon possible.

Rationale: Food habits of demersal species utilizing this area may change with sludge abatement, may correlate with changes in benthic communities and can be used to estimate changes in resource productivity.

(3) Organic contaminants in selected species (R-modified sampling)

Liver, gonad, muscle and gut contents will be sampled from winter flounder at Station NY6, the most severely polluted site, R2, an "enriched" site that may be sludge-influenced, and NY11, the cleanest area, twice yearly. Lobster muscle and hepatopancreas will also be sampled. The suite of measurements will include selected PAHs, PCBs and chlorinated pesticides. Collaborative support for tissue analyses will be provided by New Jersey Department of Environmental Protection (NJ DEP) Office of Science and Research.

Rationale: Selection of flounder and lobster muscle and lobster hepatopancreas will address possible human health risk problems. Flounder liver and lobster hepatopancreas are contaminant-accumulating organs which should provide a signal of uptake due to sludge. Comparisons of levels in flounder gonadal tissue with samples taken from other polluted sites may provide data relating contaminant effects to reproductive success. Gut contents will be used to determine relationships between contaminant loads in sediments/benthos and tissues and will serve as the best indicator of recent contaminant exposure.

(4) Migration of winter flounder (B)

Winter flounder captured in the trawls during the broadscale surveys will be tagged onboard ship and released at the point of capture.

Rationale: Little is known about the inshore movements of winter flounder utilizing the dump site. Tag returns will indicate possible migration patterns and population composition.

(5) Gross pathology (R, B)

Using established indicators of gross pathology, fish will be visually examined for lesions, fin rot and other visible evidence of pathological state.

Rationale: Data can be used to examine possible links between somatic condition of resource species utilizing the dumpsite and contamination levels in their habitats.

(6) Benthic macrofauna (R, B - modified)

Samples of benthic organisms will be collected with a Smith-McIntyre grab at each site, identified to species and counted. Samples from the broadscale surveys will be a secondary priority and will be processed after replicate samples are completed. Meiofauna (intermediate in size between microbes and >0.5 mm macrofauna) will also be monitored.

Rationale: Changes in benthic communities are accepted indicators of biological effects of sludge over space and time. These data will also be used for comparison with fish and lobster diets, to help explain any changes in diet, and for correlations with sediment chemistry.

(7) Bacteria in sediments and tissues (R and other sites)

Samples of surf clams will be collected from the dumpsite and reference areas on NEC's clam dredge surveys (6/86; 6/88). These will be provided to FDA for analysis of pathogens. FDA/EPD will also collect water and sediment samples for analysis of Clostridium and coliforms (see Section IV). In addition to signaling potential contamination of shellfish and habitats, coliform bacteria and Clostridium perfringens spores are sampled as indicators of sludge fates and concentrations. Other anaerobic bacteria are enumerated to help interpret changes in sediment chemistry. Direct bacterial counts, using epifluorescent microscopy, will also be made.

Rationale: The closure of shellfish beds within a 6 nautical mile radius of the dumpsite and inshore from that circle (a total areal closure of approximately 800 sq. km) resulted from the microbial contamination of this resource. Monitoring at the Philadelphia site did document a post-dumping decline and four years after dumping ceased it was recommended that the area be reopened for clam harvesting.

(8) Water chemistry (R, B)

Variables to be measured include temperature and salinity, dissolved oxygen, sulfide and nutrients, pH, and turbidity. Samples will be taken at 0.1 and 1.0 m above the sediment at stations R2, NY5, NY6, and NY11 and also at 3 and 10 m above the seabed at station NY6. At outlying stations water samples will be taken only at 1 m above bottom and there will be no determinations of nutrients.

Rationale: Temperature and salinity are important determinants of fish-shellfish distributions and indicators of water mass movements. Temperature also has an important influence on dissolved oxygen concentrations (a critical variable for biota). Sulfide and ammonium-nitrogen, which are toxic to some marine organisms, are generated in sediments as the natural products of anaerobic degradation of organic material such as that in sewage sludge, and then diffuse into the overlying waters. Measurements of pH are needed to determine extents of ionization in other chemical variables, while turbidity at certain levels can restrict fish and clam distribution and hinder feeding. Sewage sludge is a significant source of turbidity.

(9) Sediment chemistry (R, B - modified)

On replicate surveys, variables measured include profiles of redox potential, pH, interstitial and acid-volatilizable sulfide, interstitial water nutrients, methane, total organic carbon, trace metals and grain size. Sediment surface samples are analyzed for BOD (13-day incubation), plant pigments and selected organic compounds (e.g. coprostanol, PAHs, chlorinated hydrocarbons, methane). On broadscale surveys profiles of redox potential, total organic carbon, trace metals and grain size will be measured along with surface values for organic compounds and acid-volatilizable sulfide.

Rationale: Changes in sediment chemistry are expected to be closely linked to changes in the rate of sewage sludge inputs. Profiles of the sediment redox potential in the upper 5 cm of sediment can be qualitatively interpreted to fill in between quantitative chemical analyses. Levels of organic compounds will be assessed to detect spatial patterns related to sewage sludge dumping and changes in these patterns as the sludge contribution is phased out. These data also can be correlated with concentrations found in resource species. Trace metal concentrations are an indicator of sewage sludge contamination over space and time, and can be compared with extensive historical data collected in this area. Grain size will be related to sediment contaminants and together grain size and chemical variables will aid in explaining the distribution and abundance of biota.

(10) Seabed and bottom water metabolism (Selected sites, Appendix Fig. C1)

Samples of sediment and overlying water are collected with a Pamatmat multiple corer and incubated at in situ temperatures aboard ship to determine rates of oxygen consumption and nutrient regeneration. Total plankton respiration (TPR) rates are also obtained by incubating water from 0.1 and 0.5 m off bottom at each of the six stations occupied. Dissolved oxygen, temperature, salinity, sediment organic carbon, total plankton respiration, and ambient bottom light levels are measured. Following incubation and rate measurements, cores are sieved for benthic infauna. Stations in and near the 12-mile sludge dumpsite have been sampled aperiodically between 1973 and March 1985. In 1973, 1974, 1982 and 1983 seabed oxygen consumption rates were obtained from sufficient stations in the New York Bight Apex to permit contouring of the variables (Fig. C1). These stations will be reoccupied in August 1987. Monthly sampling at six stations began in March, 1985 across the Christiaensen Basin and the 12-mile site. Four of these stations overlap with broadscale stations and one overlaps with replicate station NY6.

Rationale: Seabed oxygen consumption is a measure of benthic community metabolism which can indicate the oxidation of organic matter and integrate the effects of pollution on benthic communities. Changes in seabed oxygen consumption have been shown to be correlated significantly with changes in volumes of sewage sludge dumped. Seabed oxygen consumption and nutrient regeneration rates will be used to determine spatial and temporal changes in benthic community metabolism related to input of sewage sludge and other organic materials. Recent measurements will be compared with extensive historical information for the same sites.

