SUMMARY

of

MASSACHUSETTS WATER RESOURCES AUTHORITY

BENTHIC AND SEDIMENT SCIENCE REVIEW MEETING

held

April 28, 1994

at

BATTELLE OCEAN SCIENCES
DUXBURY, MA

prepared by

Carlton Hunt
BATTELLE OCEAN SCIENCES

Margarete Steinhauer
CONSULTANT

and

Ken Keay
MWRA

June 1, 1994

ms-22

PREFACE

The science review meeting summarized in this document was held to evaluate progress towards answering questions posed in the MWRA Outfall Monitoring Plan, to identify indicators of change and endpoints in the Massachusetts Bay system, and the adequacy of the monitoring design to capture changes that may occur following commissioning of the outfall. To stimulate discussions, meeting participants were challenged with several questions related to these issues. The participants responded to this challenge with stimulating and relevant discussions and raised a number of other questions. During the discussions several of the questions to the workshop were addressed. Answers to other questions were not fully developed. Even so, the meeting is viewed as having successfully communicated our present understanding of the Massachusetts Bay ecosystem. The discussions resulted in several suggestions for improving the monitoring design. Some of these suggestions may be implemented in 1994.

citation:

Hunt, C., M. Steinhauer, and K. Keay.. 1994. **Massachusetts Water Resources Authority Benthic and Sediment Science Meeting.** MWRA Enviro. Quality Dept. Misc. Rpt. No. ms-22. Massachusetts Water Resources Authority, Boston, MA. 119 pp.

INTRODUCTION

The 1994 MWRA benthic and sediment science review meeting was held at Battelle on April 28, 1994. There were 26 attendees, including MWRA personnel, regulators, members of the academic community, and project scientists (see Appendix A). Carlton Hunt (Battelle) discussed the goals and objectives of the workshop, and the charge to participants (included in agenda handout). Summaries of the sediment chemistry data and benthic features were presented by project scientists. A summary of the workshop presentations and discussion is provided here. Appendix B includes the workshop agenda and copies of the introductory overhead slides. Copies of graphics and written materials provided by the workshop presenters are included in Appendix C.

The goals of the workshop were to evaluate

- Questions posed in the monitoring plan.
- Benthic parameters being measured and their role as indicators of meaningful change.
- Concepts of meaningful change, key monitoring variables, and appropriate action levels.
- Adequacy of the baseline monitoring design and data to capture changes that may occur after commissioning of the outfall in western Massachusetts Bay.

To solicit discussion around these issues, the following questions were presented:

- Are the baseline data sufficient to understand the ecosystem being monitored? Why or why not?
- To what extent does our current understanding of the system allow focus on a reduced set of stations or parameters?
- Is spatial and temporal coverage provided by the monitoring plan adequate to meet its goals?
- What is the role of the various benthic measurements in the monitoring program?
- What are meaningful levels of change for the benthic system?
- Can monitoring questions now be phrased as quantitative hypotheses reflecting meaningful levels of change?

In addition to participating in the discussions, meeting participants were specifically asked to

- Identify monitoring issues (questions) that have been resolved and those still needing attention.
- Refine the role of each parameter being measured in the monitoring program and to identify any additional parameters or measurements.
- Identify key indicator parameters and their endpoints.
- Help resolve and justify the values that represent meaningful change for the monitoring parameters.
- Suggest alternate presentations of data.
- Generate statements that may be used as the basis for developing hypotheses.

Summaries of the presentations are included below, followed by a summary of the meeting discussions.

SOFT-BOTTOM SEDIMENT ORGANIC CHEMISTRY
Damian Shea (North Carolina State University)

- Organic chemistry of sediments collected in 1992 is generally similar to historical data and characteristic of coastal sediments from urban areas.
- Harbor does not have distinctive chemical signature. Therefore, an approach to monitoring export of effluent contaminants to the Bay could be to develop diagnostic ratios of selected parameters indicative of effluent contamination. Candidate effluent "signature" compounds are LABs and coprostanol. One monitoring approach would target effluent "signature" compounds together with compounds having toxicological properties.
- For most organic contaminants, a two- to three-fold change can be detected within a station. Although absolute concentrations of contaminants are most sensitive to change, data normalized to organic carbon (i.e., the most readily available concentrations) are important in understanding meaningful change.

SOFT-BOTTOM SEDIMENT INORGANIC CHEMISTRY — M. Bothner (USGS)

- Since the 1980s, silver concentrations in effluent have been declining primarily due to source reduction. Short-term increase in silver, such as that observed at station 3 in 1993, can be attributed to severe resuspension resulting from major winter storms.

- Because of low background sediment concentrations, silver can be a sensitive indicator of sewage effluent. Silver concentrations correlate well with *Clostridium perfringens* spores, a biological sewage tracer. In sewage, concentrations of silver can be 1000 times greater than in ambient surface sediments.

- Although concentrations of silver can be highly variable in the upper 0.5-cm sediment, when normalized to the sediment mud content, a gradient of decreasing silver concentrations out from the Harbor can be detected.

- Elevated concentrations of silver were also detected in surface sediments from Cape Cod Bay. Because there are no known sources of silver in this area, water current patterns may facilitate transport and deposition of silver contaminants from Boston Harbor.

CHEMICAL BIOLOGICAL RELATIONSHIPS (1992 SOFT-BOTTOM RESULTS) Ken Keay (MWRA)

Review of 1992 Faunal Results

- The benthic survey in August 1992 established 12 stations in the farfield and 20 stations in the nearfield, suitable for soft-bottom sampling.

- Nearfield stations could not be located in the immediate vicinity of the proposed outfall because of the lack of suitable soft-bottom sediments.

- Nearfield stations that could be occupied generally showed a gradient from depositional muds inshore (nearest to Boston Harbor) to coarser sands in the soft-bottom sediment areas nearest the outfall.

- The type of benthic community found in the nearfield generally corresponded to the sediment type. Three distinct benthic communities were identified.

- The 1992 data from the nearfield were indicative of a dynamic area characterized by frequent physical disturbances. The sediment profile photographs revealed layered sediments, indicating that during storms, transport processes covered muddy areas with sand and vice versa.

- In the farfield, three major benthic community groups were associated with station characteristics: (1) a community identified at relatively shallow stations near Boston Harbor, (2) a community found primarily at deep-water stations in northern Massachusetts Bay and Stellwagen Basin and, (3) a community restricted to the two station locations in Cape Cod Bay. Cape Cod Bay stations showed evidence of *Molpadia/Euchone* assemblage first observed in this area in the late 1960s. The offshore station east of Stellwagen Bank was uniquely characterized by benthic fauna generally associated with deep-water shelf environments.

Design Modifications for 1993 Sampling

- Based on data collected in 1992, the monitoring program's regulatory/oversight committee mandated changes to the nearfield monitoring design. A sampling design of 20 stations with 1 replicate was changed to 9 stations with 3 replicates for infauna and 2 replicates for chemistry analyses. The farfield station east of Stellwagen Bank was dropped.

Chemical-Faunal Relationships — 1992 Data

- High correlations were found among contaminant concentrations and bulk sediment properties (e.g., TOC, grain size). Partial correlations controlling for the effects of TOC or percent silt+clay removed some of the covariance.

- At the farfield stations, Pearson product-moment correlation analyses revealed no significant relationships between faunal diversity (three measures) and sediment or contaminant parameters. Similar results were obtained with partial correlation analyses controlling for effects of TOC and grain size.

- The data revealed significant negative correlations between faunal diversity and TOC and/or grain size. Many significant correlations between diversity measures and contaminants were also noted, even in partial correlations controlling for associations between variables and TOC and/or grain size.

BENTHIC STABILITY AND 1993 SOFT-BOTTOM INFAUNA RESULTS
Roy Kropp (Battelle) and Eiji Imamura (Marine Research Specialists)

- Based on preliminary 1993 results, the community structure of the nearfield infauna appeared to resemble the community structure observed in 1992 (see figures in Appendix C-4). The composition was numerically dominated by annelids, except at stations NF-2 and NF-17 where molluscs and crustaceans, respectively, dominated.

- Compared to 1992, the infauna from four farfield stations (FF-7, FF-10, FF-11, and FF13) appeared to be less abundant in 1993, particularly at station FF-10. The composition was numerically dominated by annelids.

- Compared to 1992, differences in grain size were observed at some nearfield stations in 1993.

HARD-BOTTOM DESIGN CONSIDERATIONS — Ken Keay (MWRA)

- In the development of the outfall monitoring design, little emphasis was placed on hard-bottom monitoring because it was expected that all nearfield monitoring could be accomplished by the soft-bottom sampling design. Hard-bottom environments monitored during outfall siting were originally not viewed as readily amenable to quantitative monitoring.

- In 1992, benthic sampling and surveillance showed small depositional areas near the diffuser alignment. These areas were identified in USGS mapping but could not readily be sampled.

- The role of hard-bottom monitoring should be re-evaluated because of the lack of soft-bottom stations that could be sampled within 1 km of the outfall — in the specific area that the water quality model predicted would receive the greatest inputs of organic carbon.

ISSUES AND DISCUSSION TOPICS

Issues and topics identified and/or discussed during the afternoon session included the following:

Nearfield Soft-Bottom Sampling Design

During the review of 1992 data and the sediment/faunal associations, several participants questioned the rationale for reducing the number of stations in the nearfield to nine. Some of the issues raised were (1) whether the reduced station design could allow detection of effects from the outfall, given the dynamic heterogenous nature of the nearfield sediments and associated fauna; and (2) whether reducing the number of nearfield stations from 20 to 9 would result in the loss of sample size necesssary to detect significant correlations or conduct regression analyses across the nearfield.

Discussion following presentation of 1993 faunal results focused on the striking increases in percent sand at some stations, and the associated change from primarily polychaete to bivalve-dominated fauna at station NF-02. These preliminary results were considered by some participants as bearing out predictions based on 1992 results (i.e., the dynamic nature of the sediment environment).

Because of the evidence for *both* temporal and spatial small-scale heterogeneity in the nearfield sediments, several participants suggested that a gradient mapping strategy in the nearfield (with replicated sampling) may again be required to separate outfall effects from faunal shifts due to changes in the sedimentary environment. Following discussion, there were suggestions that the mapping strategy should be investigated. Related design considerations that were suggested and discussed included the following:

- Focus sampling on "suitable" fine sediments (i.e., examine grab sample on deck and, if sediments appear too coarse, move to sample another area. This suggestion was rejected because of the tendency to bias the results and also because of the significant increase in ship time that would be required.

- Several meeting participants were not comfortable with the gradient mapping approach because collection of replicate faunal and sediment grab samples from about 20 stations would dramatically inflate the budget. One alternate suggestion was to conduct replicate sampling at two or three stations in areas where sediment stability is expected. Single samples would be obtained at the remaining 17 or 18 stations. One candidate station for repliction is

NF-12 (USGS station WH-3), where Mike Bothner has shown long-term stability in grain size and silver content. At this station, both silt+clay and silver concentrations increased ≈10% following severe storms in the 1991-1992 winter.

- Some discussion focused on station selection. Suggestions were made to allocate stations by a stratified random design, to re-occupy the 20 stations sampled in 1992, or to abandon stations on the nearfield periphery and establish new stations in the center of the nearfield. Advantages and disadvantages of all three suggestions were considered.

- Other discussion included linking real-time video to grab samples to facilitate sampling the small depositional areas that could not be sampled in 1992. One participant suggested supplementing the Young-modified Van Veen grab with an equivalent Smith-McIntyre sampler to allow sampling of coarser sediment sites and deeper-dwelling fauna.

Farfield Station Design

- There was brief discussion on the *Molpadia/Euchone* assemblage identified in the Cape Cod Bay samples in 1992. It is not clear whether the sampling equipment used in the present program adequately samples large, sparsely distributed organisms such as *Molpadia oolitica*. No specific recommendations were made concerning this issue.

- A suggestion was made to move one northern Stellwagen Basin farfield station (FF-01 or FF-14) inshore to shallower waters off Gloucester. The rationale for this suggestion was that the deepwater Massachusetts Bay and Stellwagen Basin stations have a high degree of faunal similarity. Also, USGS sediment inventories do not indicate that preferential contaminant deposition occurs in the northern areas of the Basin. Having a reference station well north of the outfall, in similar water depth, was viewed as a persuasive reason to re-allocate resources. There was general consensus on this recommendation, and use of one of the reference stations from the Gloucester NPDES monitoring program was suggested.

- A suggestion was made that station FF-07 be moved to the center of the circulation "gyre" in Cape Cod Bay (see Appendix C-2). In the discussion that followed, Dr. Bothner pointed out that the "gyre" is based on data from a limited number of surface drifters and that the available data suggest that characteristics of station FF-07 are probably not significantly different from those in the center of the gyre.

Open Issues

- **Hard-Bottom Study** — The rationale for a hard-bottom study would be to supplement nearfield monitoring, especially in the area within 1 km of the outfall where soft-bottom sampling has not been feasible. Most of the discussion focused on need for such a study. The point was made that, from a regulatory perspective, there is no difference between hard-bottom and soft-bottom. There was much discussion on an intensive, photo-transect approach to monitoring the boulder and cobble fields on the submerged drumlins in the outfall area. Other possible quantitative approaches include (1) the deployment and recovery of settling plates/blocks or sediment traps and (2) contaminant analyses of the surficial floc material on the rock surface. One participant noted that new technologies are being developed to identify anthropogenic signatures in iron/magnesium crusts that form on exposed rocks. Other participants again suggested that video-guided sampling might allow occupation of stations characterized by small areas of depositional sediments in the immediate vicinity of the effluent outfall. No consensus on this issue was reached, but there was general agreement that sampling be attempted and that a compromise approach, similar to that suggested for soft-bottom sampling design, might be useful. This approach might entail a reconnaissance survey combined with a smaller-scale quantitative survey.

- **Infaunal Biomass** — Members of the OMTF have recommended this analysis. Reasons for conducting biomass measurements include its compatibility with EMAP data (in anticipation of EMAP/REMAP presence in the Bays) and for reinforcing hypotheses based on community structure or diversity. However, since the recommendations were initially made, the future of the EMAP program in the Bays is uncertain. Furthermore, biomass measurements rarely provide information that cannot be obtained by community structure or diversity analyses. Therefore, general consensus and recommendation of the meeting participants was that biomass measurements are not critical to the monitoring program.

- **Grain-Size Analyses** — A recommendation was made to provide sediment grain-size data, particularly for the sand fraction (2.0-0.0625 mm), in discrete phi-size (Φ) intervals rather than in sand, silt, or clay fractions. Discussions among the meeting participants suggested that Φ-size analyses would improve the ability to interpret faunal shifts, especially in the dynamic region surrounding the outfall. It was suggested that the benefit of Φ-size resolution within the silt-clay fractions is debatable, although geochemists support the utility of such data. The meeting participants recommended that Φ-level analyses be carried out on the sand fraction, and that MWRA examine automated techniques for rapid and inexpensive silt-clay Φ-size analysis.

- **Sieve Sizes** — In the past, several recommendations concerning sieve sizes had been made. Current practice involves field-sieving through nested 500- and 300-μm-mesh sieves. In 1992, samples were sieved through a 300-μm-mesh in the field, and through nested 500- and 300-μm sieves in the laboratory when samples were transferred to alcohol. Similar protocols were carried out during the outfall siting studies. Both procedures result in similar *total* community abundances (300-μm + 500-μm), but it was suggested that the two different protocols result in 500-μm-mesh data that are not wholly comparable. The current practice is more comparable to procedures (sieve through 500-μm screen only) used in major programs such as EMAP. One participant emphatically questioned the need for 300-μm-level data. Some participants noted that the abundance of small opportunists can increase if organic deposition increases. The sorting laboratory noted that the time required to sort the 300- to 500-μm fraction is minimal compared to the labor required to sort the >500-μm fraction. Eliminating the 300-μm sieve might, therefore, only result in very modest cost savings. No consensus was reached or recommendation was made concerning this issue.

- **Seasonal Sampling** — Several program reviewers have recommended that some level of seasonal faunal sampling be incorporated into the monitoring program. Seasonal sampling data collected from the nearfield during the outfall siting study indicate faunal stability. The limited data collected in the farfield between May and August 1992 also indicated some faunal stability. The winter-spring period was identified as the "best" seasonal period for within-year replication studies. Consensus of the meeting participants was that sampling more than once per year would provide useful information, but that the late summer sampling currently being conducted was probably sufficient to detect any changes potentially induced by the operation of the future outfall.

- **Contaminants in the Benthos** — During an OMTF meeting in 1993, a recommendation was made that the MWRA evaluate the feasibility of conducting analyses of contaminants in the benthos to supplement the contaminant measurements in the sediments, and to assess the body burdens of the infaunal prey of demersal fishes and shellfish. Meeting participants who had sampled and analyzed small infauna, such as the spionids that dominate much of the nearfield, vouched for the difficulty and frequent failures associated with the techniques. Sampling for rare, high-biomass individuals was viewed as equally problematic. Meeting participants generally indicated that such measurements would be difficult to obtain, and of minimal use even if successfully made. The group recommended that measurements of contaminants in the benthos not be pursued. One participant suggested that if contaminants in the infaunal prey of commercially important demersal fish/shellfish species were of interest, contaminant analyses of stomach contents would be the appropriate matrix. No recommendations relevant to this issue were made by the meeting participants.

- **Frequency of Contaminant Analyses** — Currently, sediments for contaminant analyses are collected every August, during the benthic community sampling. As in the past, the suggestion was made that the full suite of chemical contaminants do not need to be analyzed annually. It was noted that, at some nearfield stations, contaminant concentrations changed little between 1987, when the siting study was conducted, and 1992. Participants unanimously endorsed measurements of grain size and TOC (and possibly spores of *C. perfringens)* at all benthic community stations. Meeting participants firmly recommended that, during all outfall surveys, samples for contaminant analysis should be collected and archived, and that samples be analyzed for contaminants in the monitoring year preceding commissioning of the effluent outfall. There was a general indication that, in 1994, sediment contaminant analyses could be deferred (archived) without burdening the program.

Other Discussion Issues

Among other questions raised during the discussions were the following:

- Meeting participants discussed LAB as an effective tracer of effluent. Participants noted that concentrations of LAB in effluent have been decreasing in recent years, and that the LAB degradation rate may be high and the concentrations of LAB in nearfield sediments are very low, even near diffuser. One question raised was whether an effort should be made to obtain information on LAB degradation rates. Some participants indicated that focusing on contaminant ratios may help assign sources and determine inputs when the future outfall becomes operational.

- The relevance of benthic monitoring was also questioned and discussed, including how monitoring of the benthic environment can relate to public concerns and how results of the benthic infauna analysis can relate to resources at risk. Clear answers to these questions were not developed and the purpose of infauna studies, as related to the monitoring program, was not defined beyond its present role.

- Some participants also questioned whether samples of the sediments between boulders and rock features should be collected (e.g., with the ROV) during the hard-bottom studies. This substrate is assumed to have a high concentration of mud — suitable for analysis of contaminants. This issue was not resolved.

PREDICTIONS/CONCLUSIONS

- Physical processes (e.g., major storms causing resuspension events) are responsible for significant impacts on the benthos and/or changes in habitat and community structure.

- Changes in the infauna community are not expected after the new outfall comes on line.

- To date, the nearfield data suggest that no type of benthic infauna community can clearly be associated with sediment chemistry data.

RECOMMENDATIONS

In addition to the recommendations discussed in the summaries above, the following general recommendations resulted from the meeting discussions:

- Annual sampling of sediment for chemistry and infauna analysis is probably adequate to detect change.
- Because stations F1 and F14 are biologically similar, one of the two should probably be moved nearshore and north in the vicinity of Salem.
- Collection and analysis of sediment cores should be conducted every five years.
- Ensure that stable sediment environments are routinely sampled (i.e., stations 9, 10, 11, and 12, which seem to be relatively stable, should be sampled annually).
- Analysis for chemical and biological sewage indicators should continue so that the effluent can be traced.
- The protocol for benthic sample collection should be more flexible to ensure that samples are representative of the soft-bottom community, and the methods for processing benthic infauna should be standardized.
- From a programmatic standpoint, the effort made to study the hard-bottom environment should be weighted the same as the effort made to study the soft-bottom environment.
- Monitoring should ensure that the carbon loading rate in the vicinity of the outfall is well understood.
- Extensive within-year temporal replication was not considered critical to the overall monitoring strategy. However, the mid- to late-winter features at selected stable stations should be well understood.

APPENDIX A

WORKSHOP PARTICIPANTS

	NAME	ORGANIZATION	PHONE
1	MIKE MICKELSON	MWRA	241-6505
2	MARGARETE STEINHAUER	Consultant	617/934-2072
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5	MIKE BOTHNER	USGS	~~617~~ 508-457-2240
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22	Ken Keay	MWRA	241-6504
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26	Marilyn Ten Brink		

APPENDIX B

WORKSHOP AGENDA AND OVERHEAD SLIDES

MASSACHUSETTS WATER RESOURCES AUTHORITY

BENTHIC AND SEDIMENT SCIENCE REVIEW MEETING

APRIL 28, 1994

BATTELLE OCEAN SCIENCES
DUXBURY, MA

AGENDA
BENTHIC AND SEDIMENT SCIENCE REVIEW MEETING
APRIL 28, 1994
BATTELLE OCEAN SCIENCES
DUXBURY, MA

1. WELCOME 0830 - 0845
   Mike Connor, MWRA Science Director
   Carlton Hunt, Moderator and Battelle Project Manager, Logistics

2. GOALS 0845 - 0915
   Carlton Hunt: Workshop Goals, Process, Charge
   Predictions
   Monitoring Design
   Workshop Product

3. PRESENTATIONS 0915 - 1115
   Soft bottom

Damian Shea	Sediment Chemistry
Ken Keay	Results from 1992 1992 Chemical biological relationships
Roy Kropp/ Eiji Imamura	1993 results: Major features, benthic stability CCB
Mike Bothner	Sediment Chemistry - inorganics

   Hardbottom

   Design considerations - Ken Keay

3. Discussion 1115 - 1230

   Detectable/meaningful change
   Monitoring Questions and Hypotheses statements
   Monitoring Design

Lunch - Provided 1230 - 1315

4. Discussions (Continued) 1300 - 1400
   Wrap up

OBJECTIVES

BENTHIC AND SEDIMENT SCIENCE REVIEW MEETING
APRIL 28, 1994

- EVALUATE QUESTIONS POSED IN THE OUTFALL MONITORING PLAN OF NOVEMBER 7, 1991

  - to determine if the questions should (can) be modified as result of the baseline study
  - to determine if new questions should be asked

- EVALUATE THE PARAMETERS BEING MEASURED TO DETERMINE

  - their role in the monitoring program (diagnostic versus indicator/endpoint)
  - their ability to detect meaningful change
  - what level of change is acceptable
  - key metrics associated with each variable
    (i.e., key indicator species vs. community measures, etc.)
  - duration/frequency/seasonality associated with meaningful change

- ADVANCE UNDERSTANDING OF MEANINGFUL CHANGE, KEY MONITORING VARIABLES, AND APPROPRIATE ACTION LEVELS

- EVALUATE IF THE BASELINE DATA ON MASSACHUSETTS BAY IS NOW SUFFICIENT TO CAPTURE CHANGES THAT MIGHT OCCUR
  - to develop testable hypotheses

QUESTIONS FOR THE WORKSHOP

Are the baseline data sufficient for understanding the system? Why or why not?

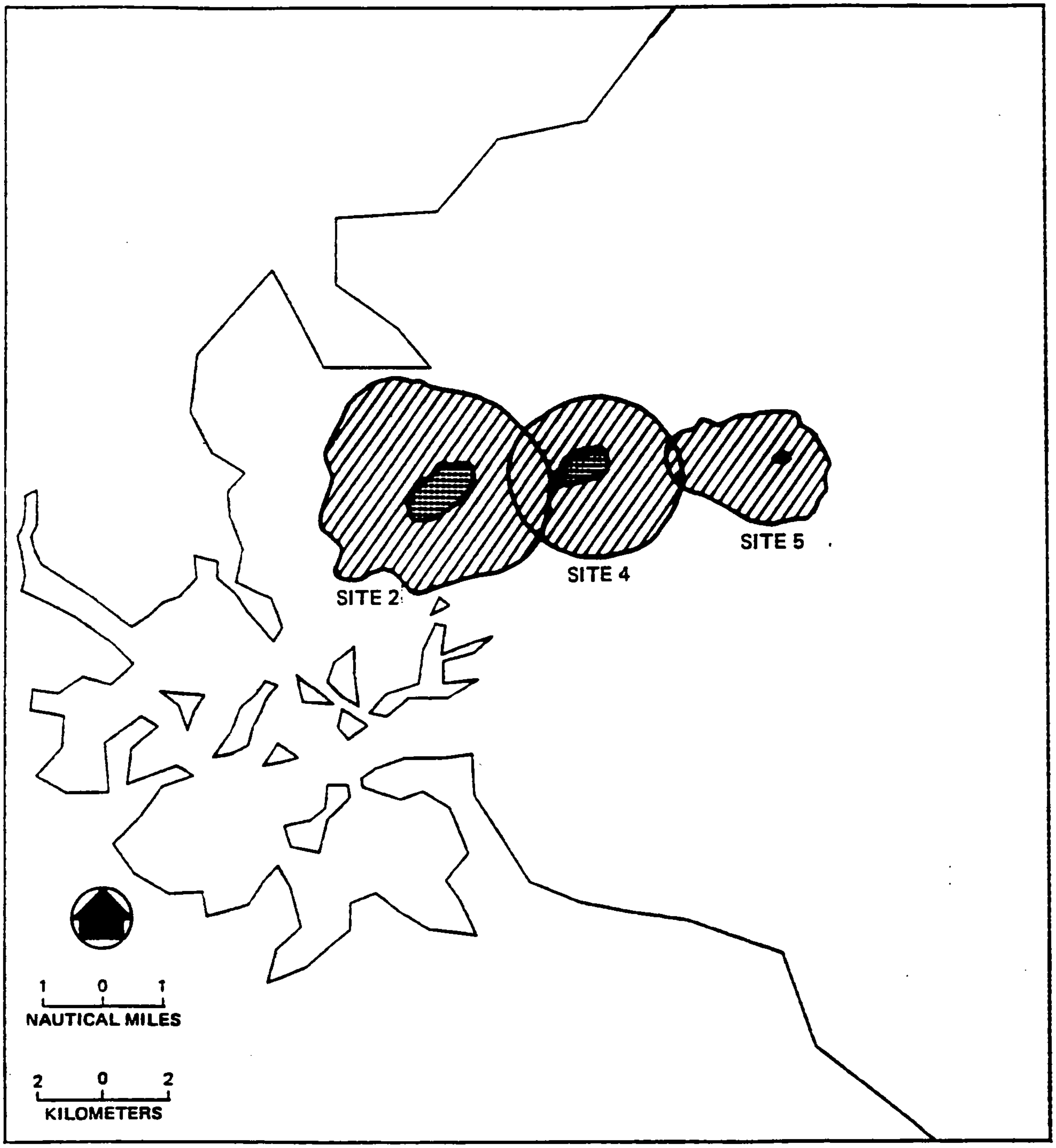
To what extent does the present understanding allow focus on a reduced set of parameters? Stations?

Is coverage in space and time adequate?

What is the role of the various measurements in the monitoring program?

What are meaningful levels of change in this system?

Can monitoring questions now be phrased as quantitative hypotheses reflecting meaningful levels of change?