(11) Pathways and rates of sludge and contaminant dispersion (Selected sites, Appendix Fig. C2)

A series of seven current meter moorings will be established and replaced on a phased six-month schedule for three years. Periodic hydrographic surveys will be conducted in the vicinity.

Rationale: Data will be analyzed to detect and define influx and efflux events in and around the Christiaensen Basin. They will also be used to modify a probabilistic dispersion model (EPA/Environmental Research Laboratory [ERL]) to portray and predict the distribution of sludge components. In addition to the above there may be "opportunistic" sampling, e.g. to determine effects of windfield changes.

IV. COLLABORATIVE STUDIES

Several other projects sponsored by government agencies and universities are ongoing or planned in the inner Bight. Coordination with these studies is highly desirable to avoid duplication of effort and to add to the overall information on the effects of the abatement of sludge dumping. Present areas of collaboration which have been established include:

1. EPA/ERL, Narragansett, RI is measuring sediment erodibility at a limited number of our stations. This information, combined with our current meter and other data, will help to predict and understand rates of dispersal of sludge constituents and effects. In addition, a cooperative effort to modify and apply the EPA/ERL probabilistic dispersion model for the dumpsite area will be undertaken.

2. New Jersey DEP, Office of Science and Research will provide support for organic analysis of selected fish/lobster tissues.

3. EPA/Edison will be measuring *Clostridium perfringens* spores in sediment samples collected at broadscale and replicate stations during most of our planned surveys.

4. FDA is analyzing (a) one composite of three samples from each sampling at each replicate station for *Clostridium*, *Vibrio*, *E. coli*, total and fecal coliforms; and (b) surf clams, ocean quahogs, sediments and bottom waters from inside and outside the current shellfish closure area for *Clostridium* and coliform bacteria.

V. DATA ANALYSIS

Data from all studies will be put in compatible formats and entered into the "1032" data base management system at Sandy Hook Laboratory. All data will be stored and processed in NEC's VAX computer at the Woods Hole

Oceanographic Institution. Data base design will be as transparent as possible to make the data accessible to other users on a near real-time basis (Appendix A). Relational data base formats for many of the variables measured already exist and have been used in previous monitoring studies.

A. Broadscale survey

At the coarsest level the broadscale grid will provide a data base for developing an atlas of computer generated contour plots. Gross changes in the geographical range of effects may be graphically evident. At a more sophisticated level the data can be used in correlative statistics. Each cell sample can be considered as a replicate of "paired" measurements. Consequently, individual measurements will not be replicated at a station. At 25 samples, six times a year, for three years, 450 data points will be generated. This should be an adequate sample size to indicate existing relationships between even the most highly variable measures.

B. Replicate survey

Data will be processed in the same manner as for the broadscale survey. The 504 replicate samples can be combined with the broadscale survey samples, yielding a total of 954 data points for correlative analyses. However, the focus of the replicate survey is to answer questions about the effects of treatments (particularly differences in contaminant levels) on sample means.

VI. ANTICIPATED CHANGES AT THE 12-MILE SITE FOLLOWING CESSATION OF DUMPING

The following are working hypotheses by which recovery will be assessed after dumping has been phased out:

1. Abundance, distribution and structure of finfish and megabenthic invertebrate communities will differ significantly among the three replicate sites prior to cessation of dumping.

2. Following cessation of dumping and demonstrated shifts in sediment contaminants and benthic forage species, abundance and distribution of finfish and megabenthic invertebrates at the most polluted sites will be similar to the relatively cleaner reference stations.

3. The diet of winter flounder, lobster and other species will change following shifts in the availability of benthic prey at the replicate sites during the period in which dumping is phased out.

4. Winter flounder which utilize the areas affected by dumping comprise a significant portion of the population of Raritan Bay.

5. The number of crustacean forage organisms in the "enriched" and "highly altered" zones will increase significantly (defined here and below as a change of >50% of the 95% confidence level).

6. The numbers of benthic species in the "enriched" and "highly altered" zones will increase significantly.

7. The areal coverage and mean density of *Capitella* in the "highly altered" zone will be reduced significantly.

8. Levels of bacteria indicative of recent sewage contamination in surf clams will decrease to acceptable levels which will permit shellfish beds to be reopened.

9. Levels of organic contaminants in gut contents of winter flounder and lobster will decrease following cessation of dumping, but body burden levels will not shift since species are seasonal migrants.

10. Black gill disease, fin erosion, ulceration, incidence of parasitism, tumors and skeletal anomalies will significantly decrease in finfish and megabenthic invertebrates.

11. The intensity of perennial hypoxia (now to 0.46 mg O_2/L) will be relieved -- minimum values 4 mg/L at 1 m above bottom, and 2 mg/L at 0.1 m -- throughout the Basin but not in isolated localities of dredge spoils.

12. The sulfide in near bottom water (averaging 4 uM) will be at concentrations above 0.1 uM only near the dredge spoils and may be undetectable throughout the rest of the Basin.

13. The seasonal cycling of redox potential will continue, but the lowest values in surface sediments (at 0.5 cm) will be ~100 mV higher than current values in the sewage sludge deposition area.

14. Trace metal concentrations in the sediment will decrease by about an order of magnitude in the depositional areas (except in dredge spoils).

15. Coprostanol in the sediment will fall to below 0.1 ppm except in very isolated localities of the dredge spoils.

16. Levels of PCBs in sediment will remain essentially unchanged.

17. With the cessation of sewage sludge dumping the seabed oxygen consumption rates in the dumpsite will be reduced from the high rates of 25 - 45 ml O_2/m^2/hr to the more natural rates of 5 - 15 ml O_2/m^2/hr. The associated benthic nutrient regeneration rates will decline comparably.

18. Seabed oxygen consumption rates in the Christiaensen Basin, may be reduced by approximately half, to around 12 - 22 ml O_2/m^2/hr, which is natural for accumulation areas if other anthropogenic inputs (i.e., dredge materials) remain constant.

19. If other sources of anthropogenic carbon, i.e., dredge spoils, remain stable or decrease, the seabed oxygen consumption rates in the whole New York Bight Apex should decrease as sludge dumping is phased out. It should then follow that dissolved oxygen concentrations in the subpycnocline waters of the Apex will be higher than while dumping is active.

20. Total plankton respiration in the bottom waters affected by inputs of sewage sludge should also decrease from the summer-fall rates of 30 - 40 ml $O_2/m^3/hr$ to the more natural rates of approximately 5 ml $O_2/m^3/hr$.

21. The cleansing of sewage sludge from the Christiaensen Basin will be accomplished by episodic down-valley transport of sludge which can be related to windfield conditions.

VII. MANAGEMENT AND COORDINATION

The Environmental Processes Division, NEC, under the direction of the Division Chief, will have lead responsibility for the study; chiefs of the three Branches of EPD are the next level of authority and will assume responsibility for development of the study design, monitoring progress and serving as contact points for information requests; Investigation chiefs and other principal investigators and collaborators will be directly responsible for studies within their disciplines. A survey coordinator will be designated to assume responsibility for integrating day-to-day functions of the study.