LEGEND

CHANGED AREA

DEGRADED AREA

FIGURE 5.1.3.a. AREAS OF PREDICTED CHANGED AND DEGRADED BENTHIC COMMUNITIES DUE TO ORGANIC ENRICHMENT UNDER STRATIFIED CONDITIONS WITH PRIMARY TREATMENT FOR ALL SITES

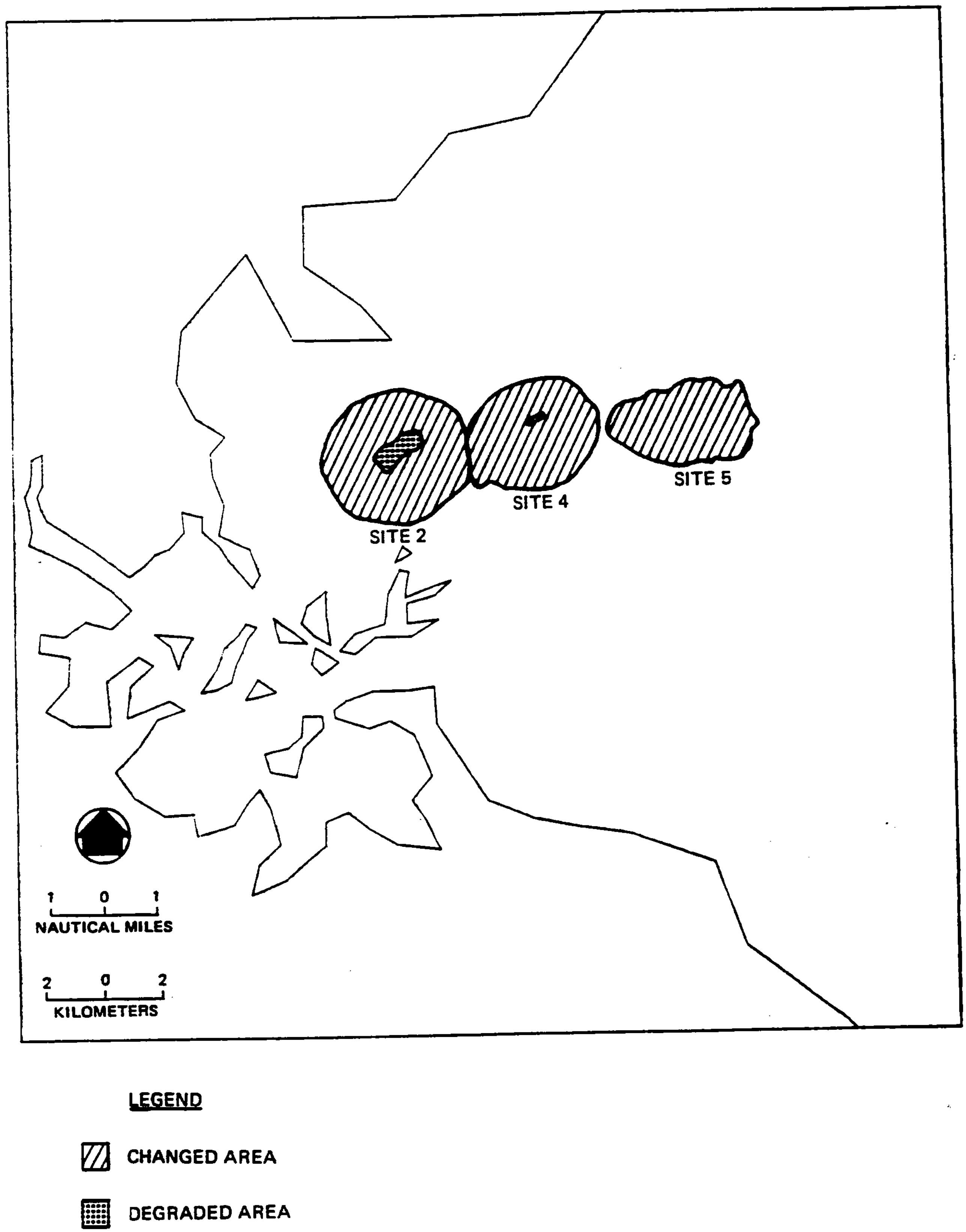


FIGURE 5.1.3.c. AREAS OF PREDICTED CHANGED AND DEGRADED BENTHIC COMMUNITIES DUE TO ORGANIC ENRICHMENT UNDER NON-STRATIFIED CONDITIONS WITH PRIMARY TREATMENT FOR ALL SITES

TABLE 5.1.3.a SUMMARY OF AREAL EXTENT OF PREDICTED SEDIMENT ORGANIC ENRICHMENT

	Primary Treatment		Secondary Treatment	
	AREA DEGRADED (Km^2) (>1.5gC/m^2/d)	AREA CHANGED (Km^2) (0.1-1.5gC/m^2/d)	AREA DEGRADED (Km^2) (>1.5gC/m^2/day)	AREA CHANGED (Km^2) (0.1-1.5gC/m^2/day)
Non-Stratified Conditions				
SITE 2	0.8	16.9	0	3.0
SITE 4	0.02	13.7	0	1.9
SITE 5	0	10.4	0	0.6
Stratified Conditions				
SITE 2	2.2	32.7	0	4.9
SITE 4	1.2	18.9	0	3.2
SITE 5	0.05	12.2	0	3.1

SOFT-BOTTOM BENTHOS IN THE NEARFIELD AND FARFIELD

NOTE: Redlined text indicates changes since the draft monitoring plan was published.

Purpose: **Detect either short- or long-term change in the sediment depositional areas. Provide information on spatial extent of changes.**

Question: **Has the soft-bottom community changed? (R-8, R-13)**

Have the concentrations of contaminants in sediments changed? (R-12)

Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased? (R-6)

Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments? (R-13)

Measurement: Benthic species composition and abundance using nested 0.3 mm and 0.5-mm sieves; PAHs, LABs, PCBs, pesticides, metals, TOC, grain size, and *Clostridium perfringens* in 0- to 2-cm fraction; sediment profile camera images (Replaced with measurement of apparent RPD on faunal grabs after 1992).

Location: 15 - 20 sites within nearfield (modified to 9 stations and analysis of triplicate grabs in 1993/1994) and 8 farfield sites (changed from 12 to 11 stations in 1993/1994 with analysis of triplicate grabs) throughout Massachusetts Bay and Cape Cod Bay for traditional grabs; same sites in nearfield for sediment profile camera imaging (See above).

Frequency: Once per year (end of summer) for biology, chemistry, and sediment profile camera imaging. A single replicate will be taken in the nearfield and triplicates taken in the farfield.

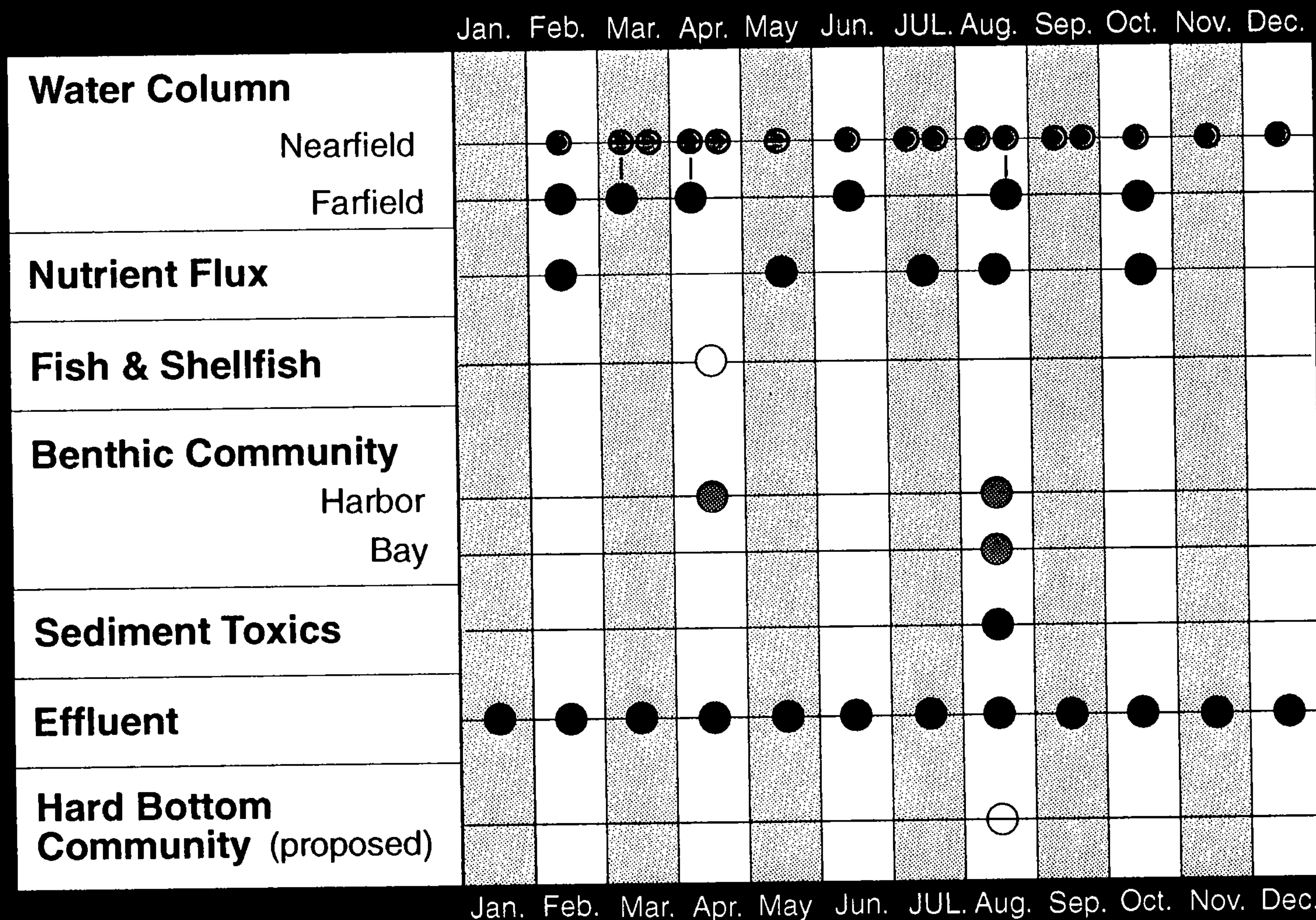
Detectable change: 10 - 100% in nearfield and 10 - 10000% in farfield for most parameters based on results of power analyses using existing data.

Data analysis: Traditional benthic ecological statistical analysis to define stations and interrelationships between stations based on faunal composition and chemistry. Regression analysis among parameters to assess possible cause of changes.

HARD-BOTTOM BENTHOS (SPECIAL STUDY)

Purpose:	**Characterize summertime (stratified period) changes in hard-bottom areas. Provide information on spatial extent of changes.**
Question:	**Has the hard-bottom community changed? (R-8, R-13)**
Measurement:	Color video camera images to determine semi-quantitative percent cover and identify dominant species.
Location:	8 sites, ideally along two transects in X pattern within nearfield. Exact locations to be determined based on bottom geology and with reference to previously occupied stations.
Frequency:	Once per year (end of summer).
Detectable change:	An adequate baseline has not been established for these parameters. Baseline data from the first survey will be used to evaluate these parameters as indicators of change and a sampling plan with corresponding detectable change will be established at that time.
Data analysis:	Qualitative and semi-quantitative interpretation of video images. Also, use data from other hard-bottom studies in region (e.g., Broad Sound survey and near-diffuser site surveys conducted by Northeastern University).

BASELINE OUTFALL MONITORING SCHEDULE



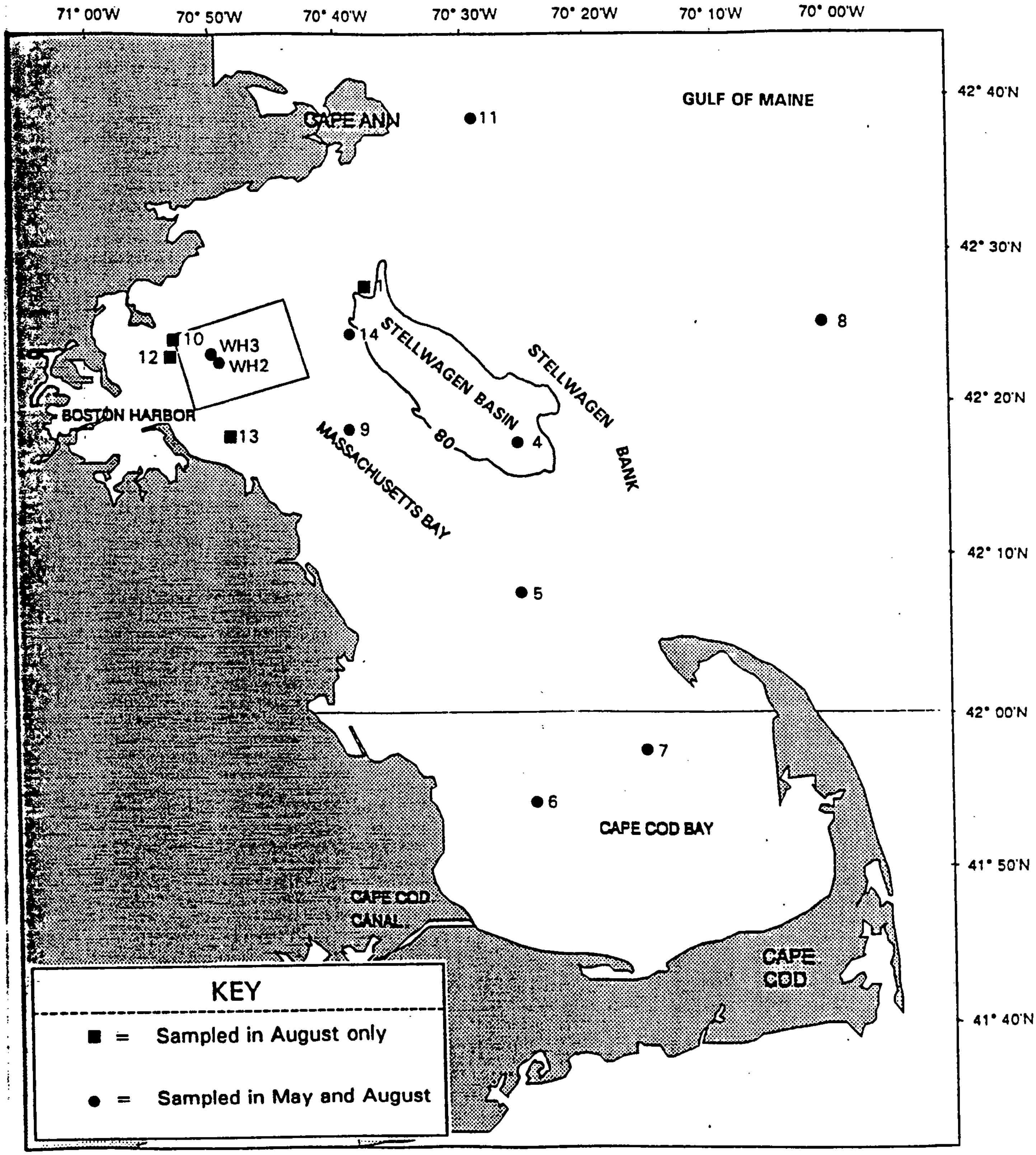


Figure 1. Location of Farfield Stations Sampled in May and August 1992. The rectangular box represents the nearfield area shown in detail in Figure 2.

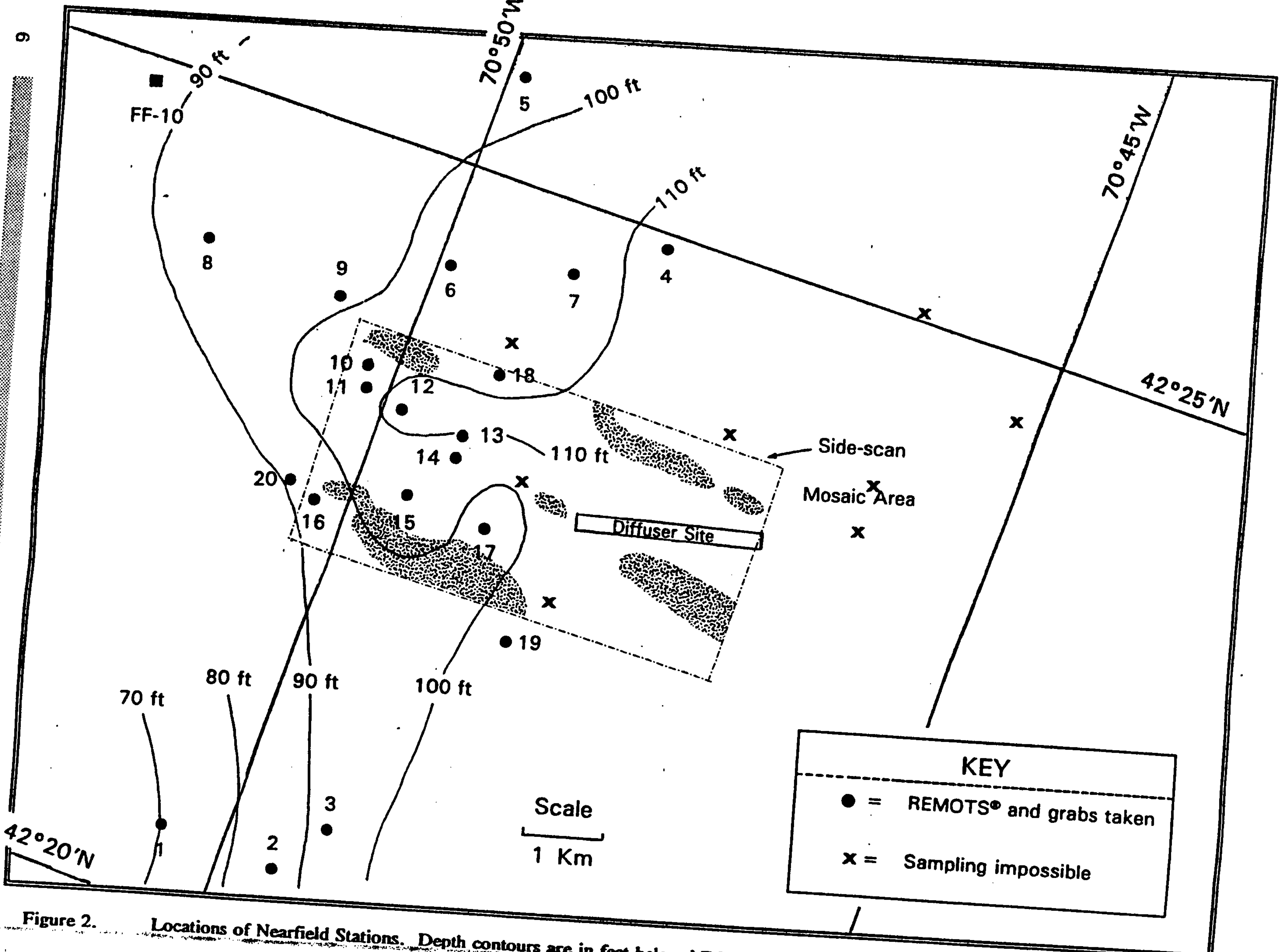


Figure 2. Locations of Nearfield Stations. Depth contours are in feet below MLW. Side scan mosaic area (dashed box) after Butman et

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OMTF Decisions re Soft-Bottom Benthic Monitoring
Meeting of July 15, 1993

OMTF Mandate

- MWRA was directed to change from a 20 station, 1 replicate/station design in the near-field to a replicated design using roughly the same level of effort. This roughly equated to 8 stations, sampled as are far-field reference stations (3 biology, 2 chemistry).
- MWRA was given approval to cease sampling at station FF-8 (east of Stellwagen Bank) and to re-allocate those sample analysis resources to the near-field study. This resulted in a total of 9 near-field stations.

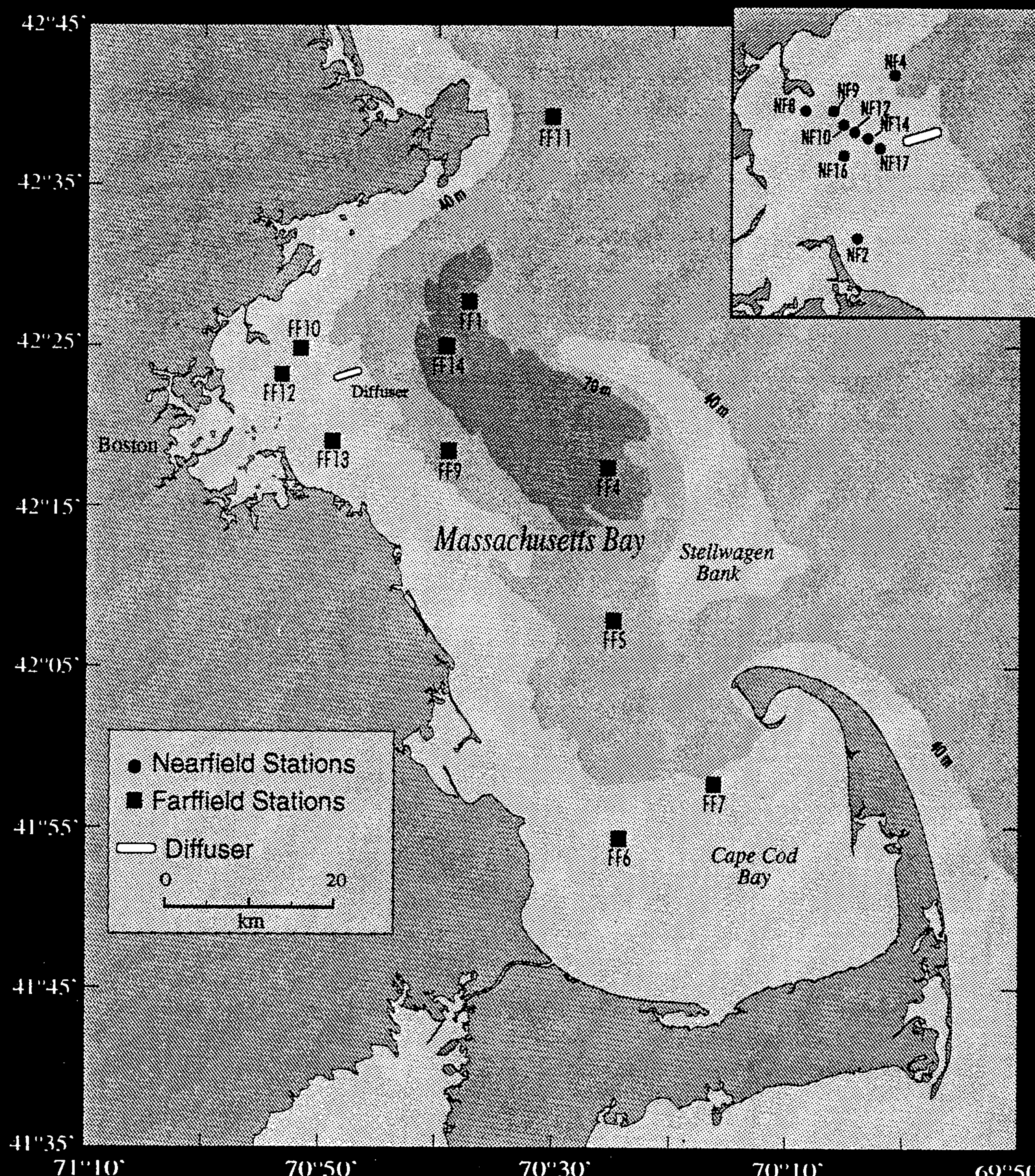
OMTF Guidance The following technical concerns were voiced by OMTF members for MWRA to consider in selecting near-field stations for continued monitoring:

- Attempt to capture the range in community types and habitat seen in the 1992 survey.
- Focus effort in the most stable, depositional areas.
- Attempt to maintain a gradient in distance from the Future Effluent Outfall.

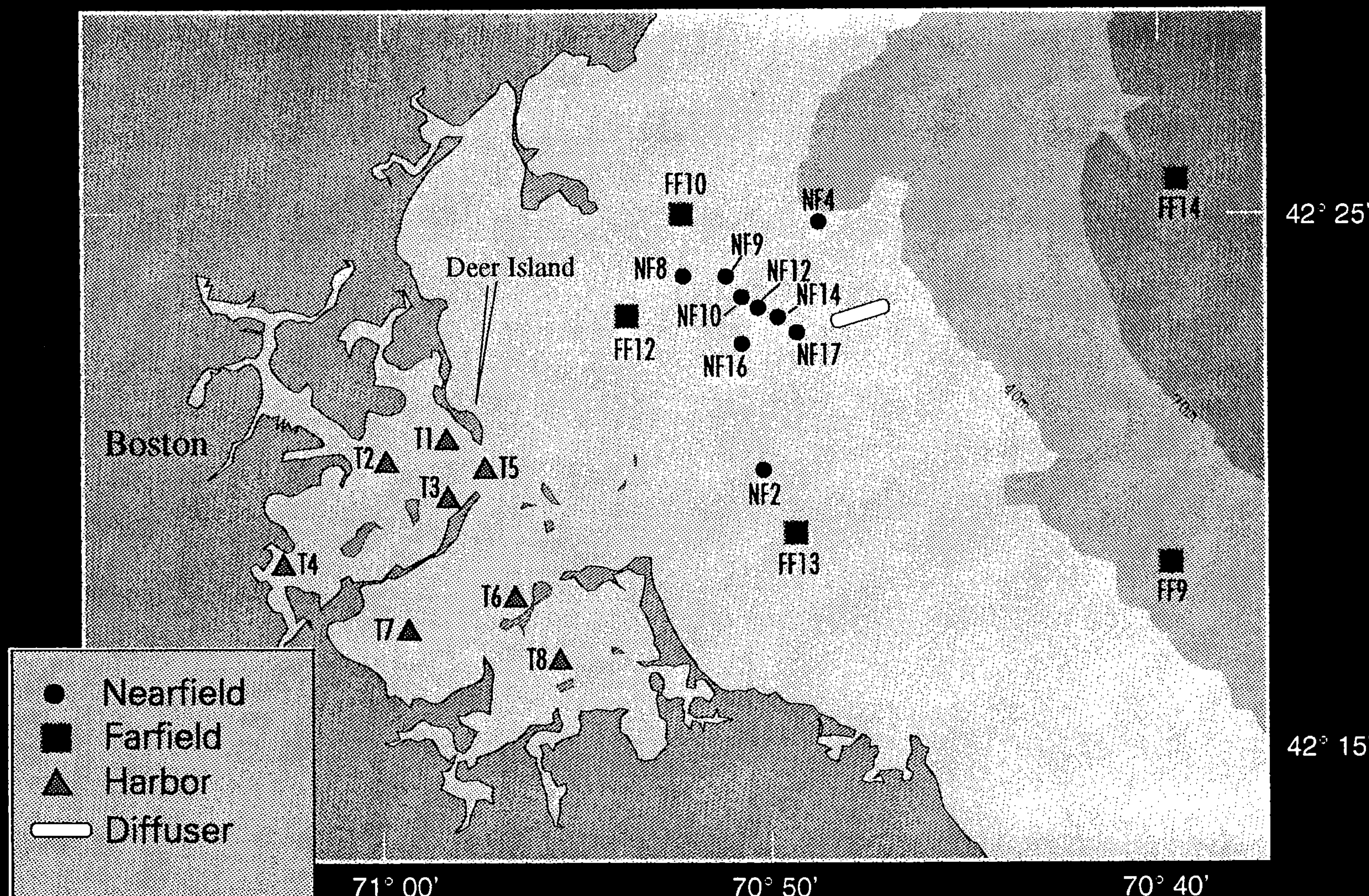
Resulting station list Following consultation with OMTF members, and working with our consultants, we selected Stations NF08, NF02, NF16, NF12, NF09, NF10, NF14, NF04, & NF17 for continued sampling. This list includes:

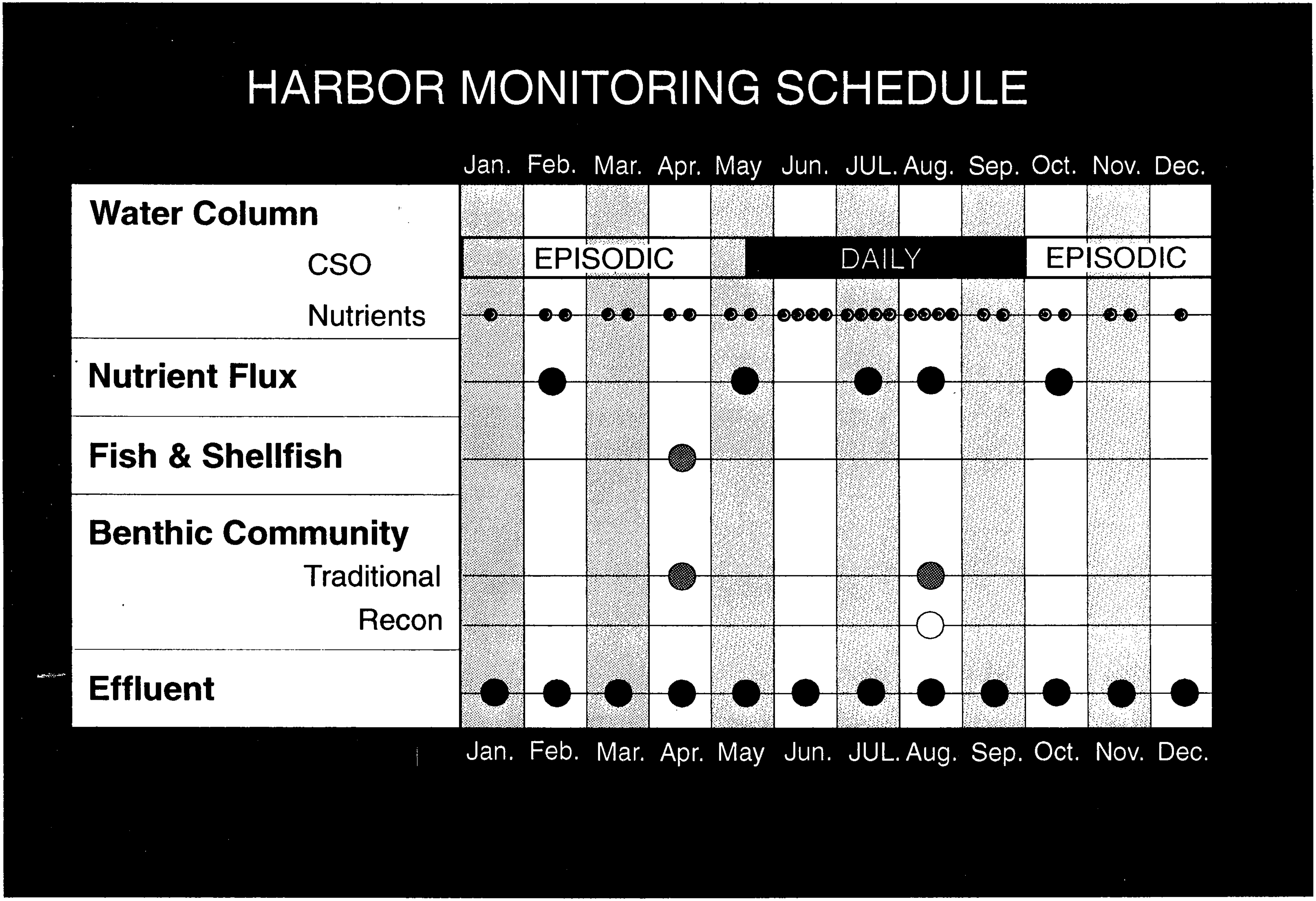
- All stations with more than 70% silt + clay in 1992 samples.
- At least 2 representatives from each of the 3 faunal station clusters identified in 1992 sampling.
- Both of the USGS long-term sediment monitoring stations in the near-field, WH-3 (=NF12) and WH-2 (=NF17).
- A range in distance and direction from the Future Effluent Outfall.