VIII. PRODUCTS AND USERS

Products will include a) quarterly reports on status, findings and problems of the overall survey and its component parts; b) detailed annual reports for each project and the overall study; c) a final report which will interpret and synthesize results of each project, addressing the stated questions and hypotheses, to document responses of resource species and habitats to sludge abatement; d) a computerized data base available for further analysis and comparisons, and e) manuscripts on study findings.

Anticipated users of the products include a) NEC/NMFS and other scientists studying fates and effects of marine waste inputs; b) NER/NMFS personnel and Fishery Management Councils, to make better informed recommendations on future use of the oceans for waste disposal; c) USEPA, to increase understanding of fates and effects of ocean-dumped sludge, and thus enhance modeling and management abilities; d) USFDA, to determine whether to reopen shellfish beds; e) state environmental departments, especially in New Jersey and New York, to help assess status of marine resources, effects of past disposal practices and strategies for future disposal; and f) political leaders, environmental groups, the media and the general public, to increase comprehension of waste disposal issues.

IX. APPENDICES

A. Statistical design

(1) Replicate survey

In a classical experimental design, treatment (factor) levels are randomly allocated to experimental units. The resultant model is quite clear when the experimental units are pigs, people or cornfields and the treatments are feed, drugs or fertilizers. However, when the experiment is an impact survey and the experimental units are micro- or mini-environments, the paradigm becomes problematic. The problem stems from a lack of control over treatments (pollution factors) and differentiation of scale.

To illustrate this, consider a simple tray experiment in which the tray is divided into 2N compartments. A pollutant is randomly (or pseudo-randomly) added to N of the compartments. Sometime later, the numbers of individuals of a particular species in each compartment are counted. The manner in which the counts are made determines how the experiment can be interpreted and analyzed. Each compartment is an experimental unit and as such is considered to be a replicate. If all of the animals in a compartment are counted, then hypotheses can be tested concerning the effect of the pollutant on the population at a scale the size of each compartment. The precision of the experiment is maximized (at that scale for N replicates). If from each compartment a core is removed for counting, hypotheses can be tested concerning the effect of the pollutant on the population at a scale the size of the core (not compartment). The precision of the experiment is not maximized since the distribution within a compartment may not be homogeneous and thus the variance of the population of cores is introduced. If M cores are taken from each compartment these samples are not considered replicates but instead are referred to as subsamples. This is because the "treatment" of coring is not replicated at the same level for each experimental unit, that is, Core 1 in compartment I has no relationship with Core 1 in compartment J. The resultant model is called nested (or hierarchical). Subsampling provides a way of accounting for the variance of the population of cores, thus increasing the precision of testing hypotheses concerning the effect of the pollutant on the population at a scale the size of the core. It is then up to the experimenter to defend extrapolation of the findings to larger scales.

Consider now the 12-MDS study. The primary hypothesis to be tested can be stated generally as: the introduction of sewage sludge affects the population of variable K (biological, chemical, or physical). We cannot control allocation of the treatment to experimental units. We can define the levels of treatment as polluted, enhanced, or unaffected and then select sites (stations NY6, R2, and NY11 respectively) representing these treatments. Because of the dispersive nature of the factor (sewage sludge) and the scalar dichotomy between it and the experimental units (micro- or mini-environments sampled in cores, grabs or tows) the treatment levels cannot be allocated to the experimental units randomly. The experimental units are perforce spatially clustered. Thus, the sites themselves are replicates and repeated samples must be considered subsamples. Hurlbert (1984) refers to this as pseudoreplication.

Although hypotheses regarding differences between sites can be tested, inferences on the effects of sewage sludge cannot be made since there is no replication over treatments. In practical terms, there is no way to differentiate between the effect of sludge and effects due to inherent environmental differences between the sites. One way to solve this problem is to replicate spatially the sites. A moment's cogitation will reveal the implausibility of this. The scale of the sludge gradient is so large as compared to the scale of the experimental units that spatial replicates cannot be randomized: they must always be clustered. A method to make treatment inferences does exist. It involves making repeated measurements over time. A detailed description of this process can be found in Stewart-Oaten and Murdoch (1986).

Let a new variable be defined as the difference between the values of a variable measured simultaneously at two sites. Allowing for the constraints of the survey, simultaneity implies within two weeks. This variable is transformed appropriately in order to ensure reasonable normality, homoscedasity and additivity. Let this new variable be repeatedly measured before and after the cessation of dumping. Then a T or U (if normality is a problem) test contrasting the before and after data will allow inferences on the effects of sewage input.

For example, suppose we measure the difference in numbers of Capitella capitata, a polychaete indicative of pollution, at stations NY6 (contaminated) and NY11 (uncontaminated) N times before and after the cessation of dumping (ignoring response time lags). We then have a treatment (addition of sludge) sampled N times at two levels (sludge, no sludge). Are these N samples replicates? Yes and no. As long as no large long-term perturbations occur locally, that is, at one site and not the other, differences between the "before" and "after" data can be ascribed to the cessation of dumping. By measuring covariates, possibly confounding perturbations can be accounted for. Thus we can say with reasonable confidence that these repeated measures can be treated as replicates.

Recalling the tray experiment, our experimental units are much smaller than the site and thus are subsamples. By repeatedly subsampling we can control for some of the heterogeneity within the sites. Within site variance is reduced by a factor equal to the inverse of the square root of the number of subsamples, e.g., 0.35 for eight subsamples.

In order to optimize multivariate sampling, one must select the variables that control the optimization procedure (e.g., those most likely to show change, those most ecologically significant, or those most expensive to analyze), obtain reliable estimates of variance for the selected variables, and predefine "significant" magnitudes of change. With regard to the recovery study, enumeration of each of these elements is either impossible, impractical, or at the least debatable. Because of resource limitations and an unlikelihood of oversampling, it is more reasonable to specify a logistically and economically feasible level of sampling. Recovery is then defined as change detectable by the survey.

By necessity, sampling will be done on day trips. Thus, vessel considerations drive the sample design. Round trip transit time is on the order of four hours. In order to describe the ecosystem as fully as possible and to allow correlative studies the full suite of measurements should be taken concurrently, when possible. It was found that a complete sample cycle consumed about an eight hour day. Considering non-survey vessel usage and weather/maintenance, an allocation of three sample days per week for two consecutive weeks per month was deemed optimal. Thus, twelve complete samples per week for two weeks, or 24 altogether, can be reasonably collected per month. Three sites were selected for the replicate study. These sites represent bathymetrically similar niches assumed to show a gradient of sludge effects; maximum, intermediate, and minimum. Thus, eight samples can be taken at each site per sampling cycle (bimonthly). In order to reduce bias due to daily and weekly variability the samples are allocated to the three sites (Table A1).

Table A1. Replicate schedule (blocked).

Sampling day	Photoperiod AM	Photoperiod PM
1	NY11 2 R-TOW 3 MAXI 1 ABO	NY6 1 R-TOW 1 D-TOW 1 MINI 2 BT 1 BT
2	NY6 2 R-TOWS 3 MAXI 2 ABO, 1 BT 3 M, 10 M	R2 1 R-TOW 1 D-TOW 1 MINI 2 BT
3	R2 2 R-TOWS 3 MAXI 1 ABO 1 BT	NY11 1 R-TOW 1 D-TOW 1 MINI 1 MINI 2 BT
4	NY11 2 D-TOWS 2 MINI 2 BT	R2 2 D-TOWS 2 MINI 2 BT
5	NY6 2 D-TOWS 2 MINI 2 BT	NY11 2 D-TOWS 2 MINI 2 BT
6	R2 2 D-TOWS 2 MINI 2 BT	NY6 2 D-TOWS 2 MINI 2 BT

ABO = Above bottom oxygen sampler
BT = Bottom trip (1M) water sample
D-TOW = Tow distal from site center
MAXI = Full chemistry workup
MINI = Partial chemistry workup
R-TOW = Tow radially through site center
R-TOWS = Water, grab, tow
D-TOWS = Tow, water grab

An Analysis of Variance design can be used for each of the three possible pairwise comparisons. These analyses will not be independent. Given two differences, the third one is then determined. Nesting of subsamples is not possible since the test variable is the difference between measures at two sites. Thus the subsamples will be averaged and this value used to get a difference, which may then be transformed. Since the course of each sampling takes two weeks it was originally proposed to block the ANOVA by week. However, sufficient slippage due to delays occurs to preclude this. A model for the survey is then:

$$X_{ijkt} = u_i + A_j + B_k + AB_{jk} + e_{ijkt}$$

where

X_{ijkt} = the observed value for the t'th replicate for site pair i at sewage sludge level j and for photoperiod k,

u_i = the overall mean value for site pair i over sewage sludge level and photoperiod,

A_j = main effect of sludge level j (fixed),

B_k = main effect of photoperiod k (fixed),

AB_{jk} = interaction effect (fixed),

e_{ijkt} = random error in the t'th replicate for site pair i at sewage sludge level j and for photoperiod k,

i = 1,2,3 (site pair index, e.g., NY6/R2, NY6/NY11, NY11/R2),

j = 1,2 (sewage sludge level index, i.e., before and after cessation),

k = 1,2 (photoperiod index, i.e., AM, PM),

t = 1,2...,N (replicate index, i.e., samples over time).

For most environmental and benthos measurements the photoperiod main effect and interactions can be excluded. In this case, the analysis is equivalent to a Student's T. This can be done similarly with the data from the broadscale survey; however, the lack of subsampling will reduce precision. Of course, more complex factorial designs can be used if hypotheses about effects due solely to differences between sites are investigated.

There are obvious problems with response lag times. Stewart-Oaten and Murdoch (1986) suggest plotting the differences against time on the abscissa in order to determine if a trend unrelated to the treatment is occurring. If such a trend is occurring, the measure should not be used in assessing change due to dumping. A trend may occur in the survey because the dumping is to be phased out gradually. However, this kind of trend can be factored out by normalizing the data to the rate of dumping. If a variable has a lag time in its responses, plotting the data may show this. Then, rather than using the dumping cessation date as the treatment cut point, the indicated lag point can be used instead.

(2) Broadscale survey

Since the purpose of the broadscale survey is to provide data for correlative analyses and graphical display over the "area of impact", the primary design consideration is the allocation of sample sites (stations) so as to provide as complete coverage of the area, both spatially and with respect to factor gradients, as possible. No overwhelming justification could be made to randomize the site selection process. The stations were subjectively selected so as to provide somewhat uniform areal coverage and to include major gradient features (Appendix B). Two of the original 25 stations (near the dredge spoil site) have been dropped from the survey because of the impracticality of trawling and/or grabbing in these areas. The present number of stations (23) fits the vessel allocation constraints. When good weather occurs, exploratory sampling may add one or two more workable stations.

B. Site locations

The following are relevant considerations in selecting station locations:

1. Known patterns of environmental variables that could affect benthic fauna and fish distributions (temperature, salinity, dissolved oxygen, hydrogen sulfide, ammonium, pH, turbidity, sediment type, sediment redox potential, sediment carbon [TOC and BOD]).

2. Bathymetry.

3. Distributions of contaminants, the concentrations of which we predict will change after the cessation of dumping (coprostanol, trace metals and organics, anaerobic bacteria).

4. Known dumping and dispersion patterns of sewage sludge.

5. Stations for which historical data exist from before cessation of dumping began in March 1986 (benthic fauna, trace metals, other sediment chemistry, fish, stomach contents).

(1) Replicate stations

These three stations were taken as given starting points about which a station array was constructed.

(a) NY6 ($40^{o}24.98'$; $73^{o}45.58'$). Dissolved oxygen, trace metals and benthic faunal samples have been collected for many years. Intensive sediment and near-bottom water chemistry has been done monthly for over three years, and fish and stomach sampling for 2 years (only 1/2 year of data exists since the fire). Benthic faunal samples have been collected monthly in triplicate (a few have been sorted) but only samples from 1984 and since October 1985 still exist.

(b) NY11 ($40^{o}18.92'$; $73^{o}45.58'$). Benthic fauna and trace metals have been sampled for many years at this site.

(c) R2 ($40^{o}26.77'$; $73^{o}46.21'$). Trace metals samples were collected monthly for one year prior to cessation. Benthic fauna and full suite of sediment and water chemistry measurements collected since October 1985 still exist.

(2) Other existing stations

All these stations have been sampled prior to cessation, some for many years.

(a) A19 ($40^{o}24.94'$; $73^{o}44.50'$). This station is in the area where the bulk of sewage sludge dumping takes place, because it is the closest part of the designated dumping area to the NY harbor entrance from which most of the sludge is transported. Because this station receives the highest average input of sewage sludge and is located in a high energy area, measurements here should have the highest variability of any station in the array.

(b) A50 ($40^{o}22.83'$; $73^{o}41.64'$), M31 ($40^{o}24.89'$; $73^{o}41.76'$). With A19, these stations define three of the boundaries of the designated dumping area. They are all slightly removed (<0.7 km) from the exact vertices to coincide with locations with pre-cessation historical data. A dumpsite recovery study should define what happens in the designated dump site.

(c) A43 ($40^{o}23.63'$; $73^{o}45.41'$), A44 ($40^{o}23.89'$; $73^{o}43.87'$), A20 ($40^{o}26.05'$; $73^{o}43.92'$). These existing stations that provide SW, SE, and NE locations approximately along the major and minor axes of the rotary tidal oscillation at a distance of 2 km from the focus of dumping. These stations along with NY6 and A19, should have the largest changes in contaminant concentrations and the greatest recovery in the biota.

(d) NY5 ($40^{o}24.89'$; $73^{o}47.63'$). In the deepest part of Christiaensen Basin adjacent to the dumping area, the water chemistry of this station has been monitored for over three years. From the trace metals data this station receives a low but detectable input of contaminants from sewage sludge dumping. Changes should be small but detectable.