Benthic Stations



BENTHIC STATIONS




HARBOR MONITORING SCHEDULE
Jan. Feb. Mar. Apr. May Jun. JUL. Aug. Sep. Oct. Nov. Dec.
Water Column
CSO
Nutrients
EPISODIC
DAILY
EPISODIC
Nutrient Flux
Fish & Shellfish
Benthic Community
Traditional
Recon
Effluent
Jan. Feb. Mar. Apr. May Jun. JUL. Aug. Sep. Oct. Nov. Dec.

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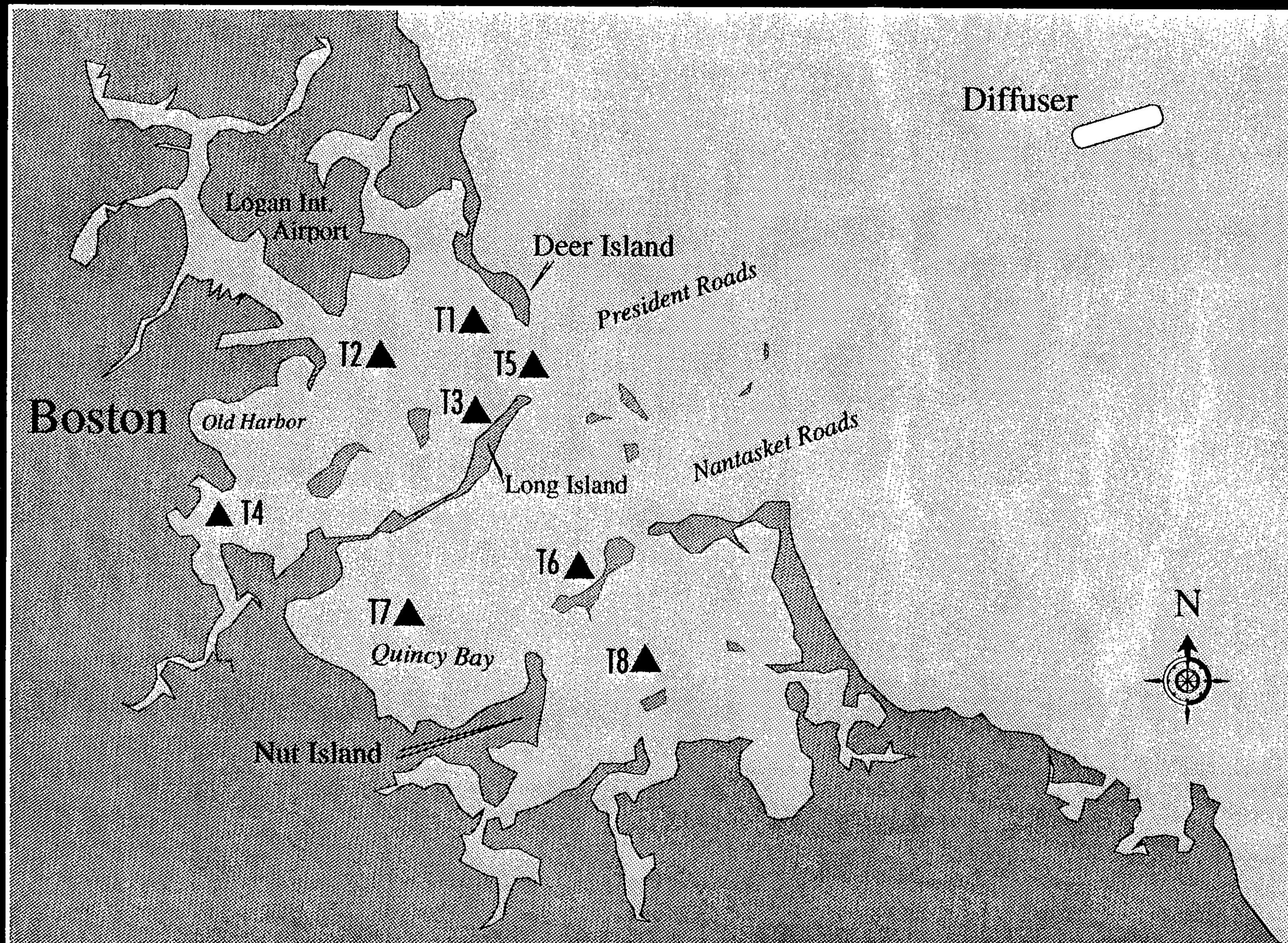
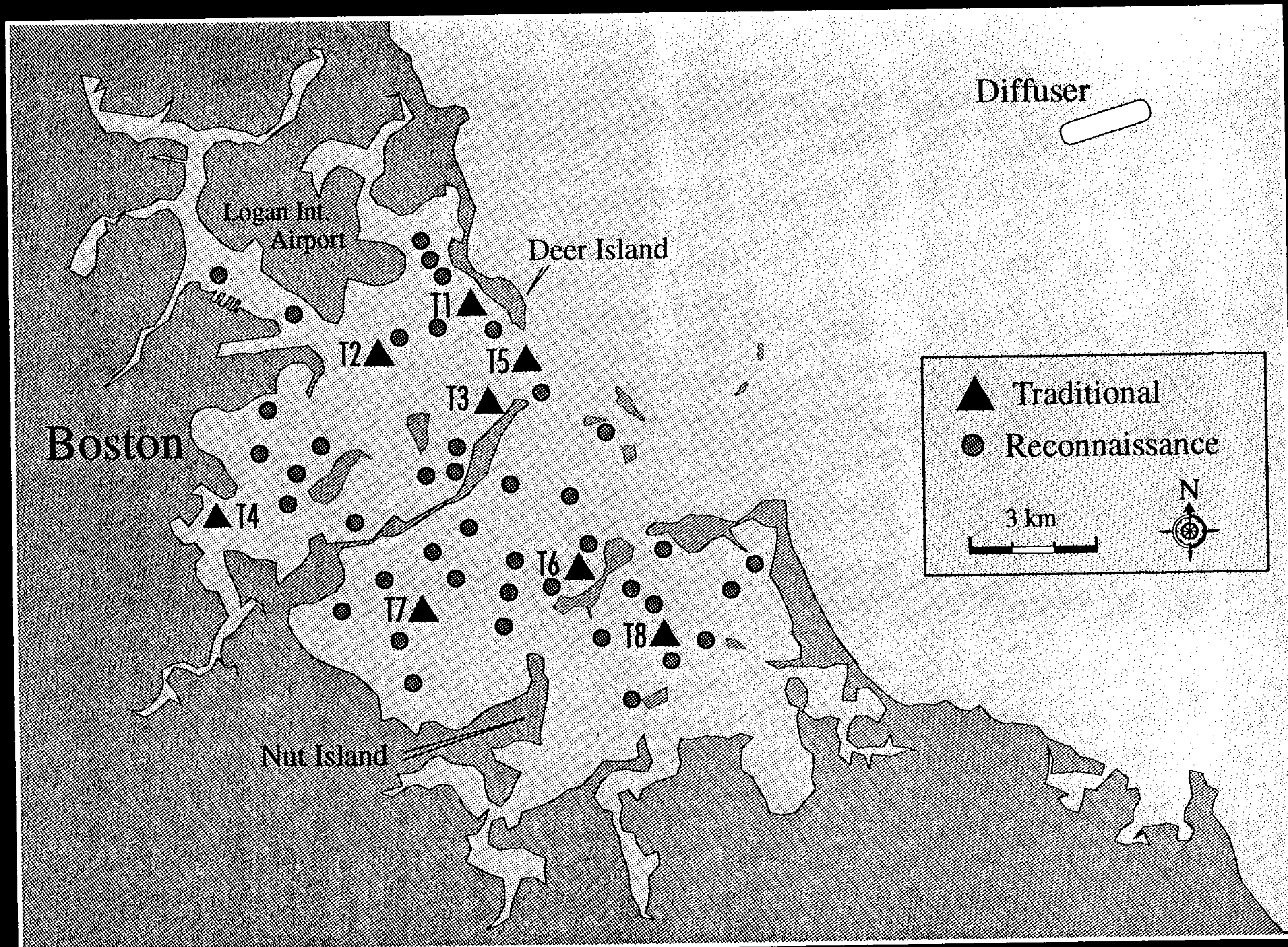
BOSTON HARBOR TRADITIONAL STATIONS



BOSTON HARBOR BENTHIC STATIONS



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Measurements in the MWRA Monitoring Program

Benthic Studies

Parameter	Harbor	Outfall	CSO
Benthic macrofauna			
Soft-bottom	○	○	
Sediment chemistry			
Toxics (Organics and metals)		○	○
C. *perfringens*	○	○	○
TOC	○	○	○
Grain Size	○	○	○
Coprostanol			○
Sediment profiles (camera)[a]	○		

[a] Image analysis includes measurements such as RPD (redox potential depth), sediment texture, and bottom community type

Measurements in the MWRA Monitoring Program

Chemical and Related Parameters

Analyte	Effluent	Tissue[a,b]	Sediment	Water Column	Benthic Flux
Nutrients	○		○	○	○
Metals	○	○	○		
PCB (congeners)	○	○	○		
Pesticides	○	○	○		
PAHs	○	○	○		
LABs	○		○		
Sterols	○		○		
Coprostanol			○		
C. *perfringens*	○		○		
Grain Size			○		
TOC			○		
^{15}N	○	○			
^{34}S	○	○			
Lipids		○			

[a] Histopathology of flounder liver and flounder age are also determined

[b] Lobster tail and hepatopancreas; flounder filet and liver

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( ) Modified for 1993/1994

Table 3. Samples to be Collected During the Soft-Bottom Monitoring Surveys

	Harbor Surveys					*Outfall Surveys*			
	Traditional		*Reconnaissance*		*CSO Study*[1]	*Nearfield*		*Farfield*	
	Survey	*Total*	*Survey*	*Total*	*Total*	*Survey*	*Total*	*Survey*	*Total*
Number of Stations	8	—	50	—	14	20 (9)	—	12 (11)	—
Benthic Infauna	24	96	24	48	0	60 (27)	120 (54)	36 (33)	72 (66) (87)
Analyzed	24	96	24	48	0	20 (27)	40 (54)	36 (33)	72 (66) (87)
Archived	0	0	0	0	0	40 (0)	80 (0)	0	0
Sediment Chemistry[2]	8	32			42	20 (9)	40 (18)	24 (22)	48 (44)
Analyzed	0	0			42	20 (18)	40 (36)	24 (22)	48 (44)
Archived	8	32			0	0	0	0	0
Ancillary Physicochemical Parameters									
Total Organic Carbon	8	32			42	20 (18)	40 (36)	24 (22)	48 (44)
Grain Size	8	32			42	20 (18)	40 (36)	24 (22)	48 (44)
Clostridium perfringens	8	32			42	20 (18)	40 (36)	24 (22)	48 (44)
Coprostanol					42				
Sediment Profile Images			150	300					

[1]A detailed Scope of Work for the CSO Study has not been developed; there is only one survey.
[2]1992 samples to be analyzed under Task 12 are not included in this table.

Table 4. Field Samples and Measurements

Parameter	*Stations*[1]	*#/Volume*	*Container*	*Shipboard Processing/ Preservation*
Macrofauna	T1-T8 NF1-NF20 FF1-FF14	3 grabs	Clean, labeled jar	Wash over nested 0.5- & 0.3-mm mesh sieves. Fix in buffered 10% formalin
Macrofauna	R2-R25	1 grab	Clean, labeled jar	Wash over 0.5-mm mesh sieve. Fix in buffered 10% formalin
Chemistry	T1-T8[2] NF1-NF20 FF1-FF14	1-2 grabs[3]/ 400 mL	Clean, labeled jar	Use teflon scoop to remove subsample from top 0-2 cm of sediment surface. Freeze (−20° C)
Grain Size	T1-T8 NF1-NF20 FF1-FF14	1-2 grabs[3]/ 75 mL	Sterile WhirlPak™ bag	As for chemistry
Clostridium perfringens	T1-T8 NF1-NF20 FF1-FF14	1-2 grabs[3]/ 100 mL	Sterile sample cup	As for chemistry
Sediment Profile Images	T1-T8 R2-R43	3 per station	—	—
Weather	All	—	—	Record general conditions
Seas	All	—	—	Record general conditions
Bottom Depth	All	—	—	Record to nearest 0.1 m
Grab Penetration	All[4]	—	—	Record to nearest 0.5 cm
Grab Sediment Volume	All[4]	—	—	Record to nearest 0.5 L
Prism Cradle Penetration[5]	T1-T8 R2-R43	—	—	Record to nearest 0.5 cm
Sediment Texture	All[4]	—	—	Describe qualitatively
Reduction-oxidation 1Potential Discontinuity Depth	All[4]	—	—	Record to nearest 0.5 cm

[1]Stations T1-T8 and R2-R43 are part of the Boston Harbor studys; NF1-NF20 are Outfall nearfield stations; FF1-FF14 are Outfall farfield stations; there are no stations designated FF2 and FF3.
[2]At traditional stations a full chemistry sample will be collected although subsample is required for TOC analysis only; the remainder will be archived.
[3]Subsample is obtained from 1 grab at T1-T8 and NF1-NF20; from 2 grabs at FF1-FF14.
[4]Record for all stations at which grab samples are taken.
[5]Record depth of penetration of sediment profile camera prism cradle relative to support frame.

Table 5. Parameters Measured from Sediment Profile Images

Parameter	*Units*	*Method*	*Description*
Sediment Grain Size	Modal phi invertal	V	Determined from comparison of image to images of known grain size
Prism Penetration	cm	V	Average of maximum and minimum distance from sediment surface to bottom of prism window
Sediment Surface Relief	cm	V	Maximum minus minimum depth of penetration
Reduction-oxidation Potential Discontinuity Depth (from color change in sediment)	cm	CA	Area of aerobic divided by width of digitized image
Presence/Absence of Dredged Material	cm, cm^2	V	Measure thickness above original sediment surface and delineate area
Methane/Nitrogen Gas Voids	#, cm, cm^2	V, CA	Count, measure depth from sediment surface, delineate area
Epifaunal Occurrence	#	V	Count, identify
Tube Density	#/cm^2	V, CA	Count
Tube Type			
Burrow Structures	—	V, CA	Identify
Pelletal Layer	cm, cm^2	V, CA	Measure thickness, area
Microbial Aggregations			
Infaunal Occurrence	#	V, CA	Count, identify
Feeding Voids	#, cm, cm^2		Measure thickness, area
Apparent Successional Stage	—		

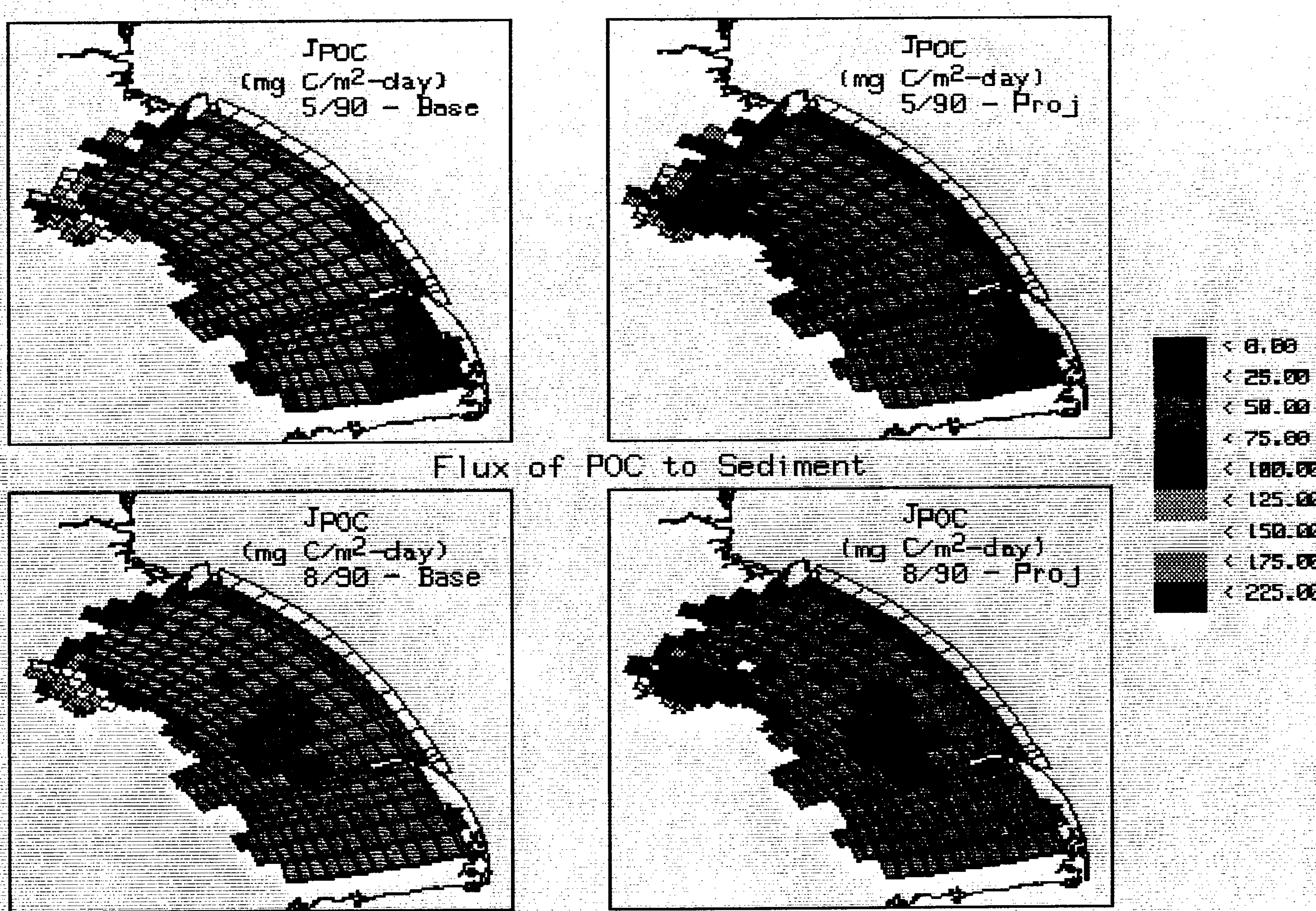
V: Visual measurement or estimate
CA: Computer analysis

Table 10. Sediment Chemistry Analytes and Method Detection Limits (MDL)

Analyte	*MDL*[1]	*Analyte*	*MDL*[1]
Physical Sediment Parameters/Sewage Tracers		**PAH (continued)**	
Total organic carbon	100	C_1-fluorenes	1
Grain size	—	C_2-fluorenes	2
Clostridium perfringens	—	C_3-fluorenes	2
Linear alkyl benzenes (C_{10}-C_{14})	5[2]	anthracene	1.32
Coprostanol (CSO Study)	—[3]	phenanthrene	1.41
		C_1-phenanthrenes/anthracene	1.74
Metals		C_2-phenanthrenes/anthracene	2
Al Aluminum	6000	C_3-phenanthrenes/anthracene	2
Fe Iron	20	C_4-phenanthrenes/anthracene	2
Ag Silver	0.25	dibenzothiophene	1
Cd Cadmuim	0.025	C_1-dibenzothiophenes	1
Cr Chromium	10	C_2-dibenzothiophenes	1
Cu Copper	5	C_3-dibenzothiophenes	1
Hg Mercury	0.025	fluoranthene	2.70
Ni Nickel	6	pyrene	2.42
Pb Lead	5	C_1-fluoranthenes/pyrenes	2
Zn Zinc	3	benzo[*a*]anthracene	1.49
		chrysene	1.83
Polychlorinated biphenyls		C_1-chrysene	2
2,4,-Cl_2(8)	0.87	C_2-chrysene	2
2,2',5-Cl_3(18)	0.48	C_3-chrysene	2
2,4,4'-Cl_3(28)	0.23	C_4-chrysene	2
2,2',3,5'-Cl_4(44)	0.67	benzo[*b*]fluoranthene	1.40
2,2',5,5'-Cl_4(52)	0.26	benzo[*k*]fluoranthene	1.67
2,3',4,4'-Cl_4(66)	0.43	benzo[*a*]pyrene	0.99
3,3',4,4'-Cl_4(77)	0.60	dibenzo[*a,h*]anthracene	1.39
2,2'4,5,5'-Cl_5(101)	0.49	benzo[*g,h,i*]perylene	2.56
2,3,3',4,4'-Cl_5(105)	0.60	indeno[1,2,3-*c,d*]pyrene	2.36
2,3',4,4'5-Cl_5(118)	0.45	perylene	4.63
3,3',4,4',5-Cl_5(126)	0.60	biphenyl	1.15
2,2',3,3,4,4'-Cl_6(128)	0.34	benzo[*e*]pyrene	1.51
2,2',3,4,4',5-Cl_6(138)	0.45	dibenzofuran	1
2,2'4,4',5,5'-Cl_6(153)	0.82	**Pesticides**	
2,2'3,3,4,4',5-Cl_7(170)	0.67	Hexachlorobenzene	0.28
2,2',3,4,4',5,5'-Cl_7(180)	0.49	Lindane	0.20
2,2',3,4,5,5',6-Cl_7(187)	0.58	Heptachlor	0.54
2,2',3,3',4,4',5,6-Cl_8(195)	0.61	Aldrin	0.42
2,2',3,3'4,4',5,5',6-Cl_9(206)	0.96	Heptachlorepoxide	0.46
Decachlorobiphenyl-Cl_{10}(209)	0.63	alpha-chlordane	0.39
		trans-Nonachlor	0.42
Polynuclear Aromatic Hydrocarbons (PAH)[4]		Dieldrin	0.40
naphthalene	0.48	Endrin	1.14
C_1-naphthalenes	0.87	Mirex	0.49
C_2-naphthalenes	1.19	2,4'-DDD	0.49
C_3-naphthalenes	1.35	4,4'-DDD	0.58
C_4-naphthalenes	2	2,4'-DDE	0.32
acenaphthylene	1.36	4,4'-DDE	0.25
acenaphthene	1.05	2,4'-DDT	0.37
fluorene	0.83	4,4'-DDT	0.62

[1]μg/g dry weight for metals and total organic carbon; ng/g dry weight for organic analytes
[2]Approximately 5 ng/g dry weight per isomer group
[3]To be determined.
[4]Approximate MDLs of 1 and 2 ng/g have been assigned to PAH for which a formal MDL determination has not been performed. The assigned MDLs are based on the analytes known response relative to PAH with determined MDLs and recent historical data.

Future Outfall Location - Sludge Removal - No Additional Treatment



CHARGE TO THE WORKSHOP

To identify issues (questions) that have been resolved and those needed further attention

To refine the role played in the monitoring program by the various parameters being measured

To identify missing/additional measurements

To help resolve meaningful change levels

To provide justification for the level of meaningful change

To identify key parameters (metrics) that are considered to be indicators and endpoints

To identify other ways to present data, other relationships

To help develop statements that can be used as the foundation for developing hypotheses.

To actively participate in discussions and focus on the objectives of the workshop

APPENDIX C

GRAPHICS AND WRITTEN MATERIALS PROVIDED BY MEETING PRESENTERS

APPENDIX C-1

Damian Shea

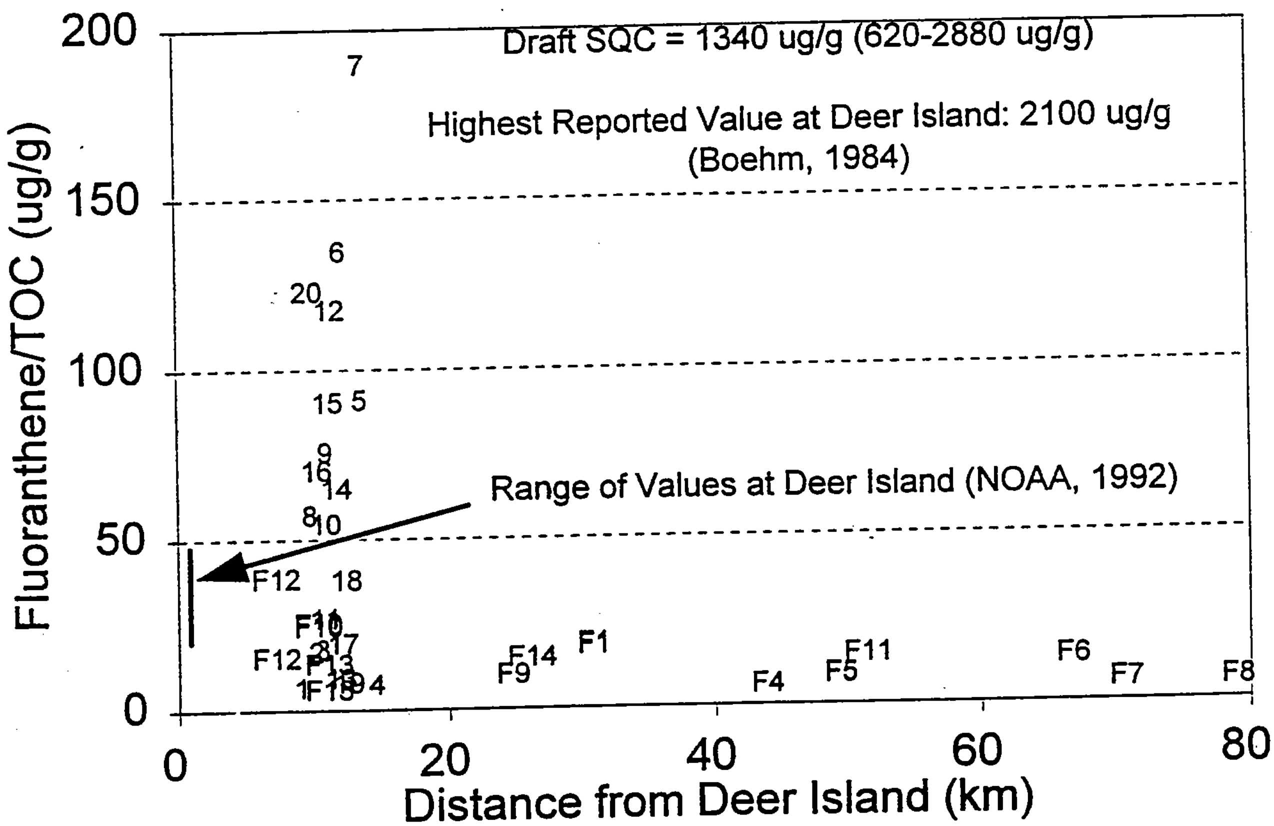
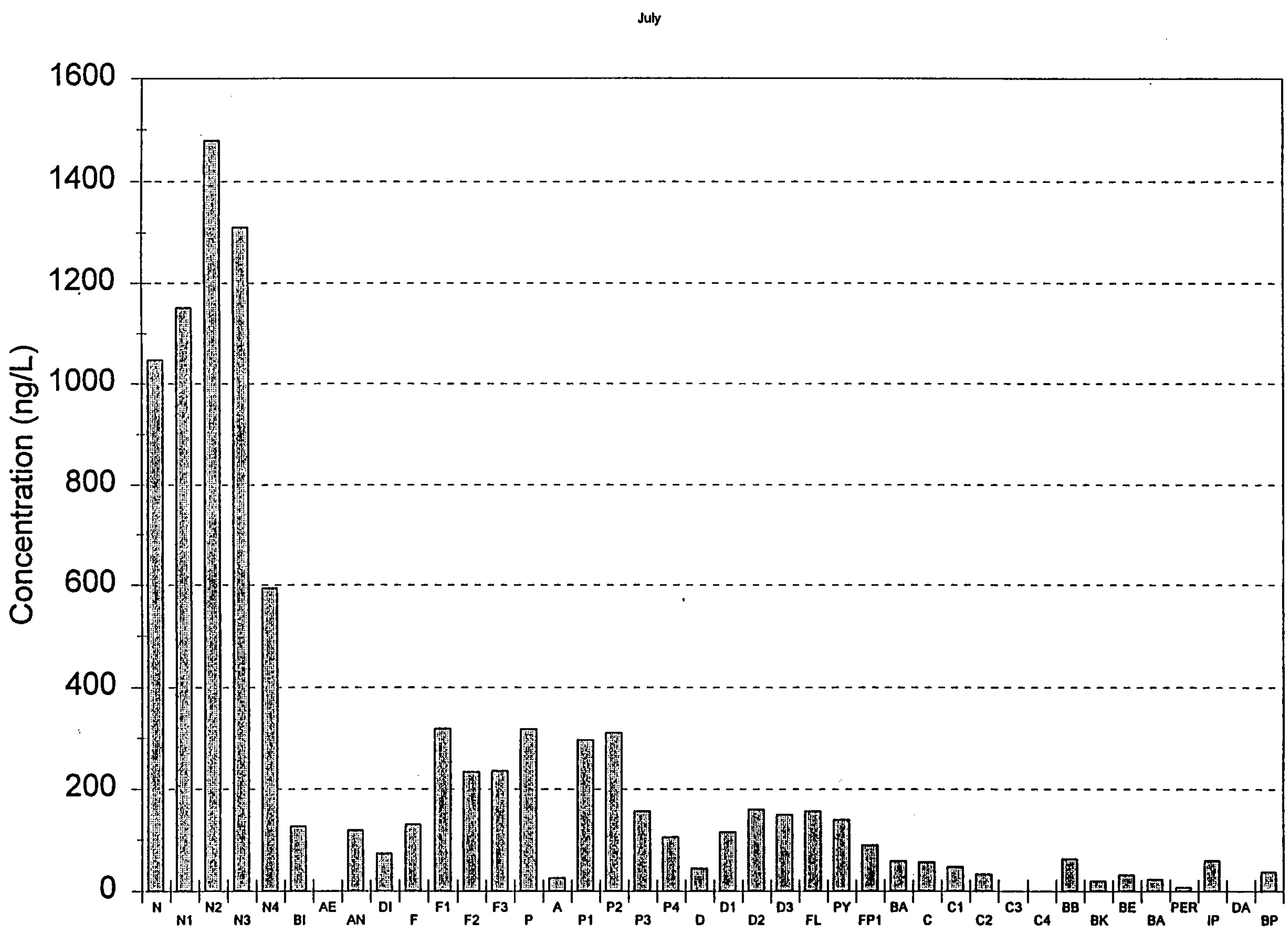


Figure 3-7 **TOC-normalized fluoranthene concentrations as a function of distance from Deer Island.**



July
Concentration (ng/L)
0
200
400
600
800
1000
1200
1400
1600
N
N1
N2
N3
N4
BI
AE
AN
DI
F
F1
F2
F3
P
A
P1
P2
P3
P4
D
D1
D2
D3
FL
PY
FP1
BA
C
C1
C2
C3
C4
BB
BK
BE
BA
PER
IP
DA
BP

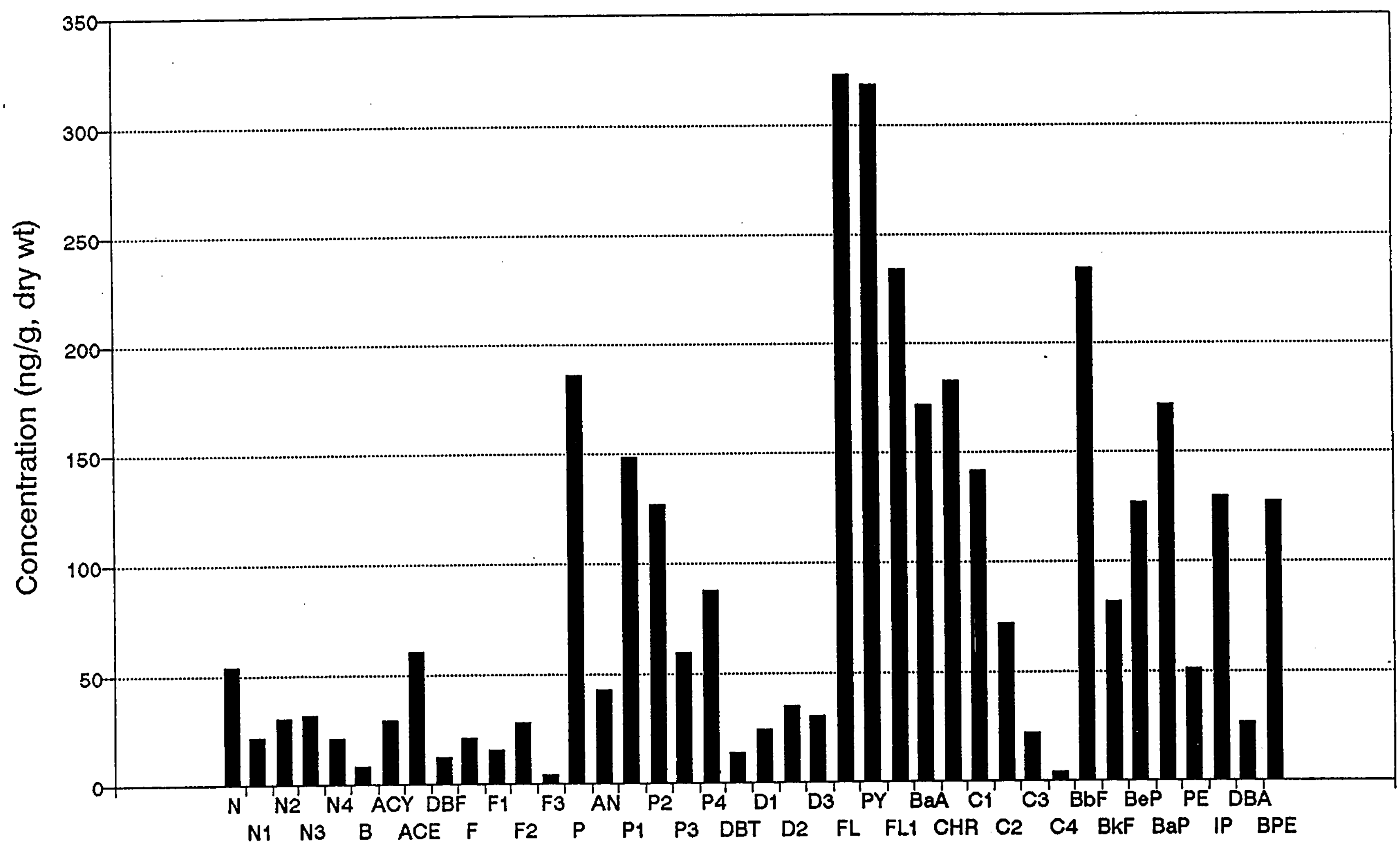


Figure 3-3 **Concentrations of individual PAH in typical sediment sample from the nearfield monitoring box.**

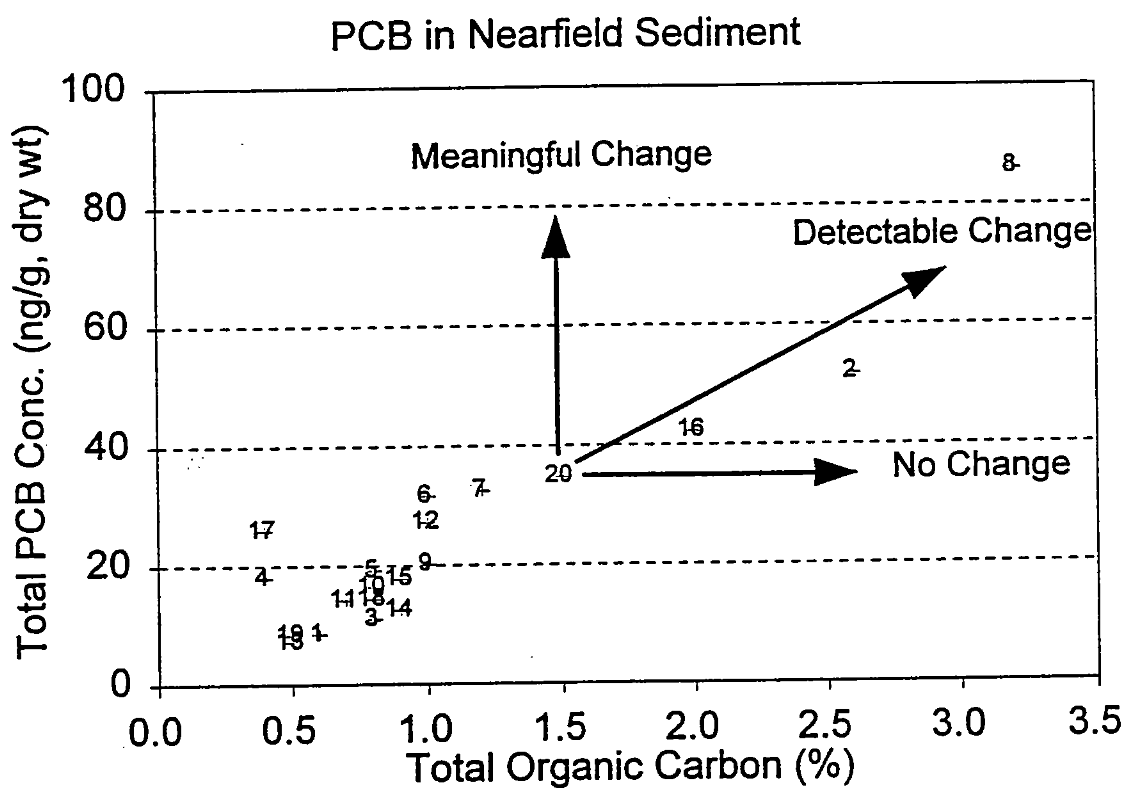


Figure 3-6 **Relationship between PCB and TOC in nearfield sediments and three plausible scenarios of change after effluent is discharged through the new outfall.**

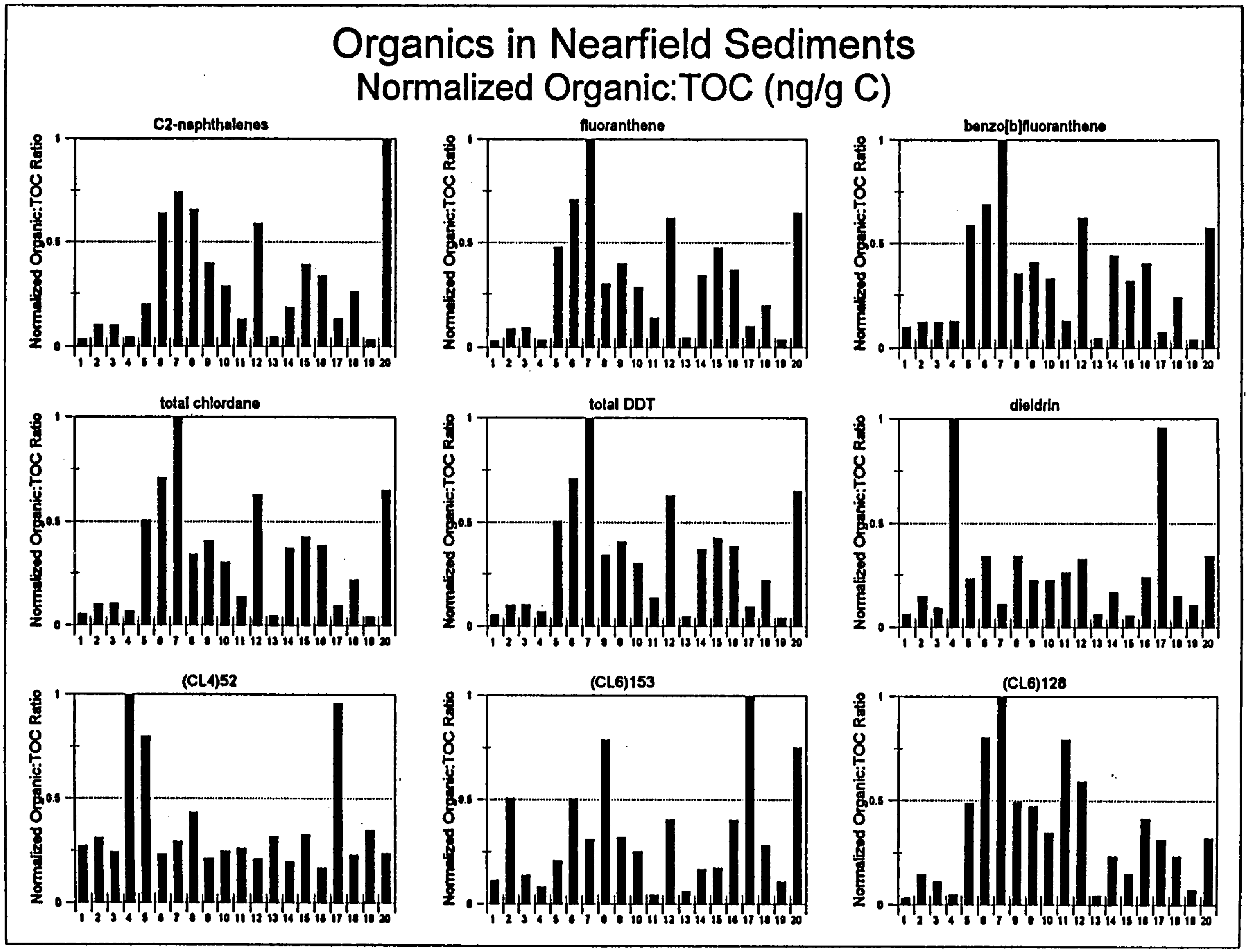


Figure 3-2 Spatial distribution of contaminant is sediment of Massachusetts Bay.
d. Organic contaminant:TOC ratio normalized to the highest value.
Farfield: station locations (x-axis) are shown in Figure 3-1.

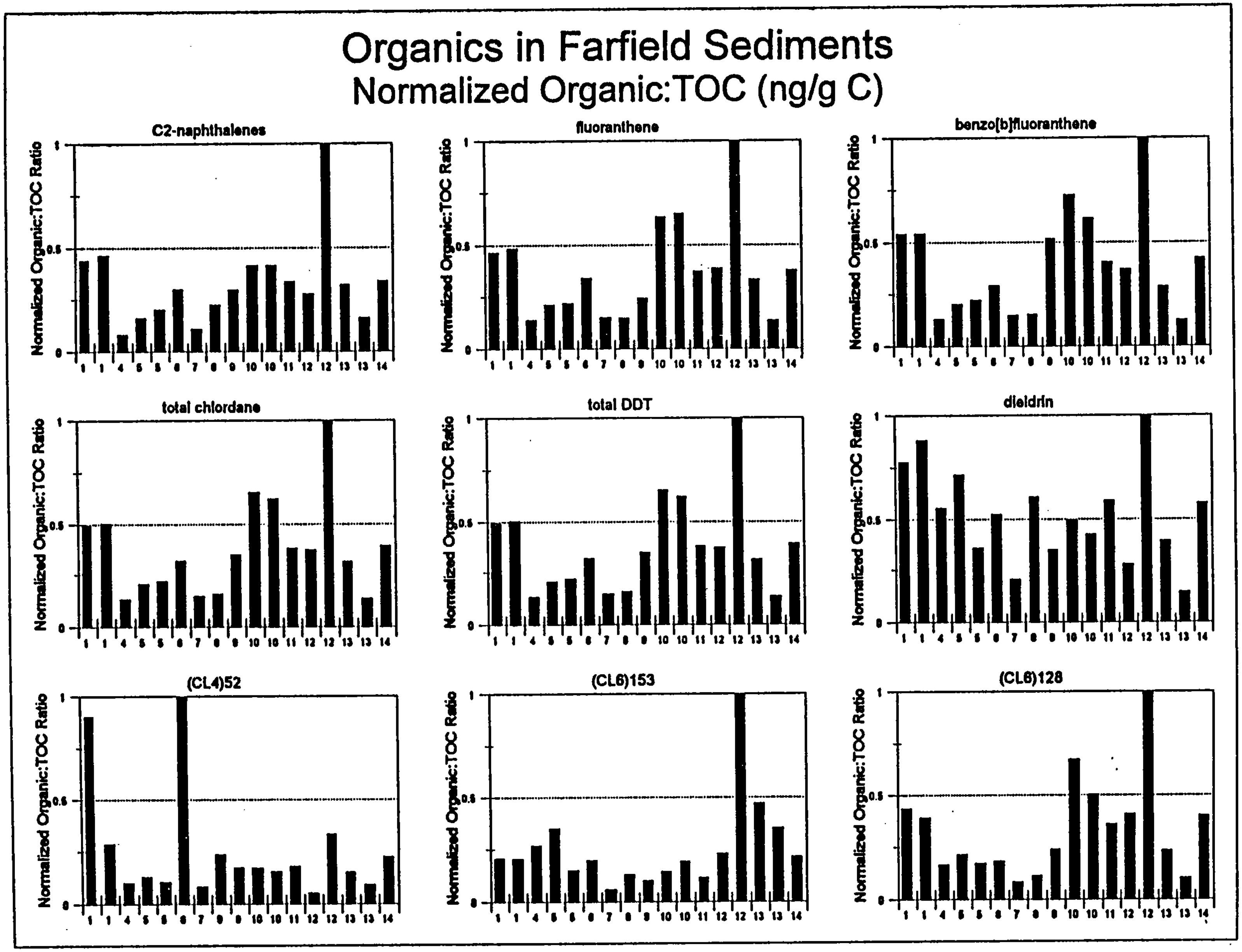


Figure 3-2 Spatial distribution of contaminants in sediment of Massachusetts Bay.
c. Organic contaminant:TOC ratio normalized to the highest value.
Nearfield: station locations (x-axis) are shown in Figure 3-1.

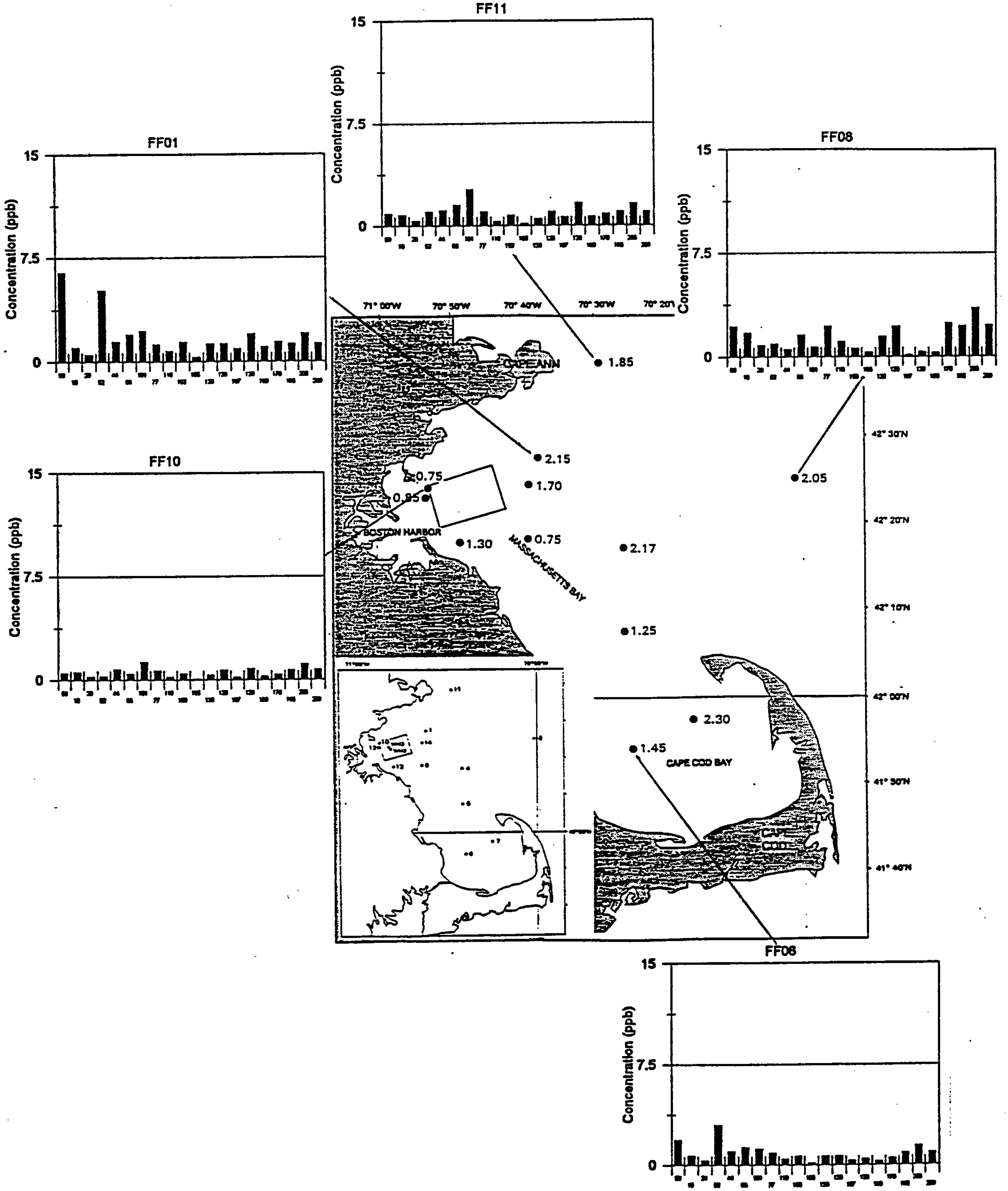


Figure 3-3 Organic contaminant distributions at several farfield stations. Absolute concentrations are shown. TOC values are listed adjacent to the station marker.

b. PCB

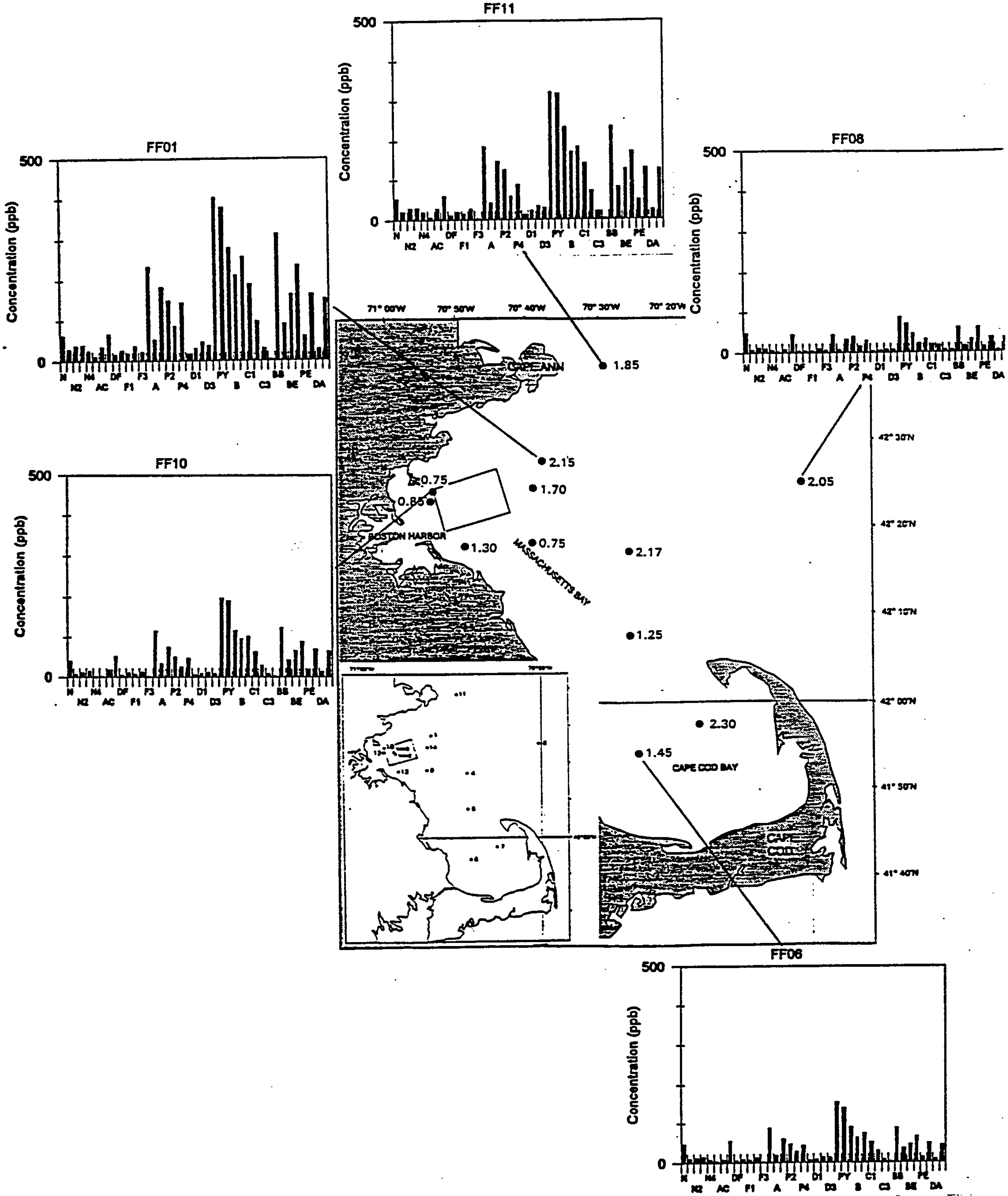


Figure 3-3 Organic contaminant distributions at several farfield stations. Absolute concentrations are shown. TOC values are listed adjacent to the station marker.