(e) A41 ($40^{o}23.36'$; $73^{o}46.78'$). This station, in the southern Christiaensen Basin, is in the deepest area of the Hudson Shelf Valley at this latitude. The station would be better located 0.8 km further W; however, difficulty has been experienced in obtaining samples there. Since A41 is equidistant between the sewage sludge and dredge spoils dumping sites, contaminant concentrations will change to an extent intermediate between changes at NY6 and M109. The results of observations at this location will help to resolve the question of which dumpsite affects which area.

(f) A13 (40°24.83'; 73°50.52'), A54 (40°21.18'; 73°50.07'), M109 (40°23.39'; 73°51.57'). These stations serve two purposes. They provide dissolved oxygen data at the western margin of the sampling area which, taken together with data from the Long Branch Transect in the coastal hypoxia area, will allow us to distinguish between the two epicenters of seasonal low dissolved oxygen in the New York Bight. Secondly, they will serve as contaminated "reference" stations since they are predominantly under the influence of the dredge spoils dumping. No change attributable to the cessation of sewage sludge dumping should be detectable. Due to past difficulties in sampling, exact locations may be modified.

(g) A26 (40°23.80'; 73°49.72'), A27 (40°23.93'; 73°49.05'), A29 (40°24.22'; 73°47.60'), A30 (40°24.32'; 73°46.97'), A38 (40°23.08'; 73°49.40'). These coordinates are tentative but represent stations east of the Dredged Material Dumpsite. They will be sampled approximately three times to determine whether a projected increase in dumping at that site is influencing contaminant concentrations in the sludge-affected area (e.g., NY6).

(h) A56 (40°18.94'; 73°47.06'), M54 (40°18.90'; 73°43.70'). Station A56 (the "Mud Hole") is substantially contaminated while M54 is not. They bracket the replicate station NY11 and thereby provide a valley and flank context for NY11. Station A56 also allows us to test the often stated speculation that contaminants in the Hudson Shelf Valley come from the movement of sewage sludge down the valley.

(i) M49 (40°21.84'; 73°39.65'), NY22 (40°24.87'; 73°39.6'). These stations were selected to be 10 km E and SE of the dumpsite and to include Cholera Bank. The northern station was moved into NY22 since there are pre-cessation data at the site. This is 2 km W of the selected point and some distance from Cholera Bank, making this the most compromised station location of the array. However, it is worth the loss of information on Cholera Bank to have pre-cessation data. Either station would make an appropriate eastern replicate station in an area that has relatively clean sediment. These stations would also provide middle distance data on the depuration of the sediments of low level contaminants (bacteria and coprostanol).

(j) NY3 (40°27.92'; 73°43.67'), A6 (40°29.77'; 73°45.30'). These stations (along with new stations R1 and R5) extend the observations beyond the basin to the N in the direction of the largest fisheries resource (surf clams) thought to be affected by bacterial contamination from sewage sludge dumping. Commercial trawling for ling and whiting is also being conducted in this area.

(3) New stations

Established to cover critical areas where no suitable station exists.

(a) R1 (40°28.94'; 73°47.44'), R5 (40°21.61'; 73°42.69'). See NY3, A6 above.

(b) R6 (40°26.67'; 73°48.47'). This is the necessary station in the western part of the northern basin. Of the basin stations, it is the one most influenced by the outflow of the Hudson-Raritan estuary. Based on trace metal profiles in stations in the basin to the East, it will be unlikely that major changes in sediment chemistry will be found in this area as a result of cessation of sewage sludge dumping. It will therefore serve as a "reference" station for the effects of the plume.

(c) R3 (40°21.57'; 73°43.09'), R4 (40°21.38'; 73°46.42'). To fill gaps in the sampling pattern at intermediate distance to the S and SSW of the dumpsite.

Work plans

(1) Distribution and abundance of finfish and macroinvertebrates

(a) Background. A fundamental problem in evaluating the impact of anthropogenic activity is the determination of the effects on living marine resources. At present there is little or no information on effects of sewage sludge at the 12-mile site on demersal finfish and their utilization of this area, i.e., habitat loss. A study focused on the effects of cessation of dumping must determine if abundance, distribution and utilization of this area change and whether this can be related to changes in chemical contaminant loads and benthic communities.

(b) Objective. To quantify changes in the distribution, relative abundance and species composition of demersal finfish in the presumed area of sludge impact.

(c) Methods. Conduct trawling surveys in the dumpsite and reference areas to determine the species of fish and crustaceans (lobsters and crabs) found in the area, their level of abundance, distribution, community structure and food habits. Trawl surveys will be made monthly in the dumpsite impacted area to coincide with seabed chemistry and intensive benthic sampling. Trawl collections will be defined to species including number and size of individuals. Trawling will be conducted seven times a year at replicate stations and every other month at the broadscale sites.

All collections of fish and invertebrates are made with an otter trawl having a 11.0-m (36-ft) footrope and a 9.8-m (32-ft) headrope. Wings, square, and bellies of the trawl are constructed of 76-mm (3.0-inch) stretched mesh 18-thread knotted nylon. The cod end is constructed of 51-mm (2-inch) stretched mesh 18-thread knotted nylon. Five 203-mm (8-inch) diameter plastic trawl floats are equally spaced along the headrope and a sweepline constructed of 10-mm (0.38-inch) chain is attached to the footrope at intervals of approximately 356 mm (14 inches).

To obtain uniformity, the trawl is towed for as close to 15 min as possible at approximately 5.6 km/hr (3 kts) at each sampling location. In addition, if at all logistically possible, trawl tows are made along isobaths to minimize sudden depth changes. It should be noted that, although tow time is kept as constant as possible, direction and distance of each tow are affected by current, tide, wind, and in some cases by the need to avoid lobster pots.

At the conclusion of each tow, the trawl is retrieved and emptied on the rear deck of the vessel, at which time all fish and invertebrates are separated and identified. All specimens of each species are collectively weighed to the nearest 0.05 kg and individually measured to the nearest whole centimeter. All specimens of each species are usually measured except when subsamples of large catches are measured. In such cases, an expansion factor (weight of total catch/weight of subsample) is applied to the number and length frequency of the subsample to estimate number and length frequency of the total catch.

Collected data are recorded at sea on data processing forms for subsequent inclusion at the laboratory into a data management system which incorporates sorting, listing, and statistical systems to simplify data recall and analysis.

(2) Food habits of selected finfish and invertebrates

(a) Background. There is an assumption that sewage sludge dumping has affected the benthic environment and biological community to a degree that it could also be affecting the use of sludge-polluted habitats by fishery resource species.

(b) Objective. Define and evaluate any difference in food habits of selected species among the areas of sewage sludge and less affected reference sites. Determine whether the cessation in dumping is followed by a measurable change in food habits.