a. PAH

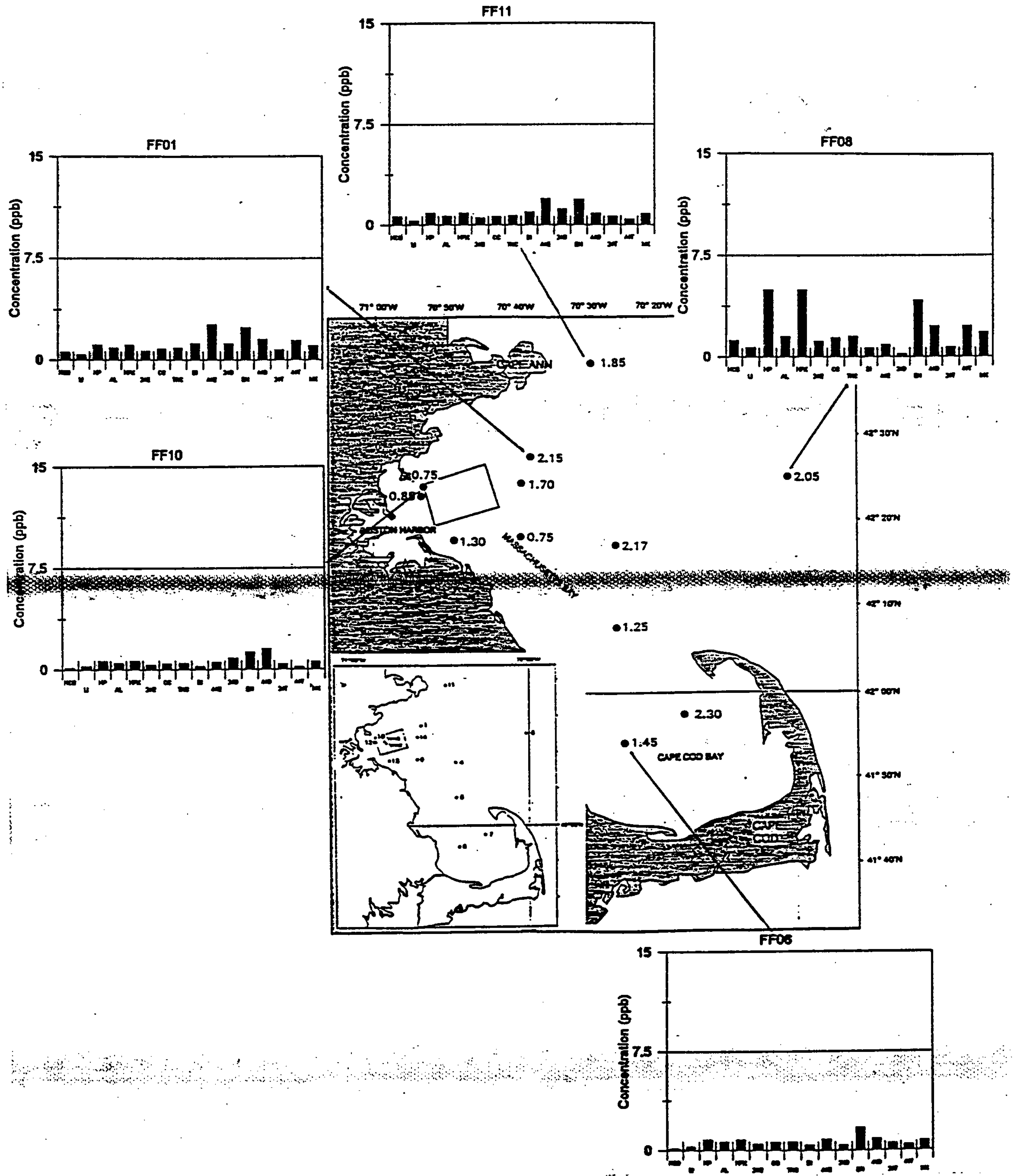


Figure 3-3 **Organic contaminant distributions at several farfield stations. Absolute concentrations are shown. TOC values are listed adjacent to the station marker.**

c. Pesticides

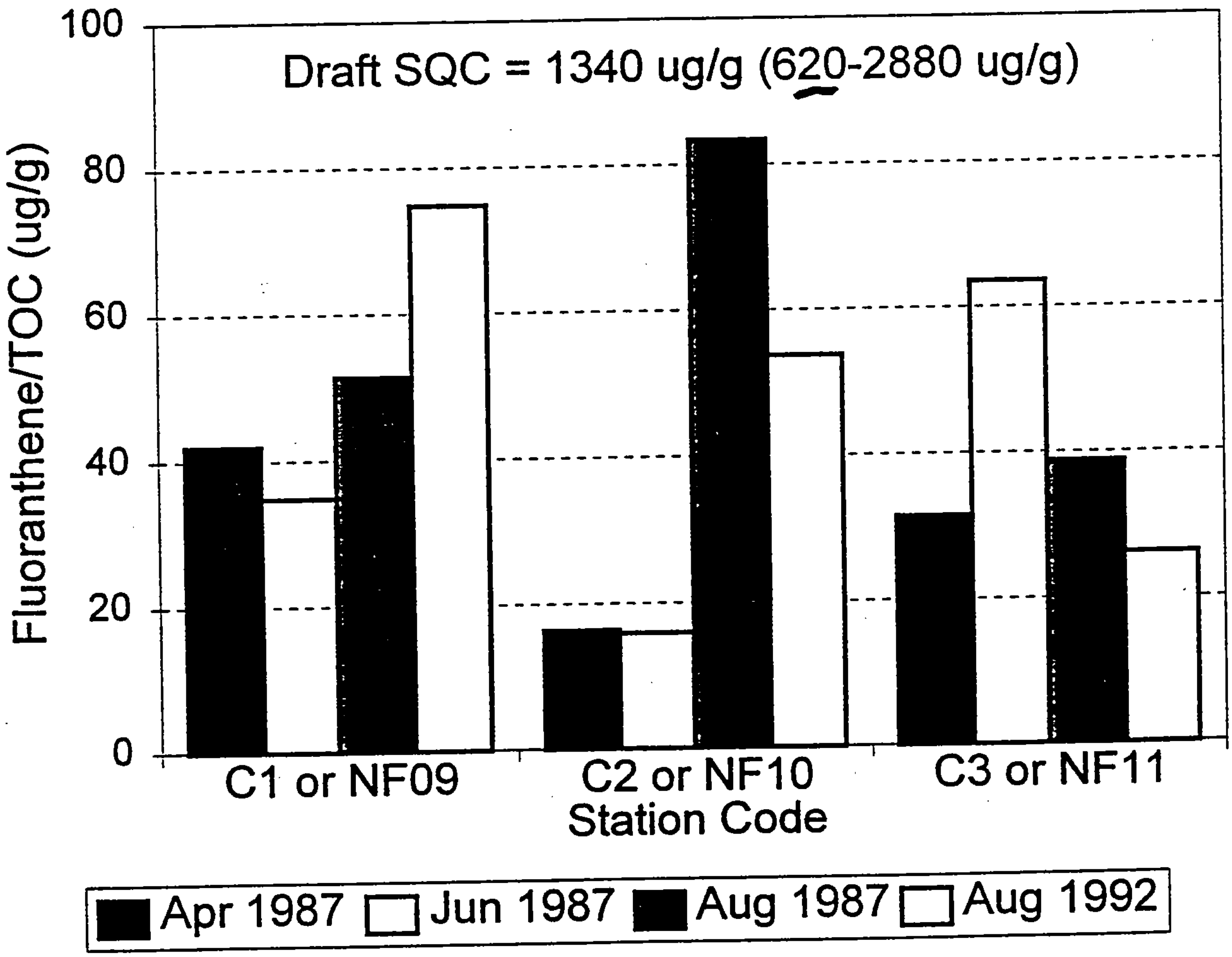


Figure 3-5 Time series of fluoranthene/TOC values at three nearfield sediment stations.

APPENDIX C-2

Mike Bothner

THE DISTRIBUTION OF SILVER IN SEDIMENTS FROM MASSACHUSETTS AND CAPE COD BAYS, and the CHANGES IN CONCENTRATION WITH TIME - PRELIMINARY ANALYSIS

M.H. BOTHNER and M. BUCHHOLTZ ten BRINK
U.S. Geological Survey, Woods Hole, MA 02543

The planned relocation of Boston's outfall for treated sewage effluent from Deer Island to a site 10 miles into Massachusetts Bay has been controversial. The objectives of the scientific monitoring and assessment programs are to determine if the relocation results in environmental and ecological changes in Boston Harbor, Massachusetts Bay and Cape Cod Bay. This study focuses on the spatial distribution and temporal changes in the sediment concentrations of silver, a sensitive indicator of sewage effluent. Prior to the operation of the new ocean outfall, we are establishing a baseline and assessing the temporal variability for silver in response to natural processes, such as major storms. This kind of information is critical for evaluating the influence of the new outfall on environmental conditions in near shore areas off eastern Massachusetts.

This document is the summary of an oral presentation given at the Benthic Sediment and Science Review Meeting, April 18, 1994, at Battelle Ocean Sciences, Duxbury, MA. The figures (accompanied by full explanations), represent slides presented at the meeting and are not discussed in the text. Approximately half of the figures and supporting discussion are also presented in a U.S. Geological Survey Open File Report (Bothner and others, 1993).

Silver concentrations in sewage particles are often 1000 times higher than the background levels in fine-grained sediments, making silver a useful tracer of sewage

5/13/94

particles in coastal Massachusetts and other marine areas. The principal sources of silver in municipal waste streams around the nation are from photographic and x-ray film processing; smaller contributions come from electronics and electroplating industries. In Boston, reclamation of silver by commercial users has resulted in a significantly reduced (80% ?) discharge of silver with sewage between 1980 and 1992.

We have analyzed sediment cores from 10 locations in Massachusetts and Cape Cod Bays. In the surface sediment (0-0.5 cm) at these locations, there is a linear correlation (R^2 = 0.83) between the concentrations of silver and spores from the bacterium Clostridium perfringens, a biological indicator of sewage particles (Keay and others, 1993). This correlation suggests that sewage is the primary source of silver in the harbor and adjacent bays.

Concentrations of silver exceed background levels in surface samples from all locations, including the area in deep (200 m) water east of Stellwagen Bank. The highest concentration (1.8 ppm), found at one site near the future effluent outfall, is at the apparent biological effects threshold (1-2 ppm) estimated by Long and Morgan (1990). The thickness of silver-contaminated sediment is about 50 cm at this site and in Cape Cod Bay and about 15 cm thick at a control station 80 km east of Boston Harbor. Most likely, the penetration of silver to these depths is enhanced by active bioturbation, but the analysis of radioisotopes will be needed to quantify this process.

The concentration of silver, normalized by sediment grain size, generally decreases with distance seaward from the mouth of Boston Harbor. However, the silver concentrations, as well as silver inventories, are anomalously high in Cape Cod Bay. As there are no known local sources of silver, these data suggest preferential deposition in

Cape Cod Bay of sewage particles that were discharged in Boston Harbor. This process may be facilitated by currents which often travel in a southerly direction along the western shore of Massachusetts Bay and sometimes recirculate in a counterclockwise pattern in Cape Cod Bay (Geyer and others, 1992). Such circulation could bring sewage-derived particles from Boston Harbor and the offshore area to Cape Cod Bay. The potential contribution from the small sewage treatment plant at Plymouth (1.8 mg/d) has not yet been evaluated.

On fifteen occasions at approximately 4 month intervals since spring 1989, the USGS has collected cores from one location in Massachusetts Bay (Station WH3 , Fig.1). The analysis of silver and Clostridium perfringens shows low variability through mid October, 1992 and a significant increase by the February 1993 cruise (Fig. 13 and 14). One possible explanation for this increase is transport and deposition of mud from Boston Harbor to Massachusetts Bay as a result of a violent storm on December 11-16, 1992. Our conclusions concerning this time-series data are preliminary. They point out the importance of documenting the natural variability in contaminant concentrations, especially following high energy events.

Continuing work on these sediment cores includes the determination of metal inventories (for Cd, Cr, Cu, Hg, Ni, Pb, V, and Zn) and the chemical associations among metals and other sediment properties, the analysis of radioisotopes and organic compounds, and the estimation of metal and sediment accumulation rates. These data will serve as a valuable baseline with which to assess the magnitude of any chemical changes that may occur in the future as a result of the relocation of the sewage outfall and of changes in the quantity or quality of discharged wastes.

REFERENCES

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Geyer, W.R., Gardner, G.B., Brown, W.S., Irish, J., Butman, B., Loder, T., and Signell, R.P. (1992). Physical oceanographic investigations of Massachusetts and Cape Cod Bays. Final report to the Massachusetts Bays Program, 100 Cambridge Street Room 2006, Boston, MA 02202. 497 p.

Keay, K., Mickelson, M., and Shea, D., (1993). Loading to and distribution of the sewage indicator Clostridium perfringens in the sediments of Boston Harbor and the Massachusetts Bays. GSA Abstracts with Programs, v.25, no. 6, p. A-127.

Long, E.R. and Morgan, L.G. (1990). The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program. NOAA *Technical Memorandum*, NOS/OMA-52. Seattle, WA: Ocean Assessments Division, NOS/NOAA. pp. 175 + appendices.

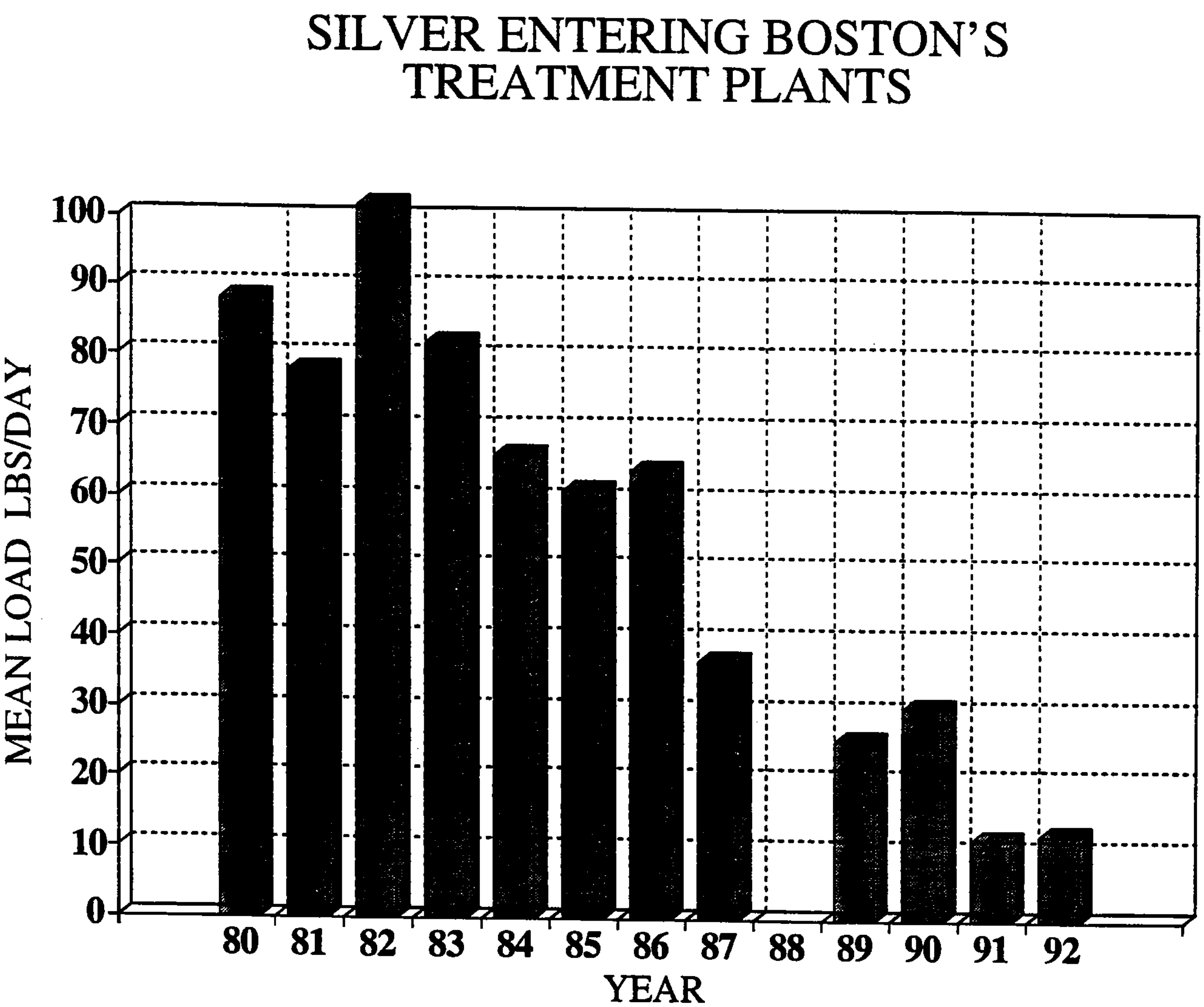


Figure 1. Histogram showing the amount of silver entering Boston's sewage treatment plants from 1980-1992. Some data for the early 1980's may be an overestimate due to insensitivity of analytical methods. However, MWRA representatives have the opinion that silver has been significantly reduced as implied by the figure, although the magnitude of reduction is not well documented. No data for 1988.

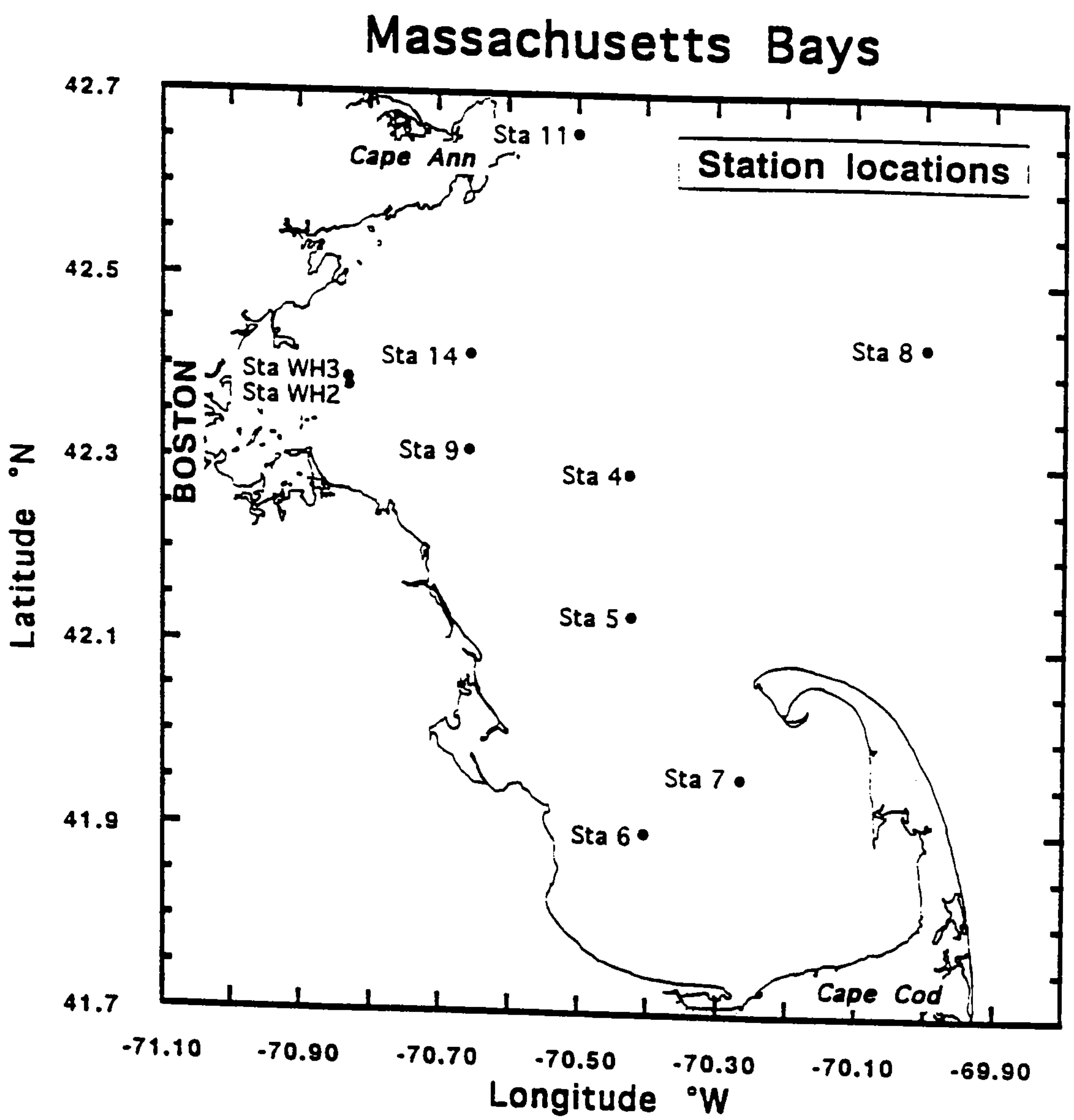


Figure 2. Sampling locations occupied during a cruise in May 1992 aboard the R.V. ARGO MAINE. Stations WH2 and WH3 are near the proposed sewage outfall site and WH2 has much less mud (2%) than WH3 (>60%).

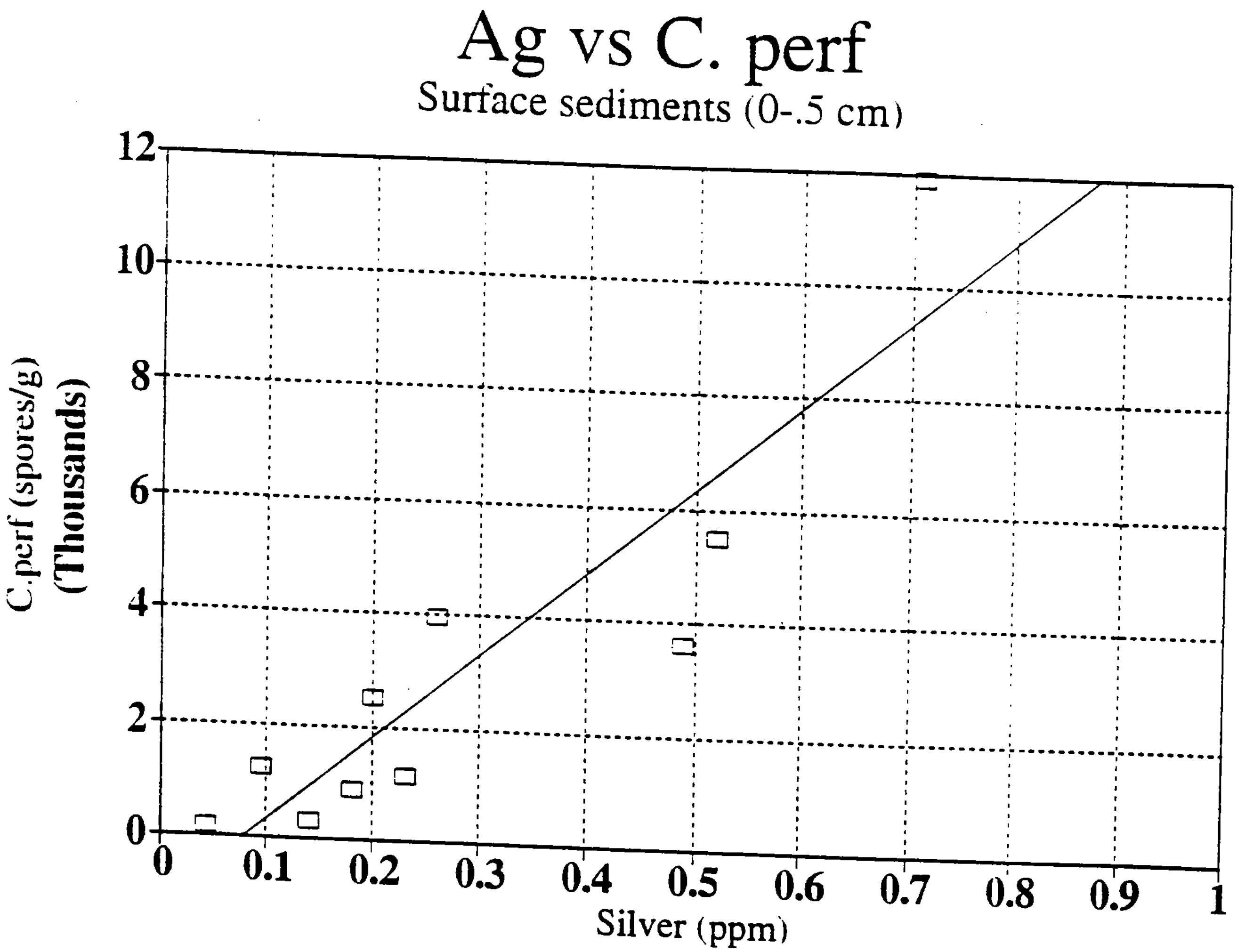


Figure 3. Plot of silver vs *Clostridium perfringens* concentrations in surface (0-0.5 cm) sediment collected at 10 locations with the hydraulically damped gravity corer. Solid line is a linear regression ($R^2 = 0.83$).

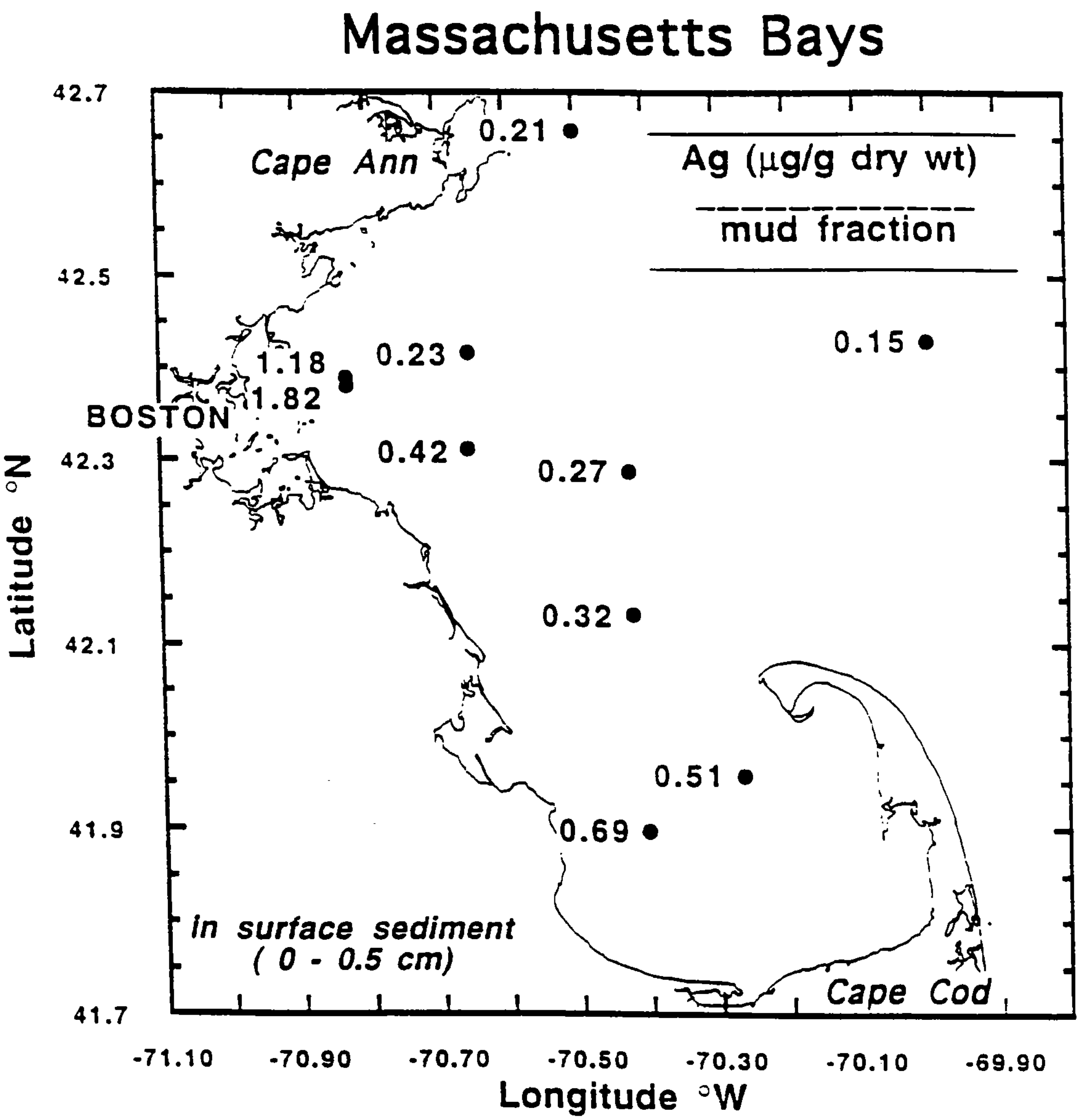


Figure 4. The concentration of silver (normalized by the % mud/100) in surface (0-0.5 cm) sediments collected at 10 locations with the hydraulically damped gravity corer.

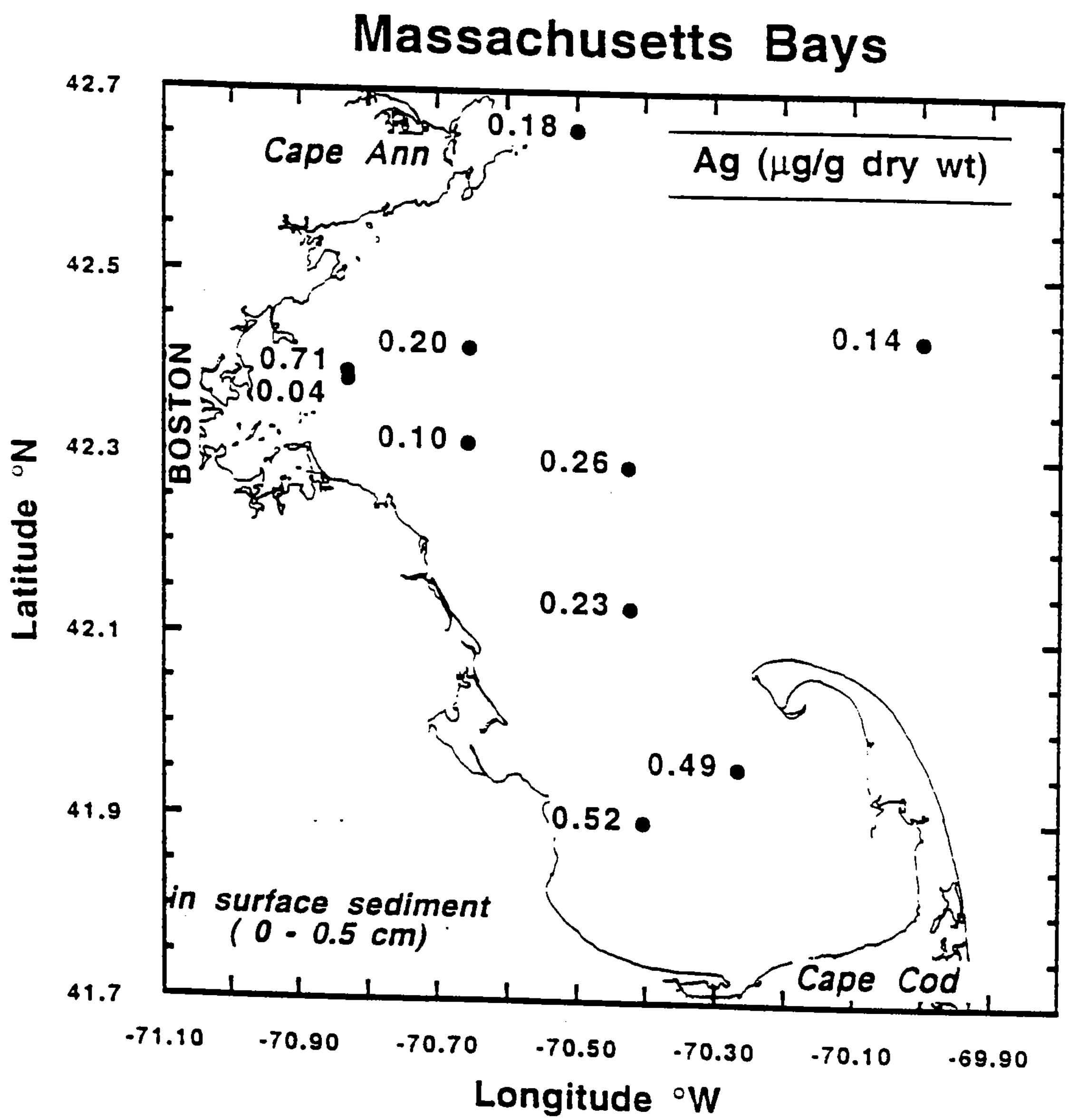


Figure 5. The concentration of silver (not normalized for textural differences) in surface (0-0.5 cm) sediments collected at 10 locations with the hydraulically damped gravity corer. Note that the lowest value (0.042 µg/g) occurs near the mouth of Boston Harbor. This sample is 97.8% sand.

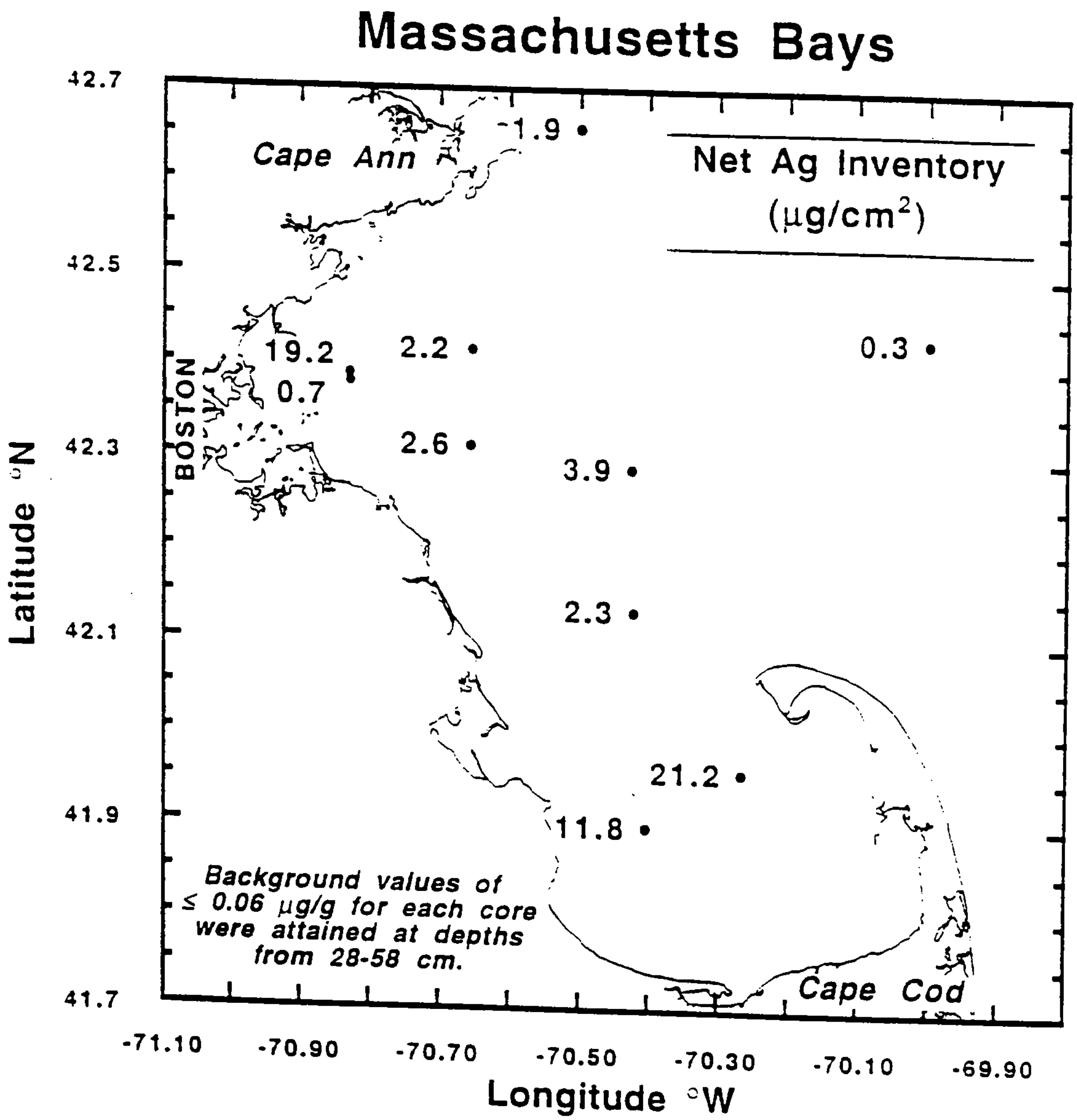


Figure 6. Net inventories of silver (micrograms/cm²) in hydraulically damped gravity cores collected at 10 locations. Concentrations are corrected for background of naturally occurring silver.

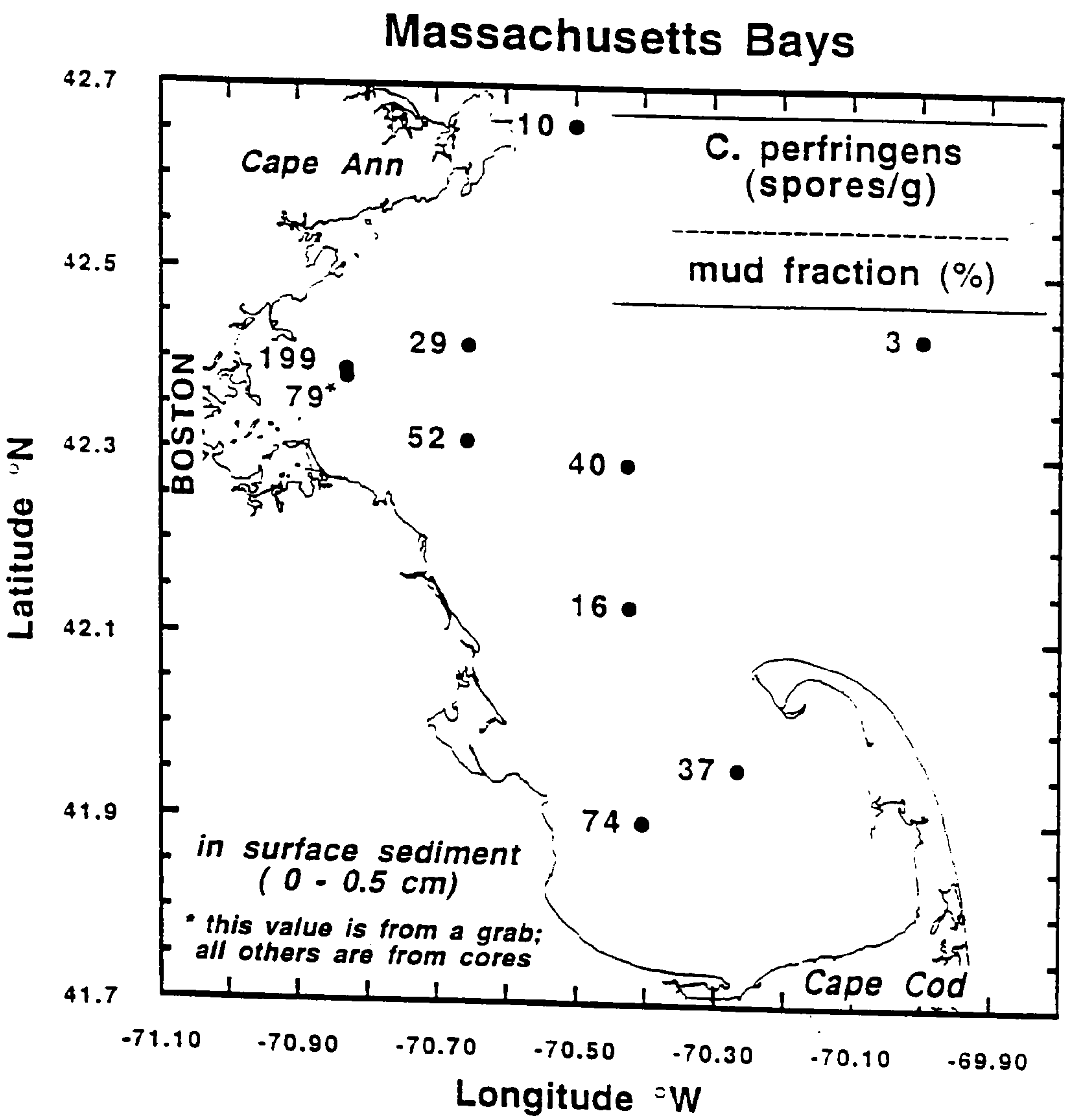


Figure 7. The concentration of the bacterium spore *Clostridium perfringens* (normalized by % mud) in surface (0-0.5 cm) sediments collected at 10 locations with the hydraulically damped gravity corer. (* Because of anomalously low values in the core top from station 2, the average of two grab samples were plotted).

Figures 8a-8j. Profiles of silver concentration with depth in sediment cores collected at 10 locations with the hydraulically damped gravity corer. Background values used to calculate net inventories are shown by the dashed line in each figure. Analytical error is within the symbol and the sample depth intervals are indicated by vertical bars. Please note that data for Station WH3 is plotted twice using different scales (Figs. 7j and 7k) in order to accommodate the wider range in concentration.

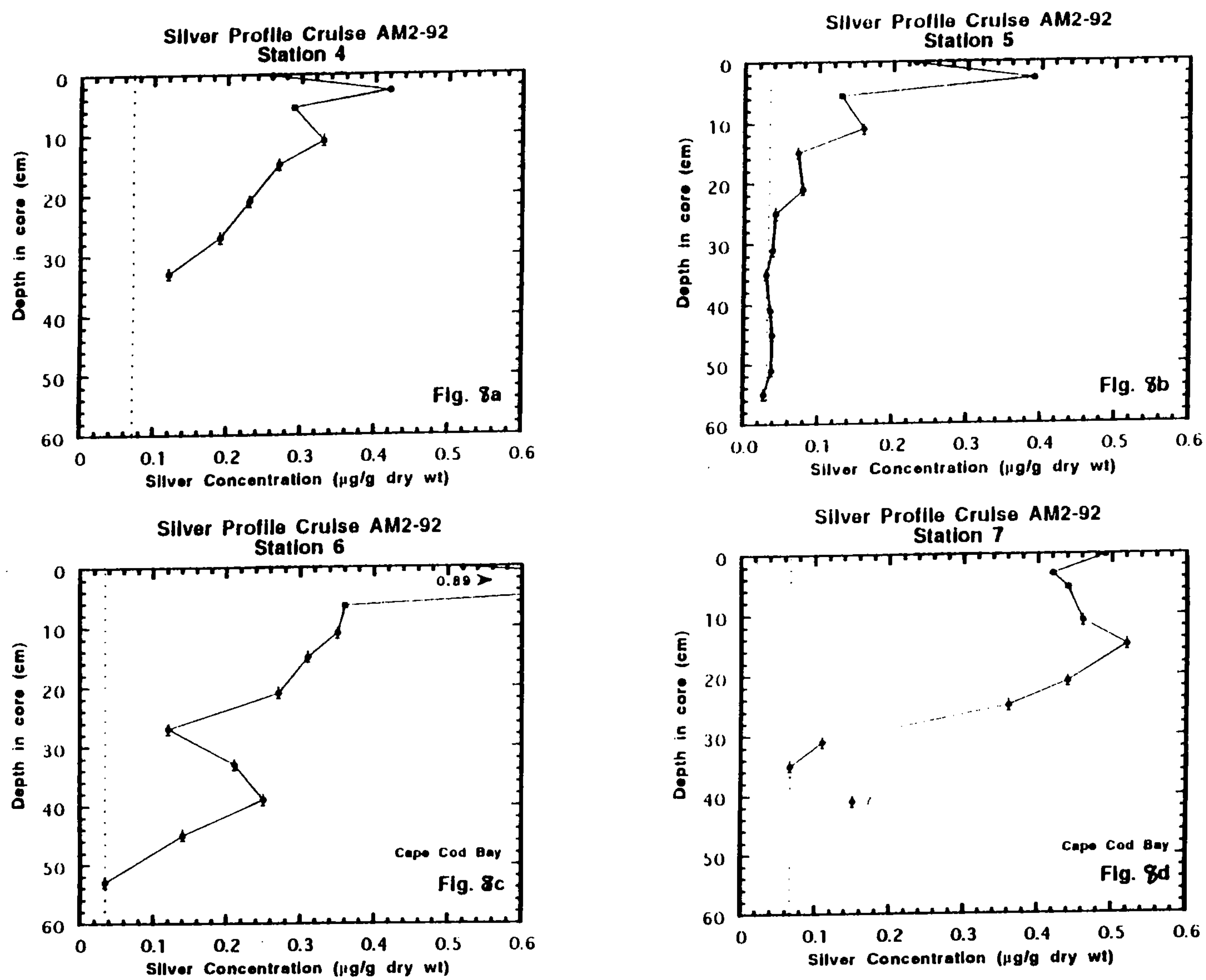
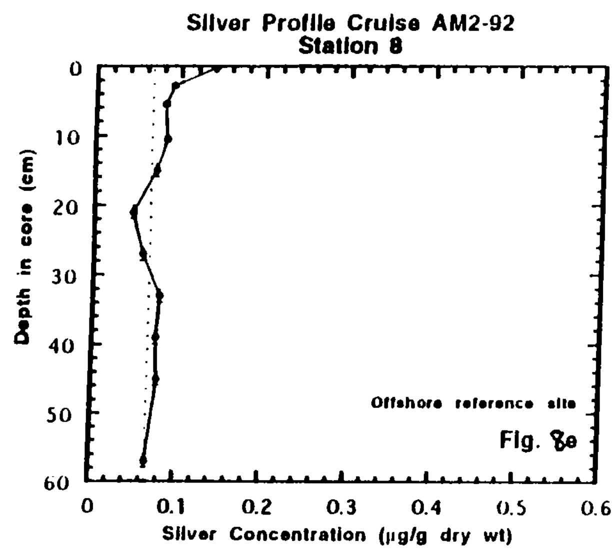
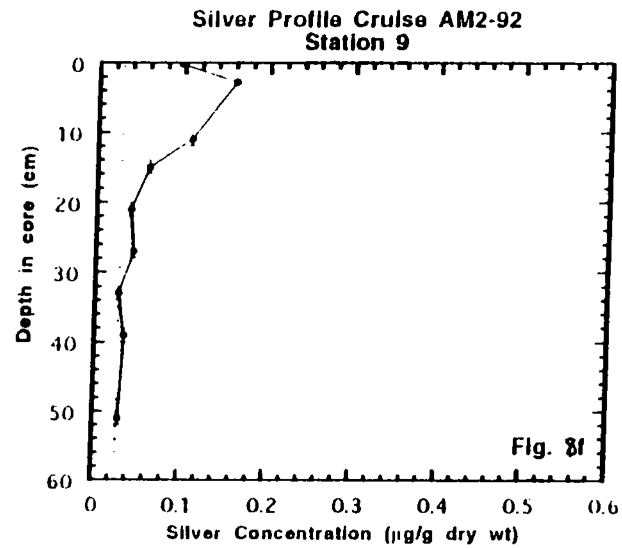
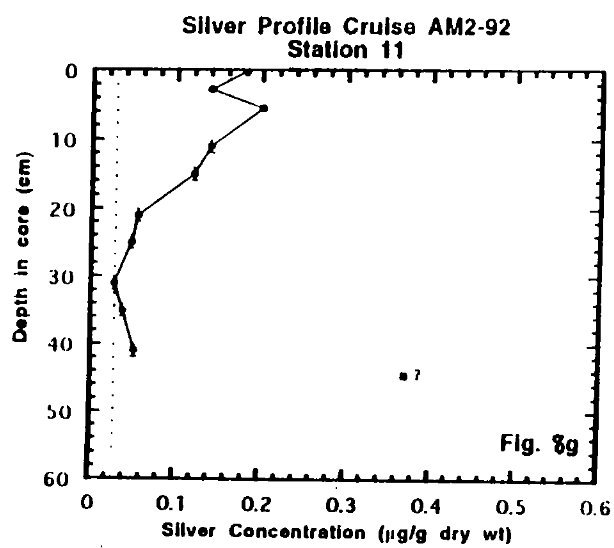


Figure 8a-8j. Profiles of silver concentration with depth in sediment cores collected at 10 locations with the hydraulically damped gravity corer. Background values used to calculate net inventories are shown by the dashed line in each figure. Analytical error is within the symbol and the sample depth intervals are indicated by vertical bars. Please note that data for Station WH3 is plotted twice using different scales (Figs. 7j and 7k) in order to accommodate the wider range in concentration.







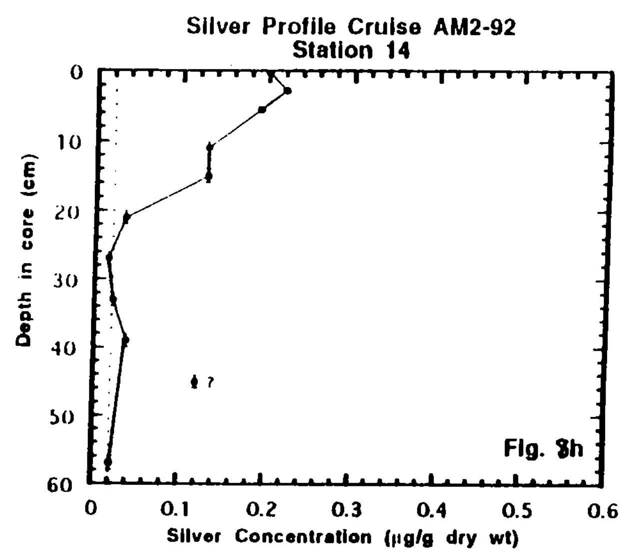
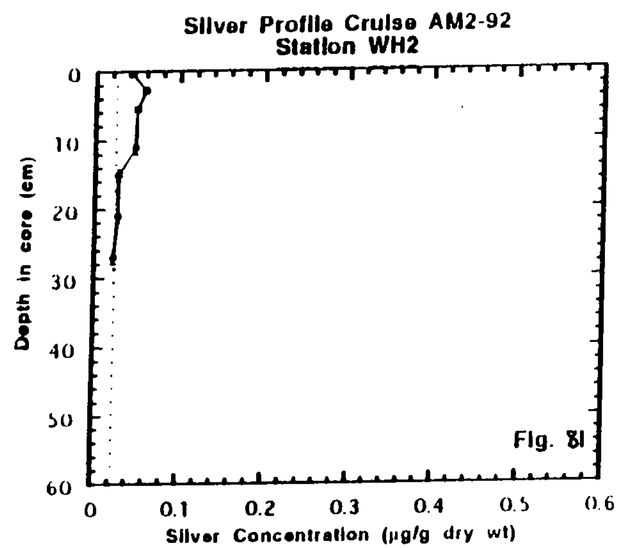
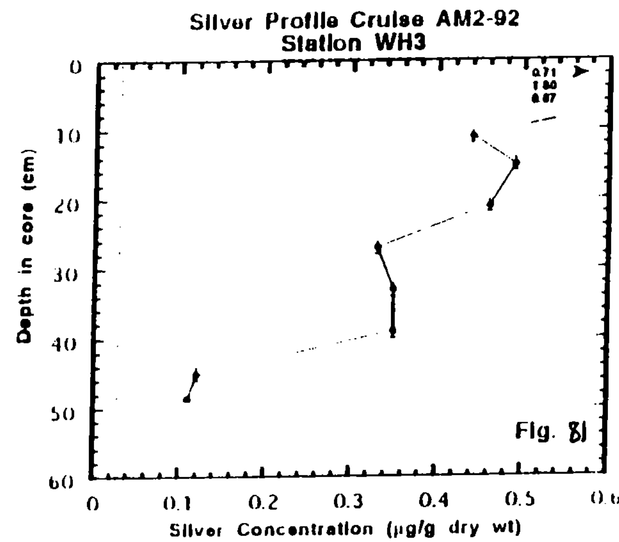
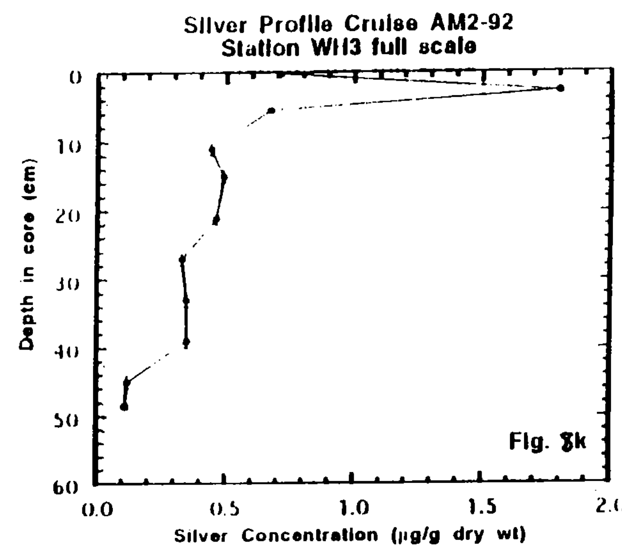


Figure 8a-j. Profiles of silver concentration with depth in sediment cores collected at 10 locations with the hydraulically damped gravity corer. Background values used to calculate net inventories are shown by the dashed line in each figure. Analytical error is within the symbol and the sample depth intervals are indicated by vertical bars. Please note that data for Station WH3 is plotted twice using different scales (Figs. 7j and 7k) in order to accommodate the wider range in concentration.







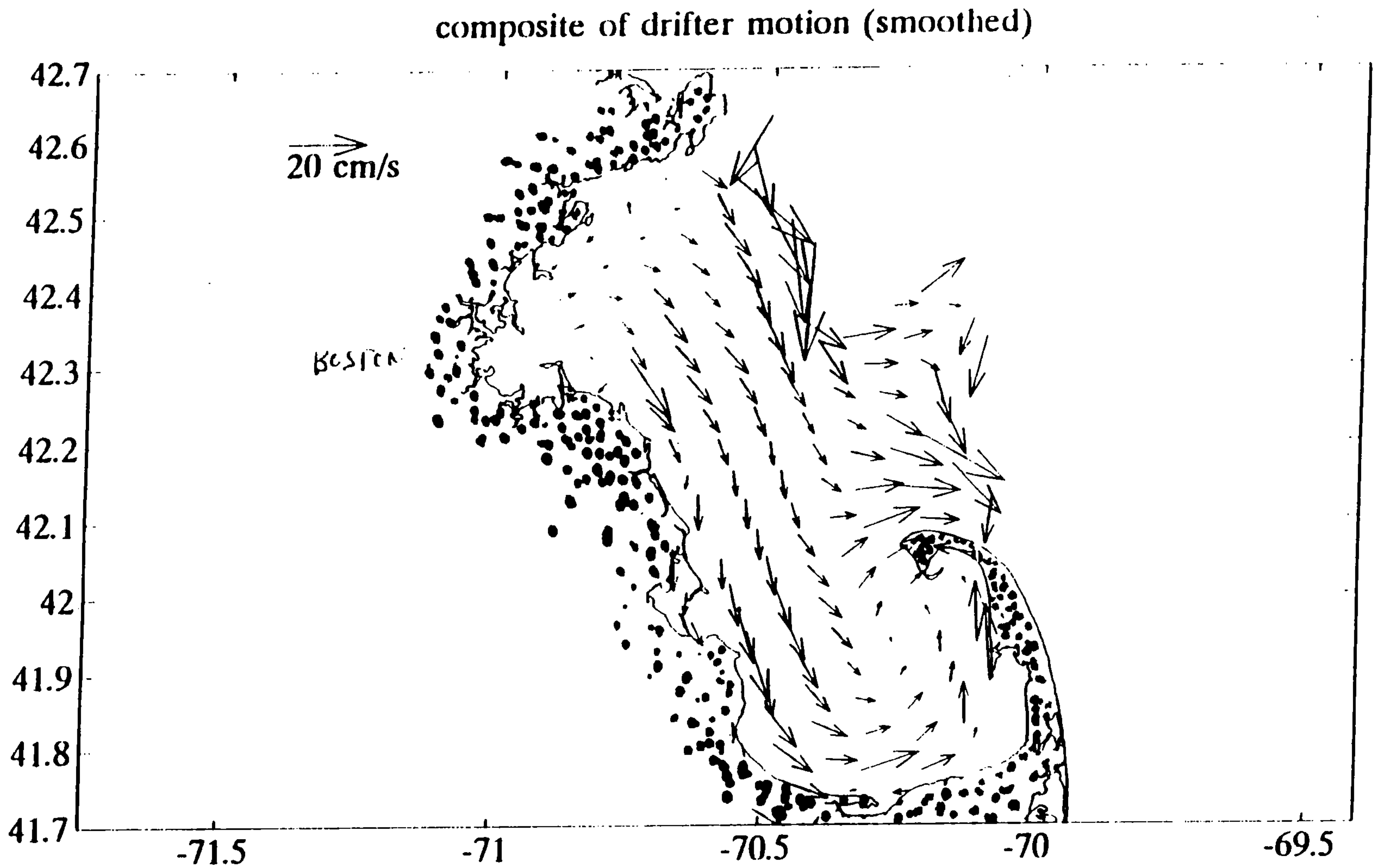


Figure 9. This figure summarizes the circulation in the top 10 meters of the water column as determined by surface drogues (Geyer and others, 1992). The point is that the southerly flow from offshore of Boston Harbor to Cape Cod Bay provides a possible mechanism for transporting silver, Clostridium perfringens spores, and other sewage tracers to Cape Cod Bay.