(c) Methods. Stomach contents of selected fishery species (winter flounder, red and silver hake, lobster) will be examined every other month at the three replicate sites based on evenly distributed collections with additional collections in August. Stomach volume is determined and percent composition, numbers and size of prey items enumerated. Winter flounder are processed on board in a fresh condition and red and silver hakes and lobster cephalothoraxes are preserved for laboratory analyses.

(3) Organic contaminants in biota

(a) Background. There is considerable concern regarding the levels of organic contaminants in key resource species (i.e., winter flounder, lobster) which utilize the areas in and surrounding the 12-mile dumpsite. Available data on organic levels in tissue of these species are sparse.

(b) Objective. Determine the level of organic contamination of selected species at the 12-mile sewage sludge dumpsite and at a reference station.

(c) Methods. Trawl surveys will be conducted twice each year to collect target species for analyses of selected organic contaminants (PCBs, PAHs, etc.) in tissue samples. Winter flounder (N=30) are taken by otter trawl at each of three sites: contaminated, NY6; enriched, R2; and reference, NY11. The cruises are timed to collect pre- and post-spawning individuals. Four tissues (muscle, liver, gonad, stomach) are removed following the protocol developed for OAD by NMFS as part of the National Status and Trends, Benthic Surveillance Project wherein only CH_2Cl_2 cleaned stainless steel implements and teflon sealed glass jars are used and dissection is done in a laminar flow clean hood. Analyses will be carried out by the methods of MacLeod et al. (1984). Lobsters are collected on the same cruises and frozen whole. If enough specimens are collected, the muscle and hepatopancreas will be analyzed by the same methods as winter flounder. Selected samples will be analyzed through collaborative support from the NJ Department of Environmental Protection's Office of Science and Research.

(4) Migration and distribution of winter flounder

(a) Background. The winter flounder is one of the most valuable of the sport and commercial fisheries of the New York Bight. Populations of winter flounder have been found by many investigators to consist of independent stocks associated with individual estuaries or coastal areas with significant differences in growth occasionally found in adjacent bays. During colder months winter flounder inhabit coastal and estuarine waters. When the water temperatures warm to approximately 15C they leave the shore area and move off into deeper water. Marking and recapture by tagging has traditionally been used to monitor fish growth and population movements.

(b) Objective. To collect and tag winter flounder in and around the 12-mile sewage dumpsite in order to monitor availability, movements and growth.

(c) Methods. At 23 locations within a 100-sq mi area 12 miles off the New Jersey shore, winter flounder are tagged and released. At each site, a 15-min trawl is conducted to collect winter flounder. After capture, fish greater than 15 cm are held in a flow-through seawater system until processing is complete. Each fish is sexed, scales removed for aging and total lengths recorded. The fish is then tagged with a yellow plastic laminated Peterson disc (1/2" diameter) imprinted with an identification number, return address and catch data request. The tag is attached with a nickle pin inserted through the nape musculature and held by a crimp in the pin on the opposite side against a blank disc. The fish is then released.

Six times a year (every other month) using a 30-foot otter trawl winter flounder are collected by the R/V *Kyma* for tagging. The 23 sampling sites are usually completed in six to eight days of sailing on the jointly shared dumpsite recovery cruises. All the tagging activities can be completed by one scientist and one technician. Recapture of tagged fish is accomplished by our efforts and the cooperation of local fishermen.

(5) Gross pathology

(a) Background. A variety of finfish in the New York Apex have exhibited pathological conditions which have been attributed to contaminant exposure. Changes in levels of organics and metals in habitats, such as the dumpsite areas used by demersal species could measurably affect incidence of external lesions.

(b) Objective. Determine changes in the incidence of gross pathology in finfish routinely collected during trawling. Correlate any changes with shifts in chemical contaminant levels.

(c) Methods. Examine selected species for incidence of external and internal pathological evidence.

Routinely record gross pathological conditions of collected finfish. External conditions recorded include finrot, epidermal ulcers, lymphocystis, skeletal and pigmental anomalies. Selected species are also examined internally.

(6) Benthic community structure

(a) Background. Recovery of a perturbed area such as the dumpsite requires successful repopulation by benthic macrofauna. This can include increases in the number of crustacean forage organisms in the "enriched" or "highly altered" zone, increases in the numbers of benthic species in the "enriched" or "highly altered" zone, and a reduction in the areal coverage and mean density of *Capitella* in the "highly altered" zone.

(b) Objective. Determine effects of sludge abatement on benthic macrofauna communities as indicators of changing biological effects in habitats of resource species. The benthic work will complement studies of chemical processes and findings will also be used in a concurrent study of fish gut contents, to determine spatial and temporal characteristics of recovery of feeding habitats.

(c) Methods. All benthic samples will be processed inhouse and it is estimated that the four subtask personnel can process a maximum of 200 samples/year. Sampling effort will be split between the replicate and broadscale surveys. The latter is of lower priority and samples will be processed as time permits after replicate samples are worked up.

Data will be related to Chemical Processes data (e.g., seabed oxygen consumption, redox and sulfide). Stations sampled also have >4 years of existing benthic data that can be used in assessing temporal change.

All sediment and benthos sampling is done with 0.1 m^2 Smith-McIntyre bottom grab. After subsampling for chemistry, materials retained on the sieve are fixed in 10% formalin and later transferred to 70% ethanol with 5% glycerin. Dissecting microscopes are used for all sorting. Identifications are to species level when possible, except for rhynchocoels.

Oligochaetes, archiannelids and colonial forms are not enumerated due to uncertainty of identification and/or difficulty of quantification.

(7) Pathogens in surf clams

(a) Background. Surf clams are present in low to moderate abundance in the New York Bight Apex. Due to the presence of sewage indicator microorganisms in clams, water and sediments, a circle with a six nautical mile radius, centered at the northwest corner of the sludge dumpsite, was closed to shellfishing in 1974.

The Food and Drug Administration has been conducting limited monitoring of abundance of microorganisms since the closure. FDA wishes to continue this monitoring to determine whether microbial contamination is reduced and whether the area can be reopened to clamming after sludge abatement. Similar monitoring by FDA and NMFS at the Philadelphia sludge dumpsite did document a post-dumping decline in microorganisms, and four years after dumping stopped it was recommended that the area be reopened to clamming. FDA is collaborating with NMFS in studying microbial recovery of the New York Bight 12-Mile Dump-site. There is a Memorandum of Understanding between the two agencies that will facilitate the collaboration.

(b) Objective. Determine trends in pathogens in surf clams and their habitats; possible determination of metal and organic contaminants.

(c) Methods. Analyze clams from NEC's dredge surveys (6/86; 6/88) for pathogens and other contaminants. Analyze water and sediments from presently condemned areas for pathogen indicators.

Pathogens/contaminants in clams: Clams will be collected from dumpsite and reference areas on clam survey and will be frozen by EPD. Clams will be provided to FDA, Davisville, RI, for analysis of contaminants and pathogens.

Pathogens in habitat: FDA personnel will collect (or in some cases EPD will provide) water and sediment samples for analysis of indicators (*Clostridium*, coliform bacteria) of sludge and pathogens.