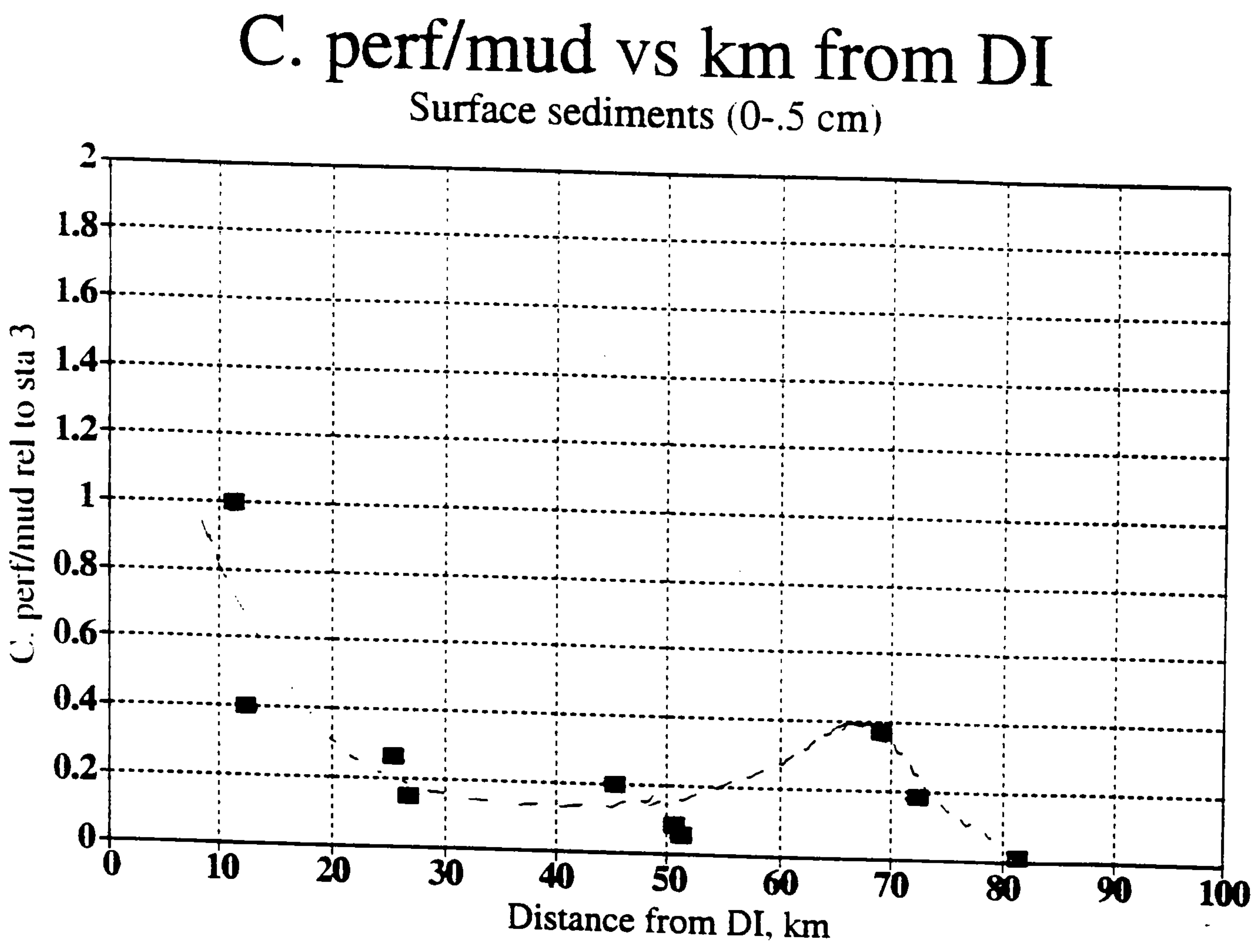


Figure 10. We have normalized the Clostridium prefringens counts by the % mud in the sediment sample and plotted the ratio relative to station 3 as a function of radial distance from Deer Island. C. perf. is considered to be a good tracer of sewage particles and has a minimal input from the atmosphere. This slide provides a pattern for a sewage tracer for comparison with silver. The pattern for silver (next figure) is very similar suggesting that silver is added to the system primarily from sewage and not from the atmosphere.

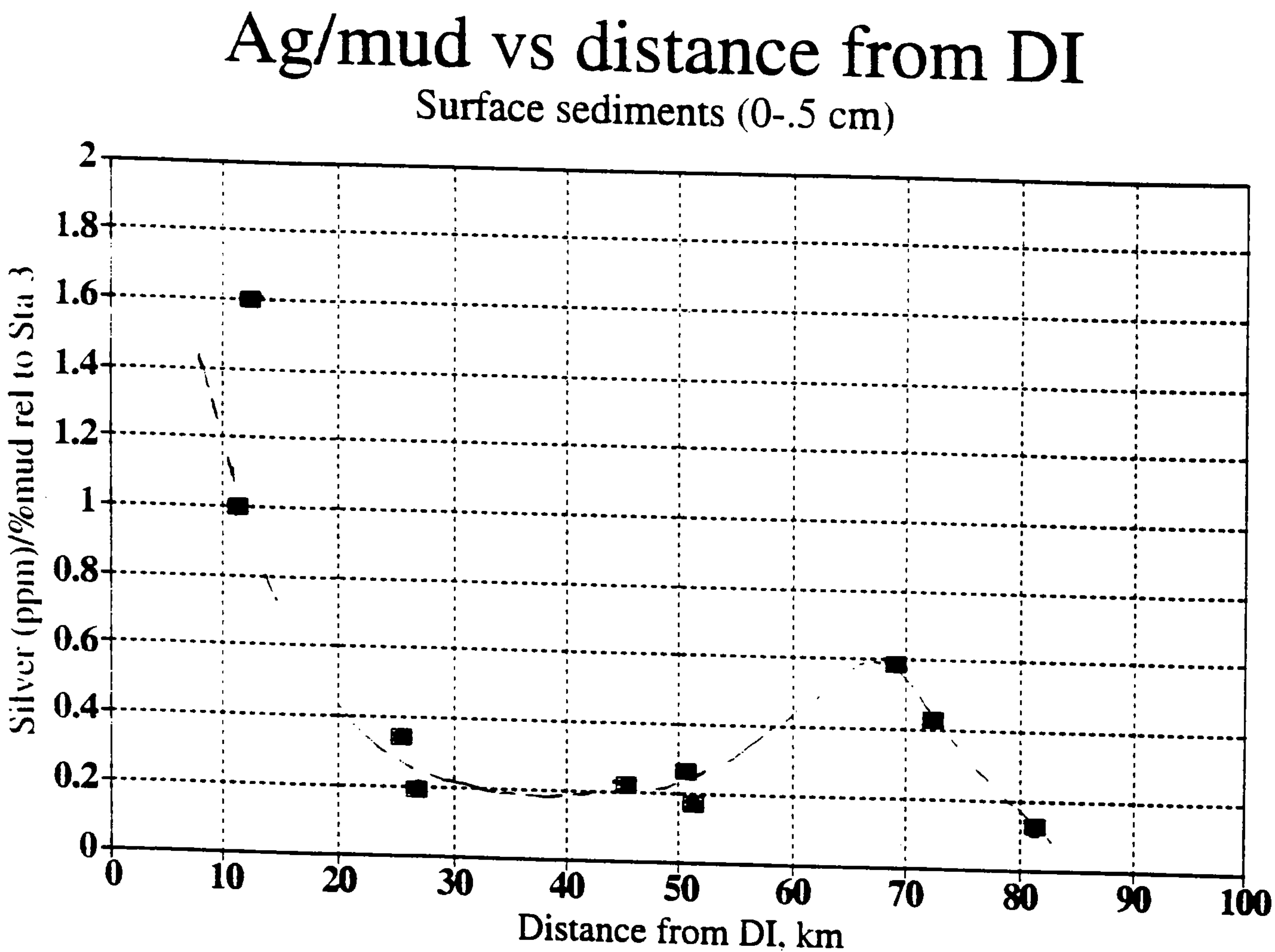


Figure 11. This figure shows the distribution of the Ag/mud ratio with radial distance from Deer Island. The ratio at each station is plotted relative to the value at station 3. The pattern is similar to the pattern of <u>C.perf.</u>/mud (previous figure) suggesting that the silver distribution is more sewage derived than atmospheric derived. The atmospheric source term for silver is not well known, and this treatment of data helps to infer the magnitude of non-point sources of silver to the system.

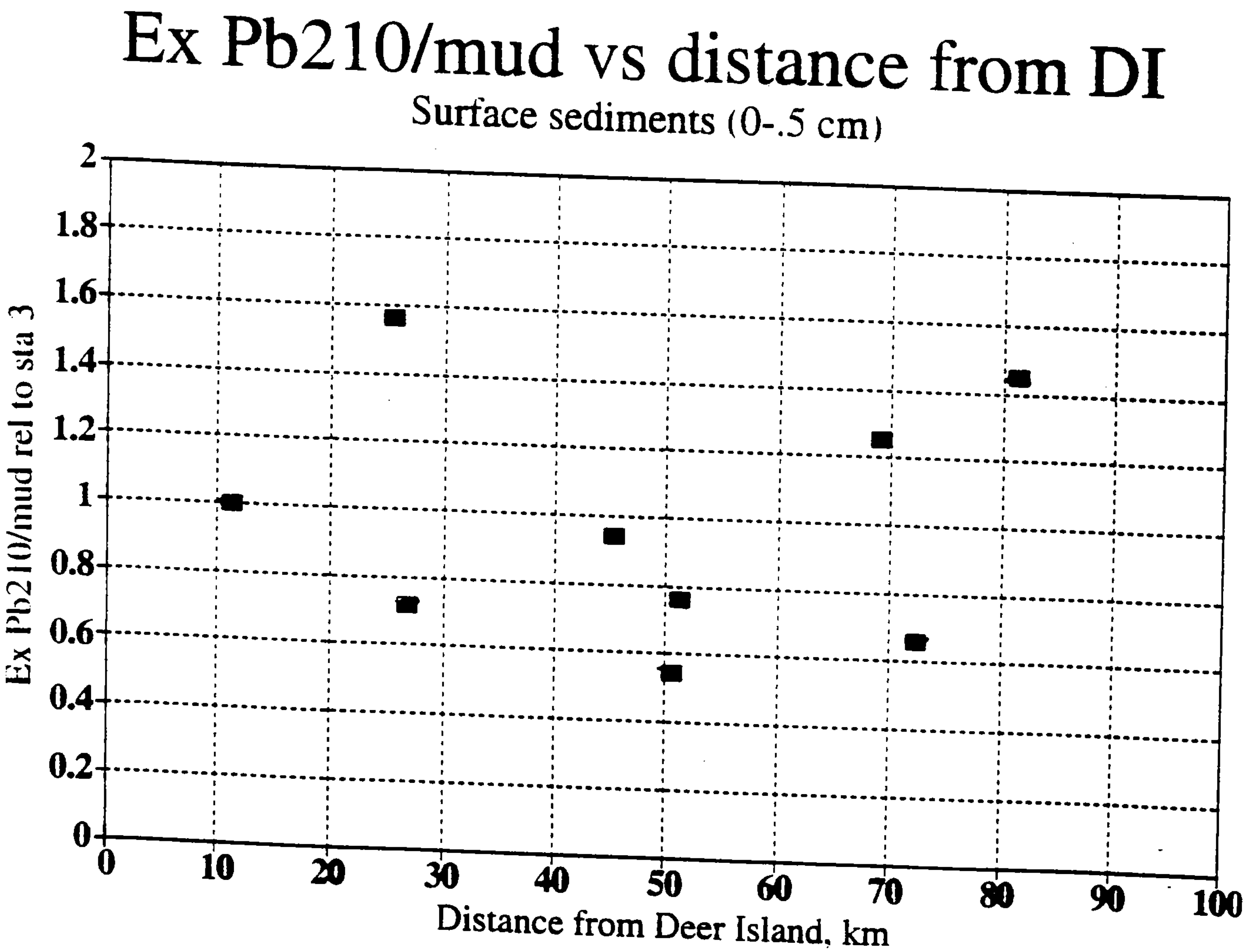


Figure 12. Excess Pb210 is shown as an example of the distribution of an element derived largely from the atmosphere, plotted in the same manner as C.perf. and silver (previous two figures). The observation that the silver pattern is quite similar to C.perf. and not similar to the atmospherically derived element, supports the hypothesis that the silver is largely derived from sewage rather than from the atmosphere.

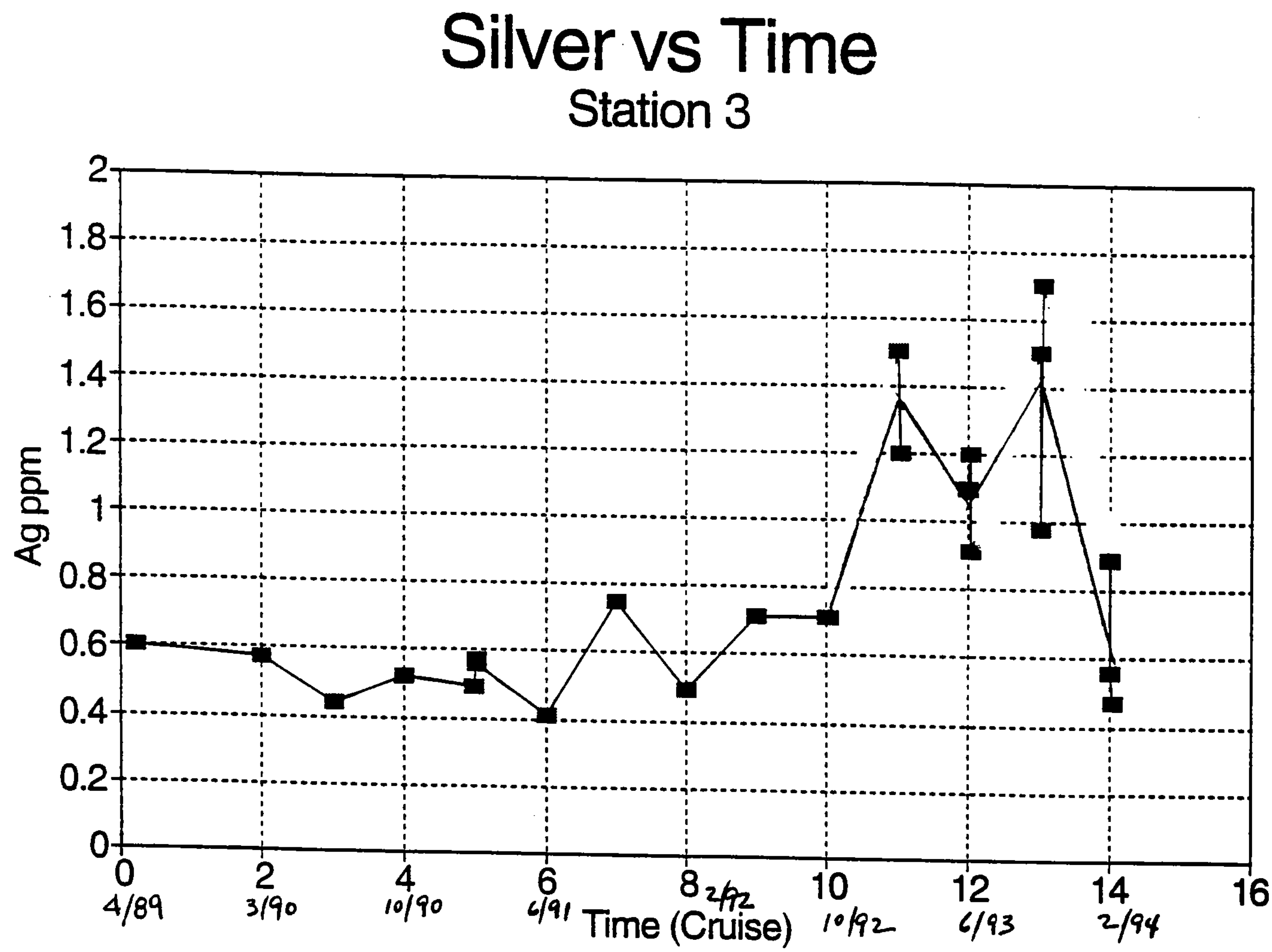


Figure 13. Preliminary data on the concentrations of silver with time in the 0-0.5 cm layer of sediment at station WH3 in Mass Bay (see Fig. 2). The vertical bars join replicate samples collected at one station, they do not represent standard deviation. The increase after cruise 10 may be related to accumulation of fine material following the major northeast storm of December 11-16, 1992. Similar changes in the concentration of <u>C. perf.</u> and %mud (next two figures) were also noted in the time series of samples.

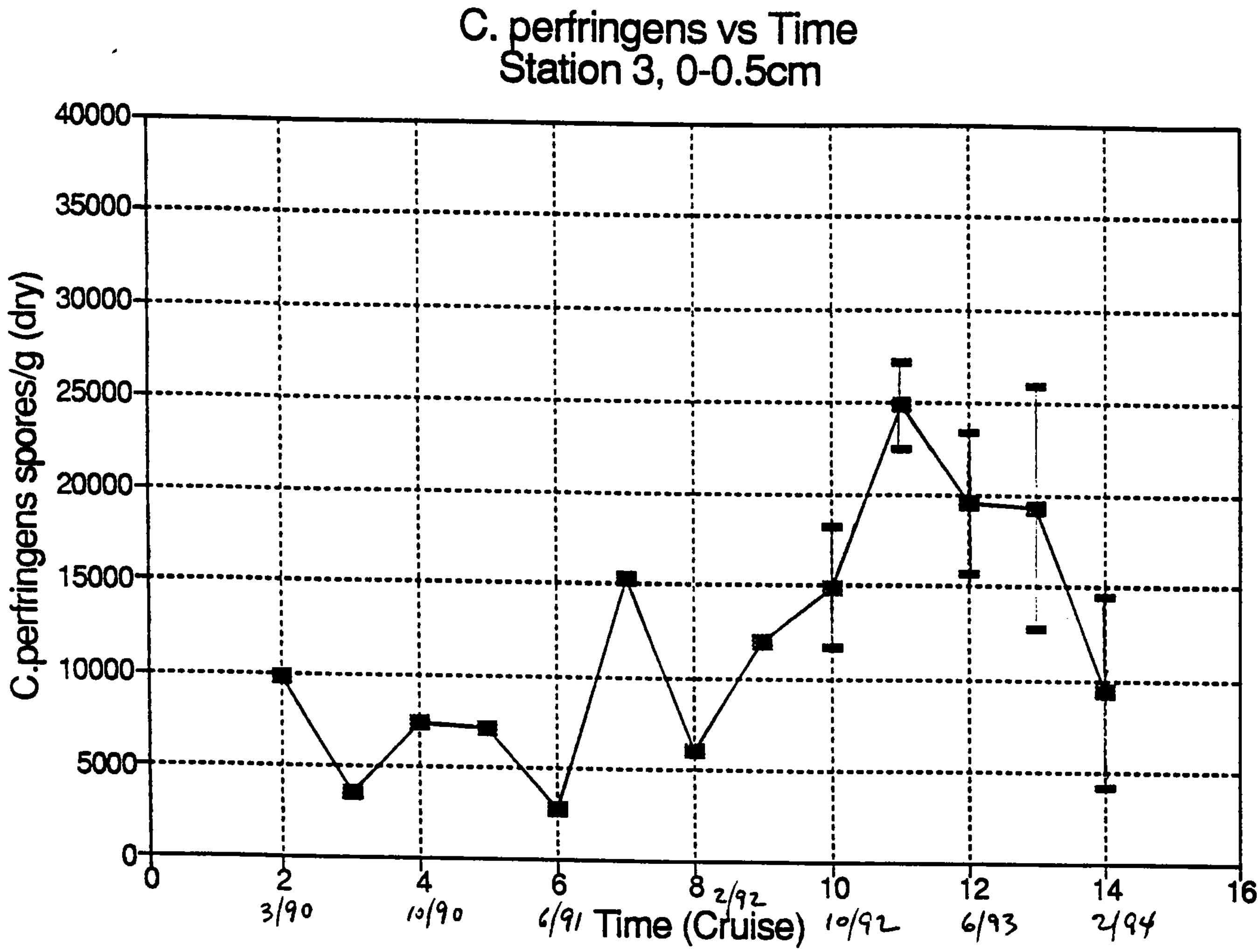


Figure 14. Concentrations of C.perfringens with time in surface sediments of station 3. Error bars represent one standard deviation among three replicate cores.

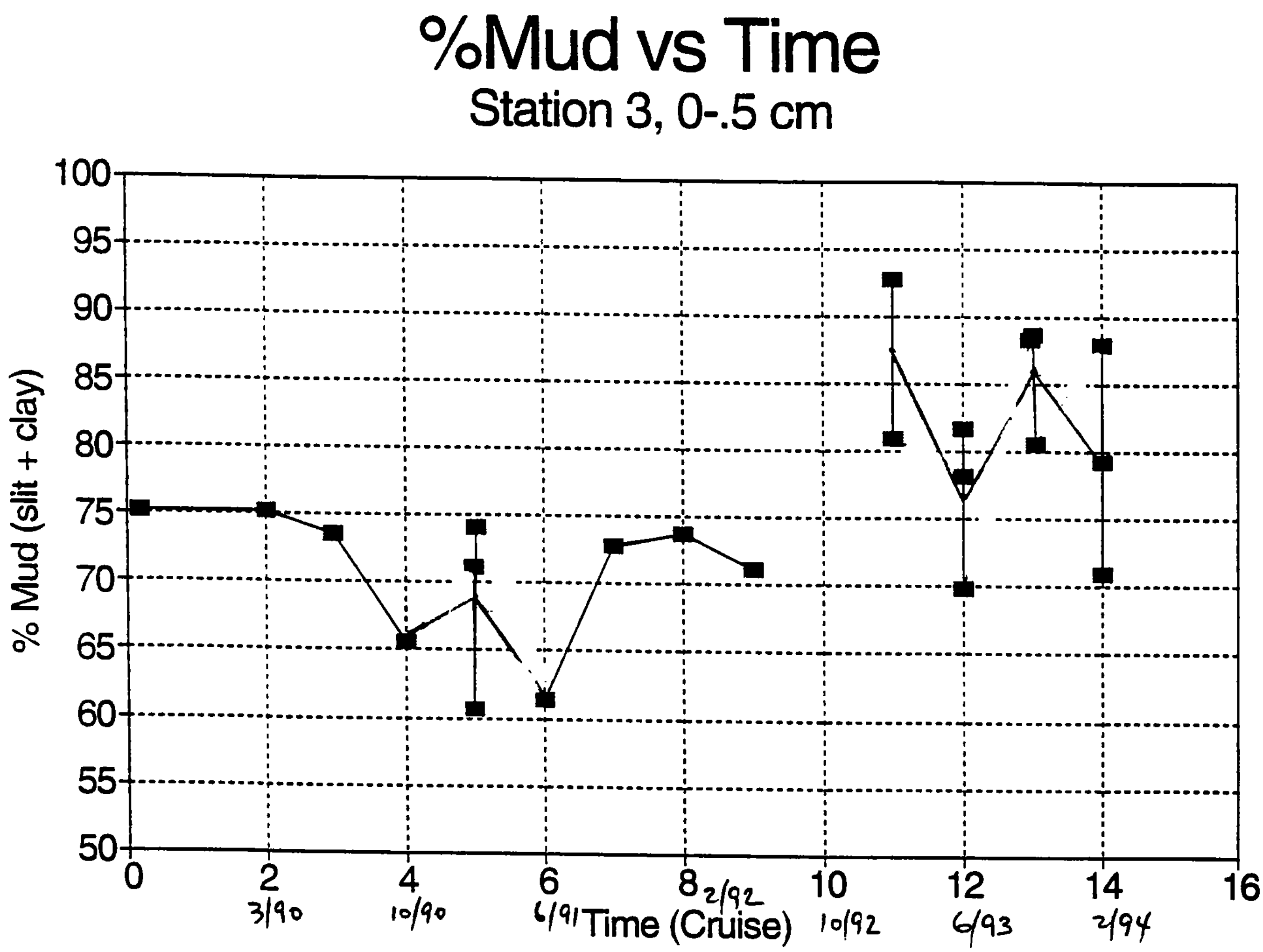


Figure 15. % Mud with time in the surface sediments of station 3. Vertical bars join replicate cores, they do not represent error bars. Data from cruise 10 is missing.

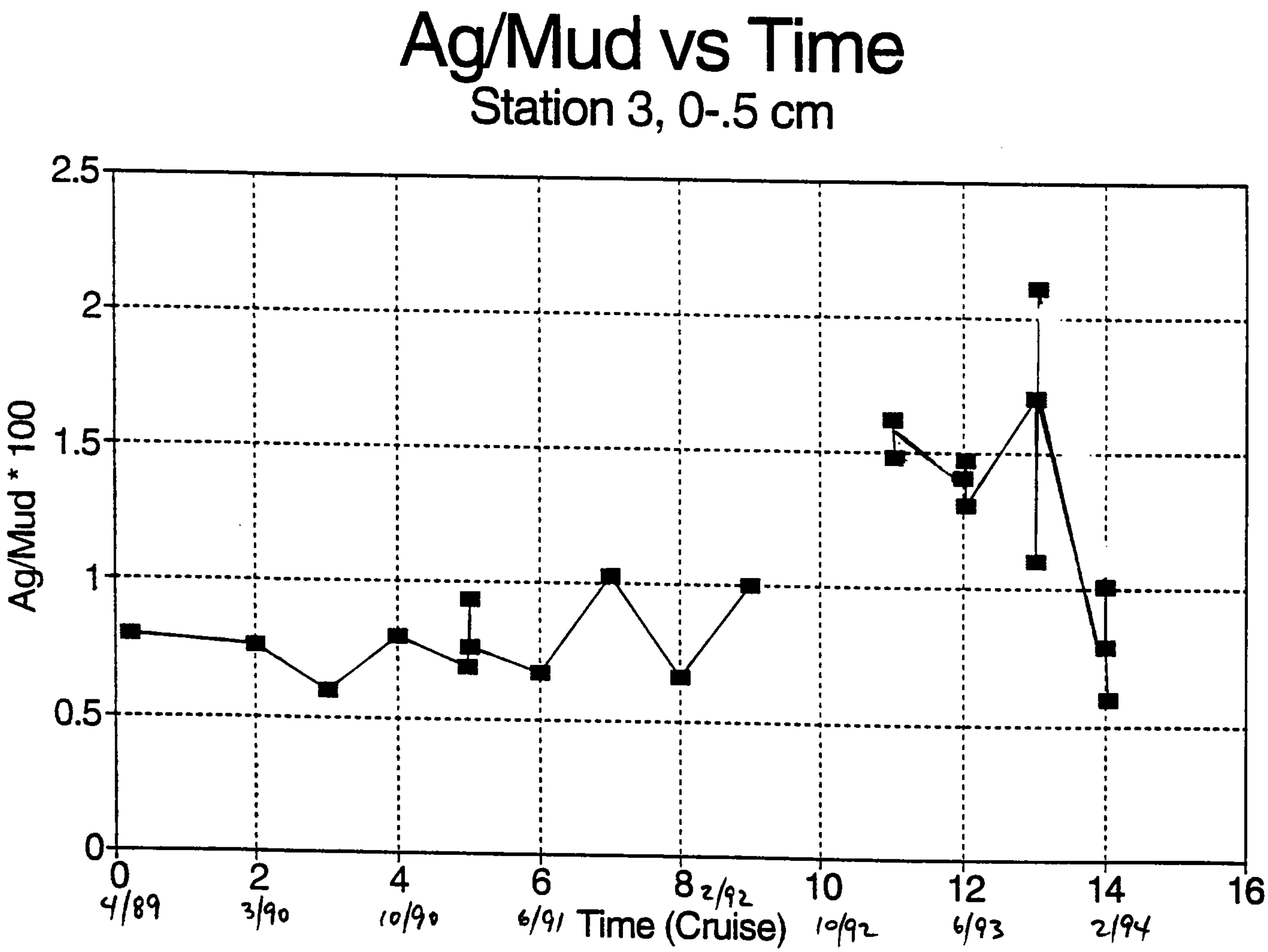


Figure 16. Preliminary data on the silver/mud ratio with time at station 3. There appears to be an increase in the silver signal after cruise 10 perhaps as a result of deposition of mud having a higher concentration of silver (and C. perf.). It is possible that export of resuspended, more contaminated, mud occurred from Boston Harbor as a result of the major storm of December 11-16, 1992.

APPENDIX C-3

Ken Keay

1992 Results

- USGS stations, 5/92 survey[1].
- Sedimentary environments in western Mass Bay. (What I showed was a copy of the figure labelled "A" with the depositional areas enhanced with color markers. The effect is closer to the figure labelled "B", out of the same paper)[2].
- August '92 Far-field map w/ FF stations added after USGS cruise circled[3].
- Locations of Near-field stations[3].
- NF On-shore/off-shore gradient, REMOTS camera penetration[3].
- NF TOC ranging from 0 - 3.2%, coutour plot w/ highest points circled[3].
- NF Faunal assemblages[3].
- NF Clustering results, Bray-Curtis, NESS @ m = 100[3].
- NF Clustering results using NNESS at M = 10, similar pattern.
- NF Clustering results mapped onto station locations.[3]
- FF Clustering, Bray-Curtis and NESS @ m = 100[3].
- FF Clustering, NNESS @ m = 10.