The joint study will provide information on the direct effects of contamination and abatement on an important resource species, and may lead to an increase in availability of the species. The *Clostridium* data will also contribute substantially to EPD's studies of fates and effects of contaminants in the Bight as sludge abatement proceeds.

(8-9) Sediment and near-bottom water chemistry

(a) Background. From past observations it is expected that detectable changes will occur in the chemistry of the water and sediment of the New York Bight in the vicinity of the sewage sludge dumping site when dumping is abated. The spatial extent of the altered area in which a change will be detectable will vary from analyte to analyte (e.g., if the prediction for coprostanol is correct, 3,000 km^2 will be affected while for sulfide the area will be 45 km^2). It is expected that there will be no change at the dredged material dumpsite.

(b) Objectives. To detect alteration in chemical processes in the Christiaensen Basin that are attributable to the oceanic dumping of sewage sludge and to determine the effect of sediment chemistry and processes on the composition and abundance of the benthic communities.

(c) Methods. Monthly (2-weeks in summer) cruises will be conducted to the area of the 12-mile dumpsite.

WATER CHEMISTRY -- On all surveys at the central point of stations R2, NY5, NY6, and NY11, the Above Bottom Oxygen (ABO) sampler will be used to collect water samples at 0.1 and 1.0 m above the sediment for the measurement of sulfide, dissolved oxygen, pH, nutrients, turbidity, salinity and temperature. In addition, samples will be collected at 3 and 10 m with a Niskin bottle at station NY6. At outlying stations, a 1.0 m bottomtripped Niskin bottle will be used and nutrients will not be collected.

SEDIMENT CHEMISTRY -- At all stations, the following will be measured in all grabs: vertical profiles (1-cm intervals) of redox potential, TOC, grain size, trace metals and from the surface sediment, acid volatilizable sulfide and organic compounds (coprostanol, PAHs, chlorinated hydrocarbons). At the central point of stations R2, NY6, and NY11 from each of two replicate grabs the following will also be measured; 2-cm interval profiles of interstitial and acid volatilizable sulfide, interstitial water nutrients, methane and pH, surface sediment BOD_{13} and plant pigments (chlorophylls) and degradation products.

(10) Seabed metabolism

(a) Background. Seabed Oxygen Consumption (SOC) integrates a wide variety of oxygen-consuming processes in the benthic community but underestimates total benthic community metabolism as it excludes chemosynthetic metabolism. Still SOC is of interest because of its 1) effect on the spatial distribution of oxygen, 2) role in the overall ecosystems' oxygen budget, 3) implications regarding the mineralization of organic matter and recycling of carbon, nitrogen, phosphorus, sulfur and other substances, and 4) usefulness in measuring the effects of pollution and other environmental factors on the overall biological activity of benthic organisms.

Measurements of SOC rates and associated variables across a transect of latitude 40°25' (including the Christiaensen Basin and the 12-Mile Site) have been obtained since 1974 (Fig. C1). Total plankton respiration (TPR) rates and other benthic rate processes have been obtained since 1985. The resultant extensive data base has indicated that areas receiving anthropogenic inputs have significantly higher oxygen consumption rates relative to surrounding areas. Changes in volumes of sewage sludge and dredge spoil dumped have been shown to alter SOC rates.

(b) Objective. The objective of this study is to document how fast the rate of seabed oxygen consumption at the 12-mile sewage sludge site returns to more natural levels as dumping ceases. Associated with high rates of SOC are high rates of nutrient regeneration. These rates are also expected to be reduced.

(c) Methods. At each of six stations, from the western side of the Christiaensen Basin, across the 12-mile site to almost the Cholera Bank (latitude 40°25') twelve cores of sediment and water are collected and incubated at *in situ* temperatures aboard ship to determine SOC and nutrient regeneration rates. Water samples from 0.1 and 0.5 m off bottom are incubated in the dark at *in situ* temperatures to determine rates of total plankton respiration. Additionally, associated variables of

DO, temperature, salinity, percent saturation, sediment carbon, and ambient bottom light levels are measured. The cores are dosed with formalin to determine the amount of oxygen uptake due to respiration and that due to the oxidation of reduced substances (an indicator of anaerobic metabolism). All cores are sieved for benthic infauna.

Three or 4 days per month the R/V Kyma occupies two stations per day with one or two scientists and two technicians. The cores are obtained by a multiple corer and are incubated overnight aboard ship. Initial and final DO and nutrient samples are taken from 12 and 4 cores respectively. The oxygen concentrations of all cores are recorded on a multi-point recorder through the use of galvanic electrodes. After dosing with formalin, the incubation is continued. Since formalin interacts with Winkler DO reagents, the rates due to chemical oxidation are read from a strip chart. All cores are sieved through an 0.5 mm screen in the laboratory and nutrient and carbon samples are frozen for later analysis.

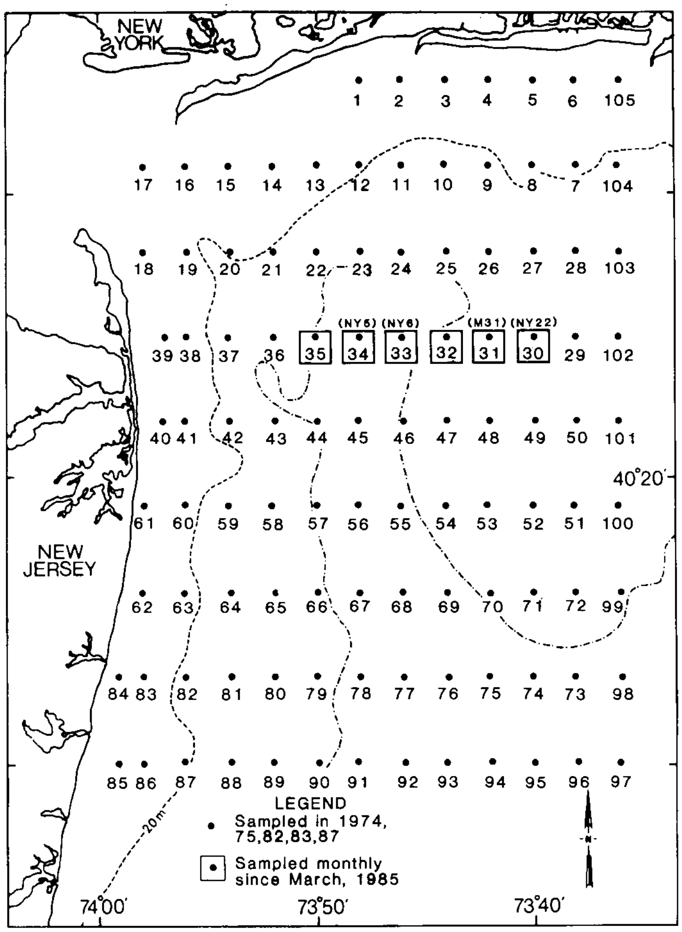

Figure C1. Location of stations occupied for seabed oxygen consumption. Dumpsite stations are designated in parentheses.

(11) Physical redistribution of sludge and associated contaminants in the dumpsite area, Christiaensen Basin, and Hudson Shelf Valley

(a) Background. The 12-mile dumpsite is in a highly variable marine environment. The water column in the vicinity of the site undergoes regular seasonal changes in stratification because of heating and cooling, wind mixing and influx of low salinity water from the Hudson-Raritan estuary. Average currents are toward the south-southwest but vary widely under the influence of local wind forcing and stratification. Field measurements, although few, clearly demonstrate the dispersive nature of the water column on sewage sludge. Dispersion is most rapid when the meteorological and hydrographic conditions include high winds and an unstratified water column.

(b) Objective. To determine the pathways and rates of sludge and associated contaminant influx and efflux in the dumpsite-basin-shelf valley area, and to improve a probabilistic dispersion model (EPA/ERLN) for portrayal and prediction of sludge component distribution.

(c) Methods. A series of current meter moorings will be established and maintained at locations in and around the Christiaensen Basin (Fig. C2). The data collected from these meters will be analyzed to detect and define influx and efflux events, with particular attention to bottom water efflux episodes from the Christiaensen Basin. A pilot array will be established in the Basin from July through October 1986.

A cooperative effort will be undertaken with a modeling group at the EPA Environmental Research Laboratory in Narragansett (EPA/ERLN) to modify their 3-D dispersion model and apply it to the 12-Mile Dumpsite area. The first iteration will use current meter data from the MESA/AOML moorings, later iterations will use data from the NEC/POB moorings maintained during the recovery study.

Members of the Fishery Oceanography Investigation (FOI) in consultation with other study participants will design a current meter sampling strategy by November 1986 and current meter deployments will begin in May 1987. Processing of the data will begin as they are available from meter retrievals.

Members of the Physical Oceanography Branch (POB) and scientists from the EPA/ERLN will conduct a series of annual cruises of about 10 days duration in the vicinity of the current meter moorings in the Hudson Shelf Valley to make hydrographic measurements to aid in the interpretation of the current meter data. In addition, sediment samples will be collected from selected stations to determine the extent of contamination and the resuspension characteristics of the ambient sedimentary surface.

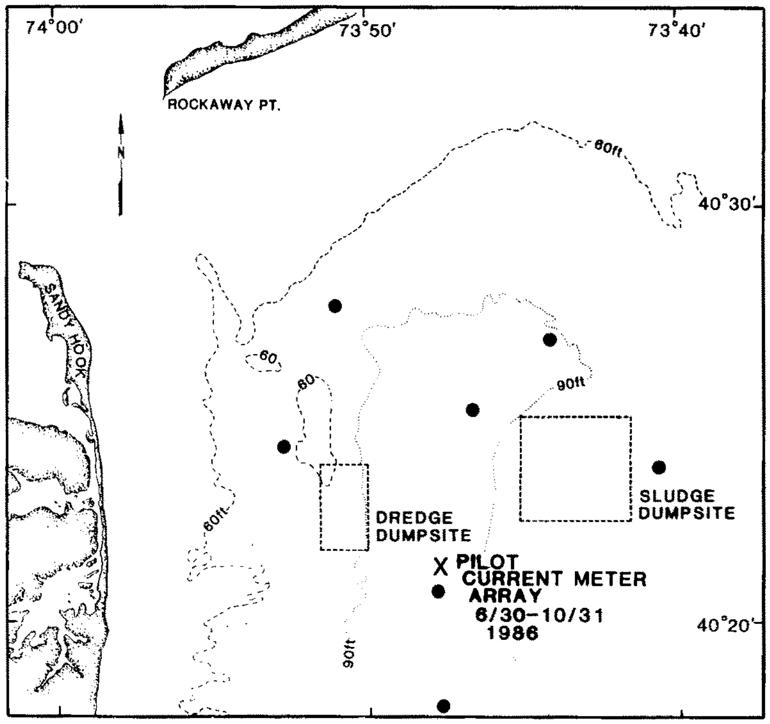

Figure C2. Location of bottom current meters.

D. Field sampling protocol

(1) Chief scientist

A Chief Scientist will be designated on each sailing day and will be responsible for:

1. Broadscale Survey station selection. This will be done in consultation with the vessel captain. The day's schedule will be made known to the onboard task leaders. The Replicate Survey schedule is fixed and cannot be modified without consulting with the Survey Coordinator.

2. Terminating or extending the sailing day. This will be done in consultation with the vessel captain. The day's schedule will be made known to the onboard task leaders. The Replicate Survey schedule is fixed and cannot be modified without consulting with the Survey Coordinator.

3. Maintenance of the Bridge Log. The CS will ensure that a proper Bridge Log entry is made for each "over the side" operation. The Bridge Log will contain position and time of each event. Time is recorded as local time. Position is recorded as Loran rates, latitude and longitude, and depth. The CS will verify that positioning is correct for each station and/or replicate.

4. Sequence of samplings. The general sequence comprises a Niskin Bottle water sample, a Smith-McIntyre grab and a 15 minute trawl

with the standard gear. This sequence can be modified when conditions warrant. A water sample must be taken for every tow. Usually a grab will be taken at the water sample site. An exception occurs in designated week 1 of the Replicate Survey when the third Maxi-grab is taken alone.

(2) On vessel task leader

Each discipline (Chemistry, Benthos, Trawl Studies) will designate an on vessel Task Leader responsible for:

1. Documentation. The Task Leader will ensure that all appropriate coding forms are correctly filled out and the samples are properly labelled.

2. Sample quality. The Task Leader will determine the acceptability of a sample and determine if a repetition is necessary.

3. Procedural protocol. The Task Leader will ensure that the specific protocols are followed with regard to collecting, measuring, processing, handling and preserving.

(3) Vessel positioning and orientation of tows

When conditions permit, certain guidelines for collecting samples and making tows should be followed:

1. Broadscale Survey. Water and benthic samples should be collected as near to the defined station coordinates as possible. These are provided on a checklist. The vessel should move off the station approximately three-eights of a nautical mile and tow such that the trawl track follows the local bathymetry and runs nearby, but not over, the station center. The water and benthos samples will then be positioned near the center of the tow track. This is done to approximate simultaneity of measurements so as to allow correlative analyses and contouring. The Broadscale Survey is designed to characterize a point.

2. Replicate Survey. In contrast to the Broadscale Survey, the Replicate Survey is designed to characterize an "environment." This environment is defined by an arbitrary ellipse drawn about the station center. The eight replicates taken at each of the three Replicate stations are partitioned into three "Radial" samples and five "Distal" samples.

   Radial Niskins and grabs (Maxi) should be taken as close to the station center as possible. The trawl procedure follows that of the Broadscale above, except that the tracks are oriented so as to minimize intersection.

   Distal Niskins and grabs (Mini) should be taken at the coordinates on the checklist. Tows should be made from the distal coordinates (in which case it is convenient to take water and a grab after the tow).

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(continued from inside front cover)

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