Modifications post 1992

- OMTF Mandate
- Far-field showing dropped station[3].
- Near-field showing retained stations[3].
- Near-field table summary w/ retained stations shaded.
- Several figures showing captured range of conditions: N of species vs. diversity.
- Clost vs. TOC.
- CU vs. AL.

Analyses of faunal/sediment patterns.

- Inter-correlated variables. CD v HG.
- LABs vs. *C. perfringens.*
- Set-up of correlation analyses.
- Synopsis of FF results
- Synopsis of NF results (3 pages)

Overheads used during later discussions

- Open Issues
- Bar-chart of benthic NF station distance from outfall by class of stations.

---

1 Bothner, M.H. 1992. Sediment sampling in Massachusetts Bay, Cape Cod Bay, Stellwagen Bank and east of Stellwagen Bank. Cruise report, R.V. Agro Maine May 15-21, 1992. U.S. Geological Survey, Woods Hole, MA 02543.

2 Knebel, H.J. 1993. Sedimentary environmenta within a glaciated estuarine-inner shelf system: Boston Harbor and Massachusetts Bay. Marine Geology 110: 7-30.

3 Blake, J.A., B. Hillbig, & D.C. Rhoads 1993. Massachusetts Bay Outfall Monitoring MWRA Env. Qual. Dept. Tech. Rep. 93-10.

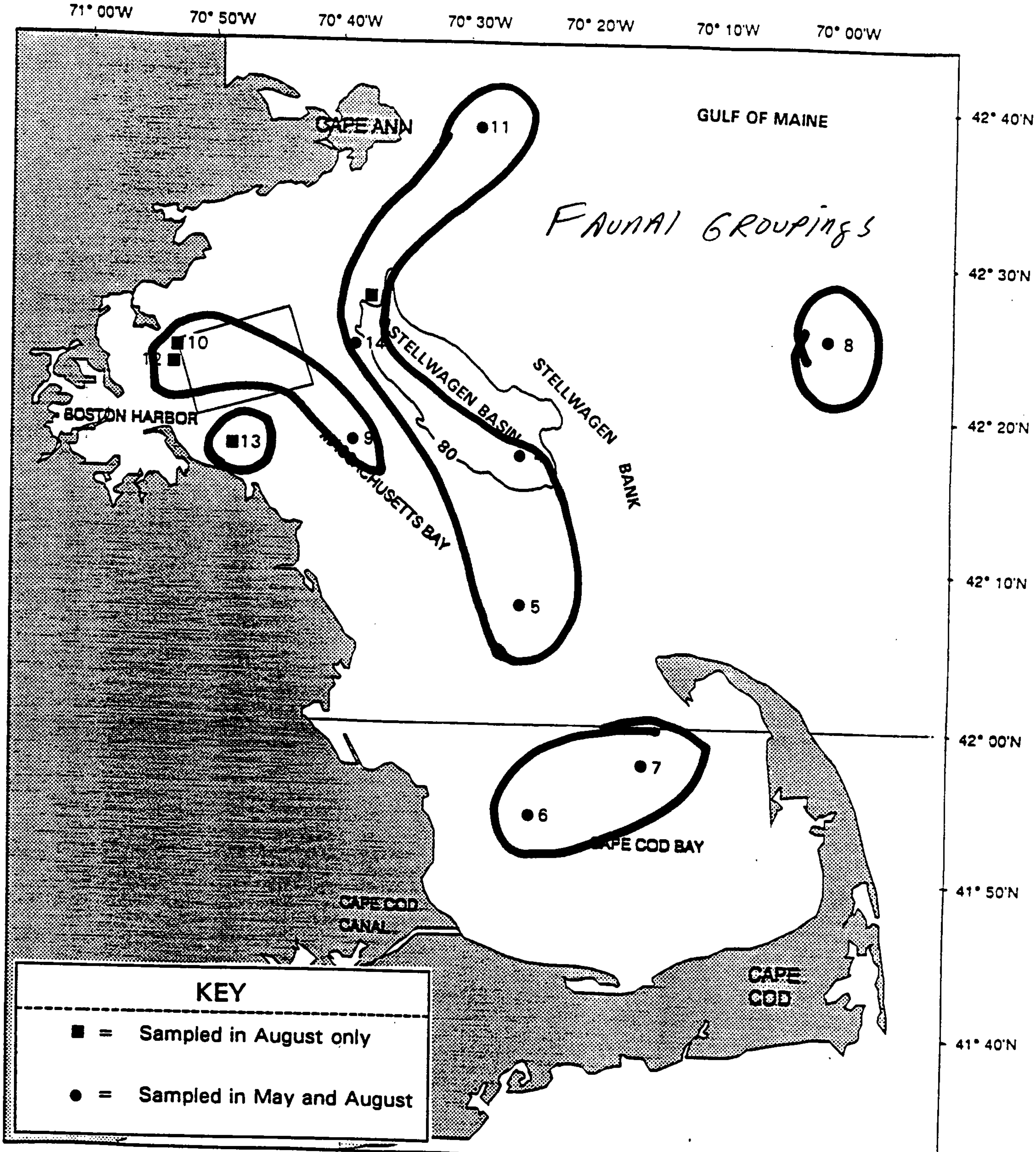


Figure 1. Location of Farfield Stations Sampled in May and August 1992. The rectangular box represents the nearfield area shown in detail in Figure 2.

SOURCE BOTHNER (1993)

Figure 1

Locations of Sediment Samples Collected May 16-21, 1992 Aboard the R.V. ARGO MAINE

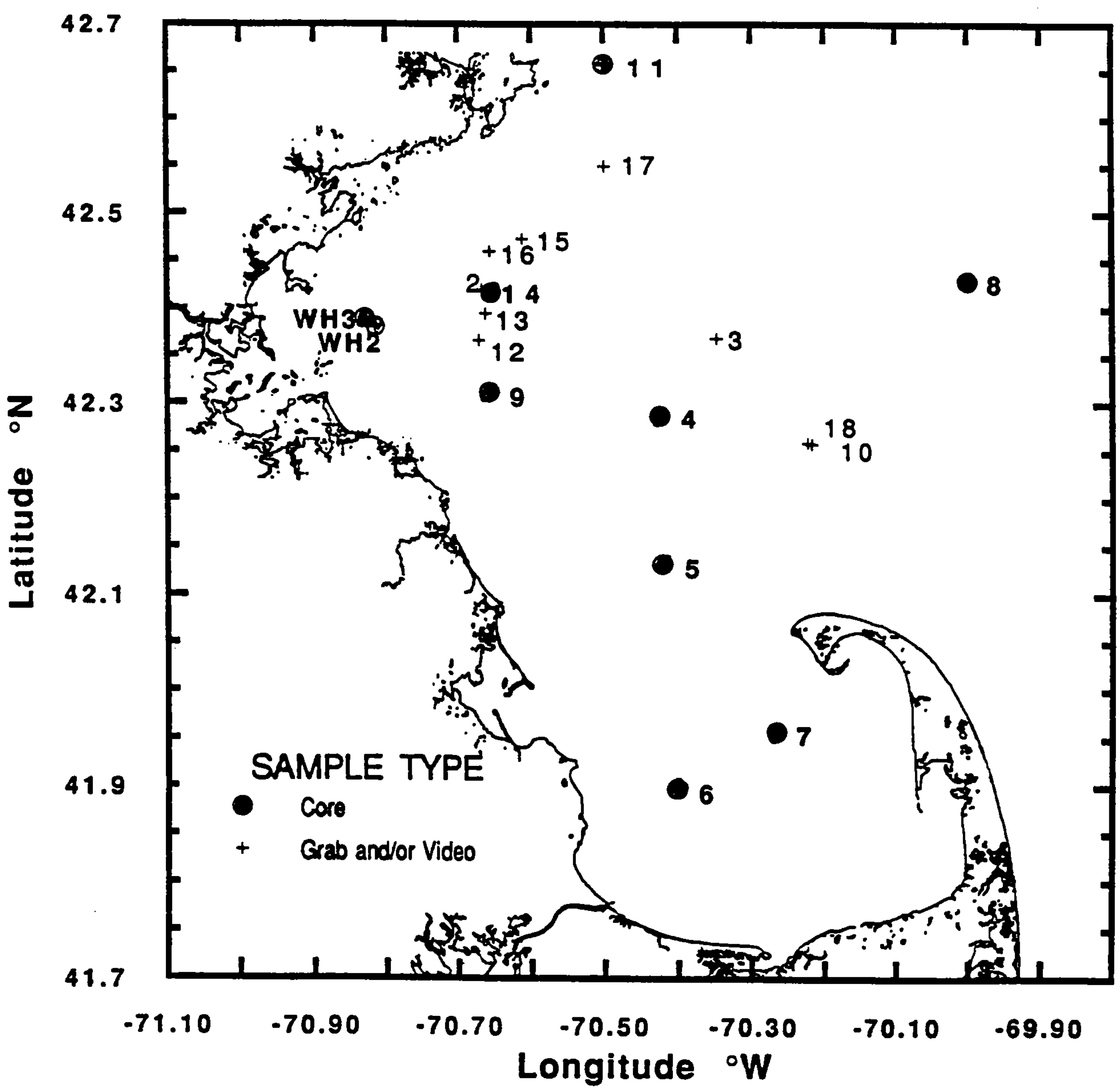
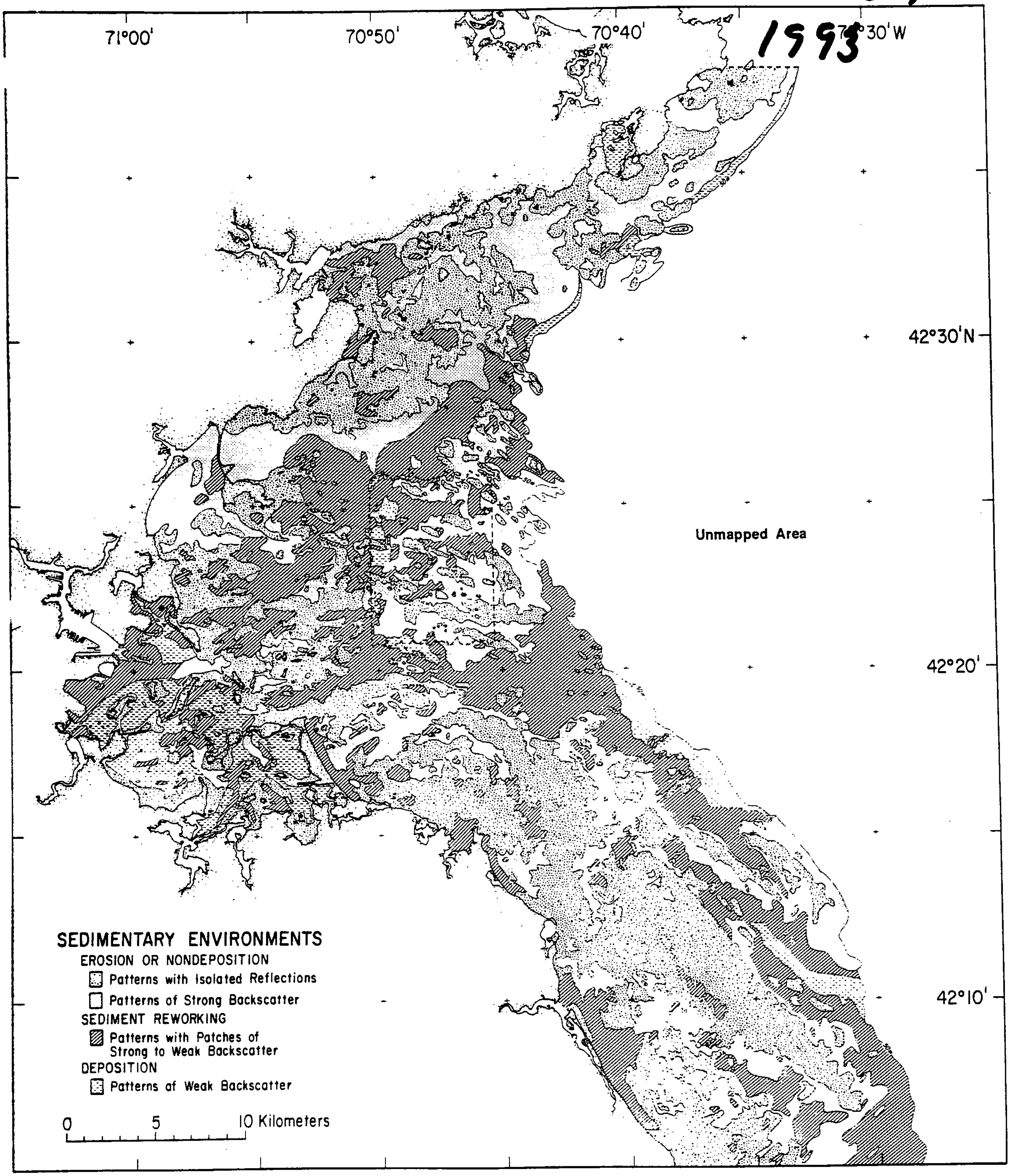


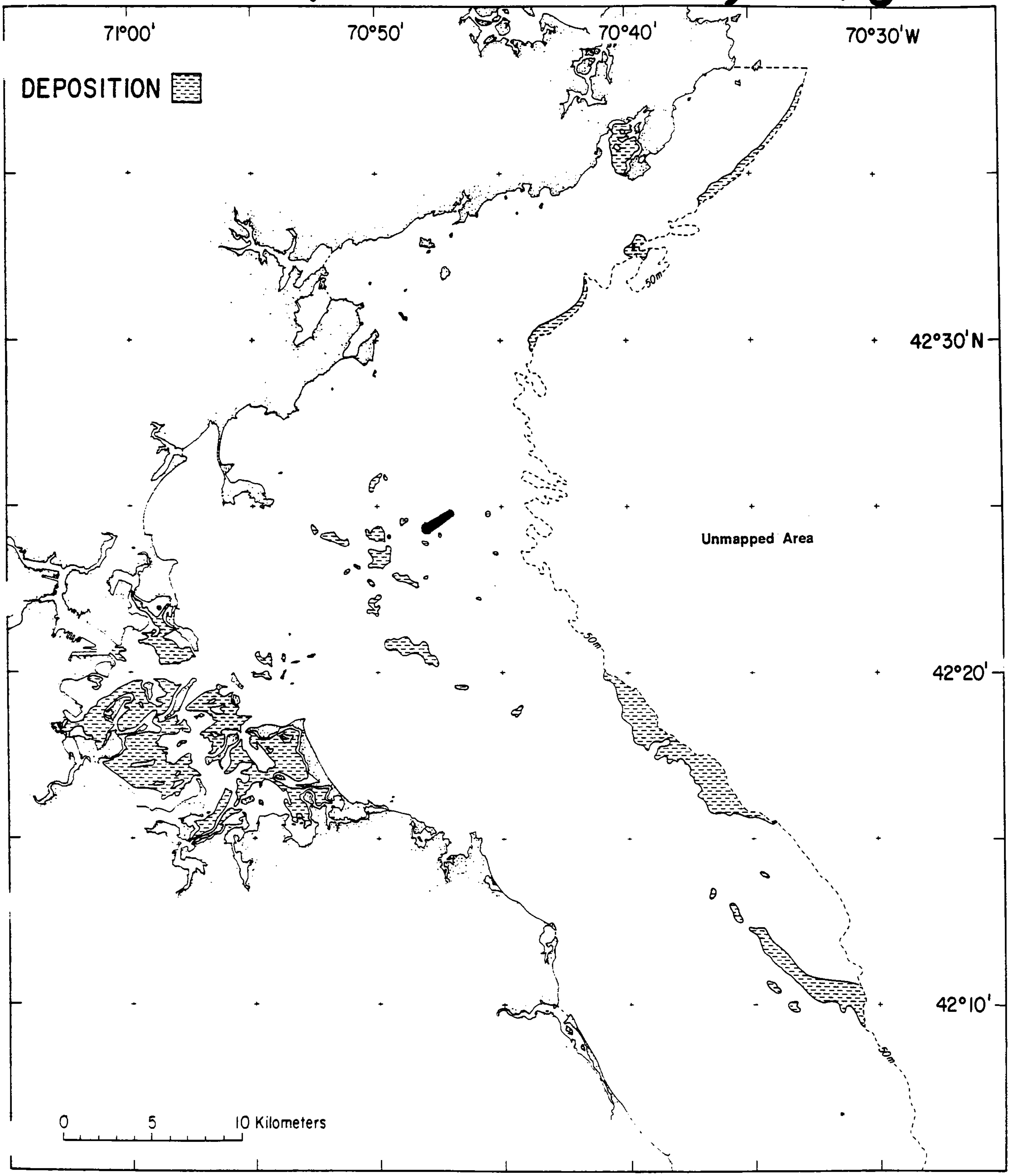
FIG. 4

FROM Knebel 1993

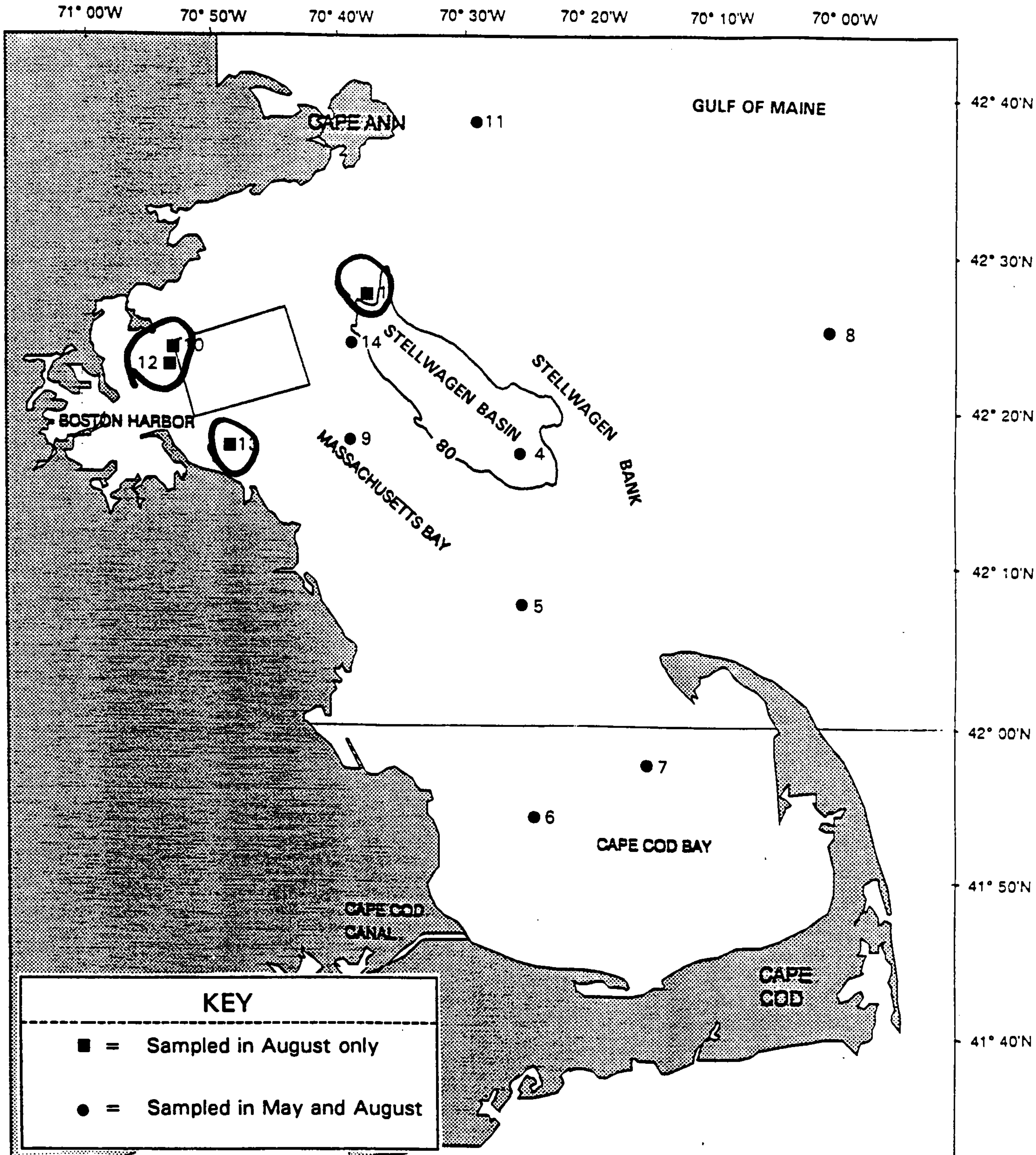


a

FROM Knebel, 1993



b



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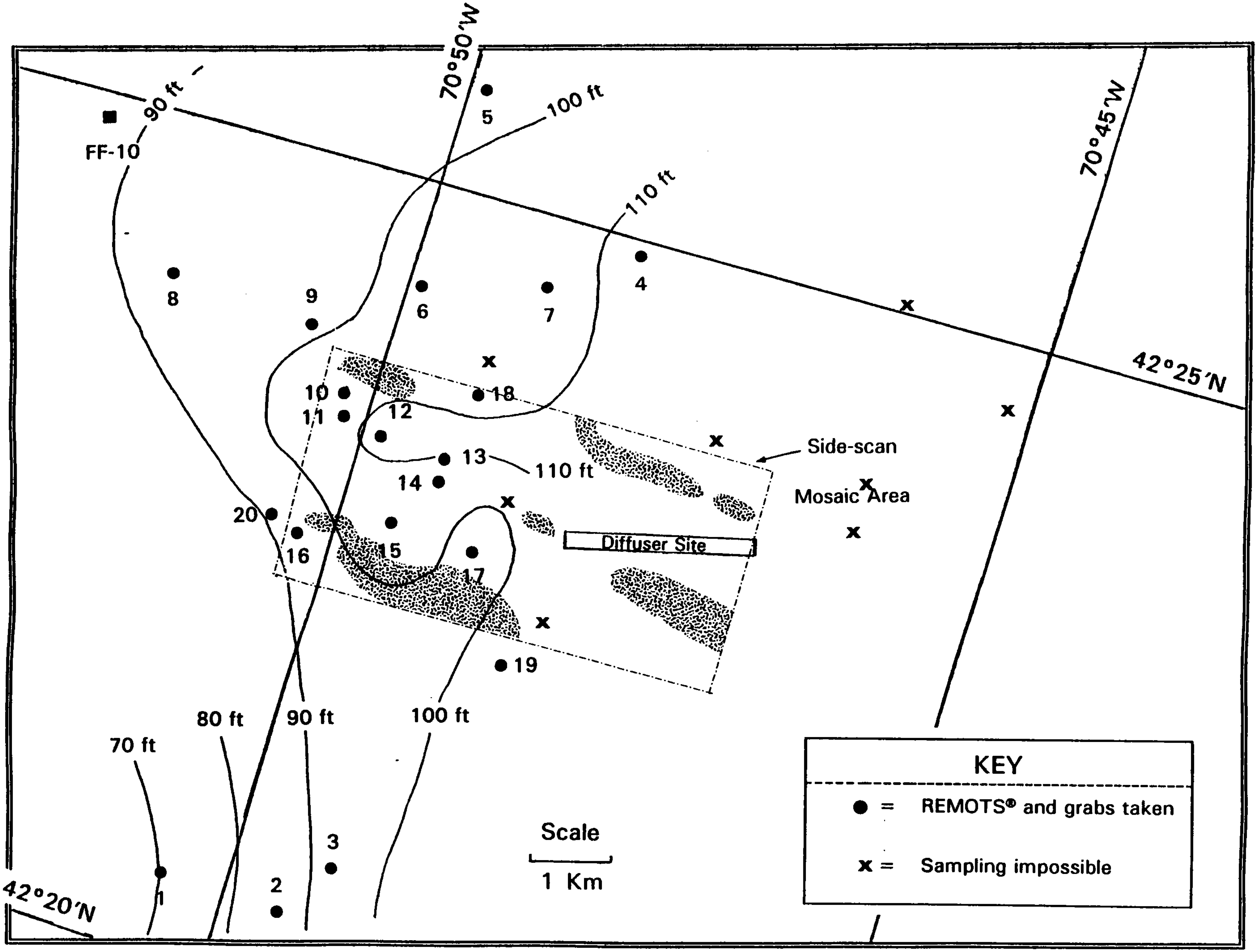


Figure 2. Locations of Nearfield Stations. Depth contours are in feet below MLW. Side scan mosaic area (dashed box) after Butman *et al.*, 1992. Shaded areas within the box are drumlins. Station FF10 has been included to facilitate contouring of data.

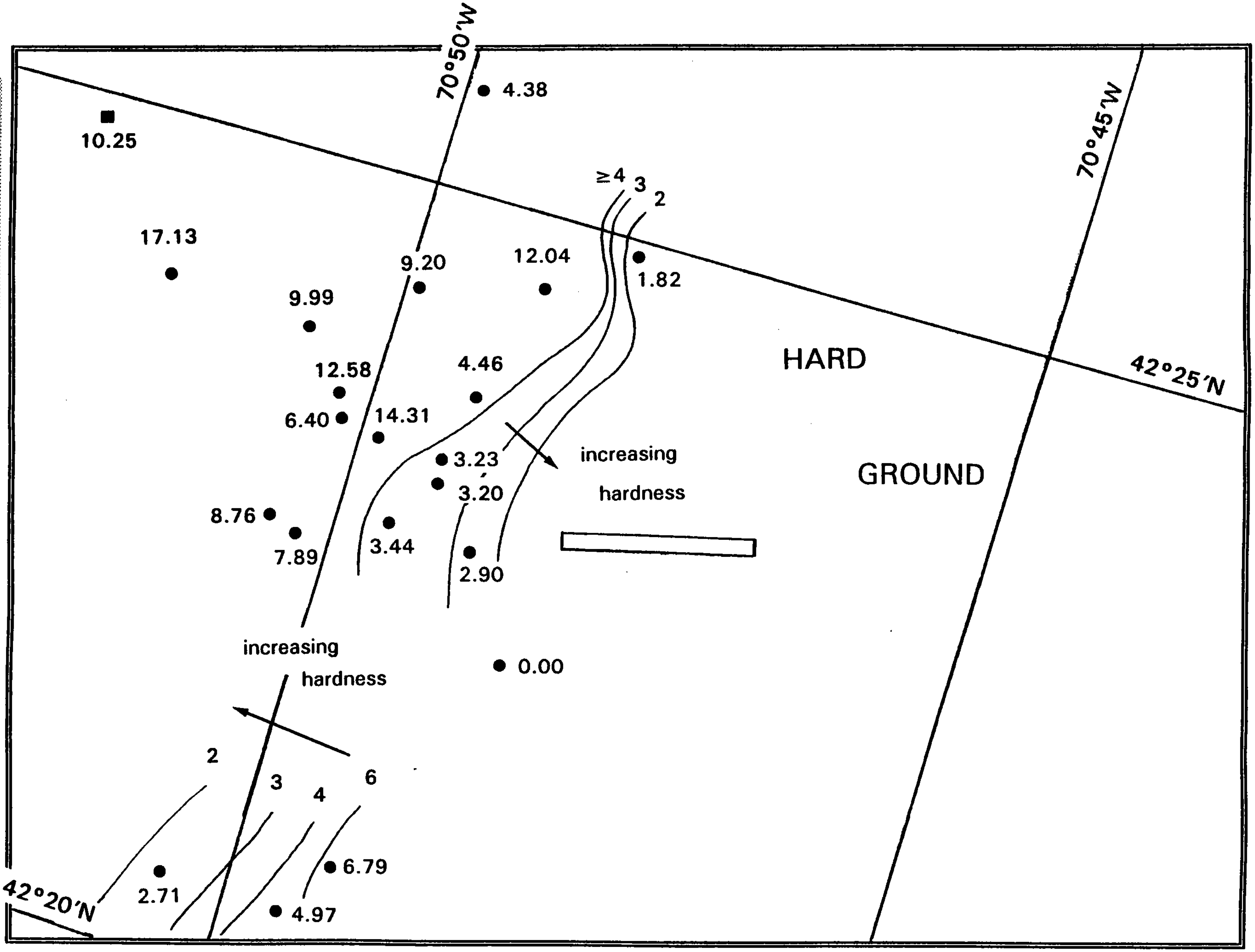


Figure 5. Mean Penetration Depth (cm) of the REMOTS® Camera Prism in the Nearfield.

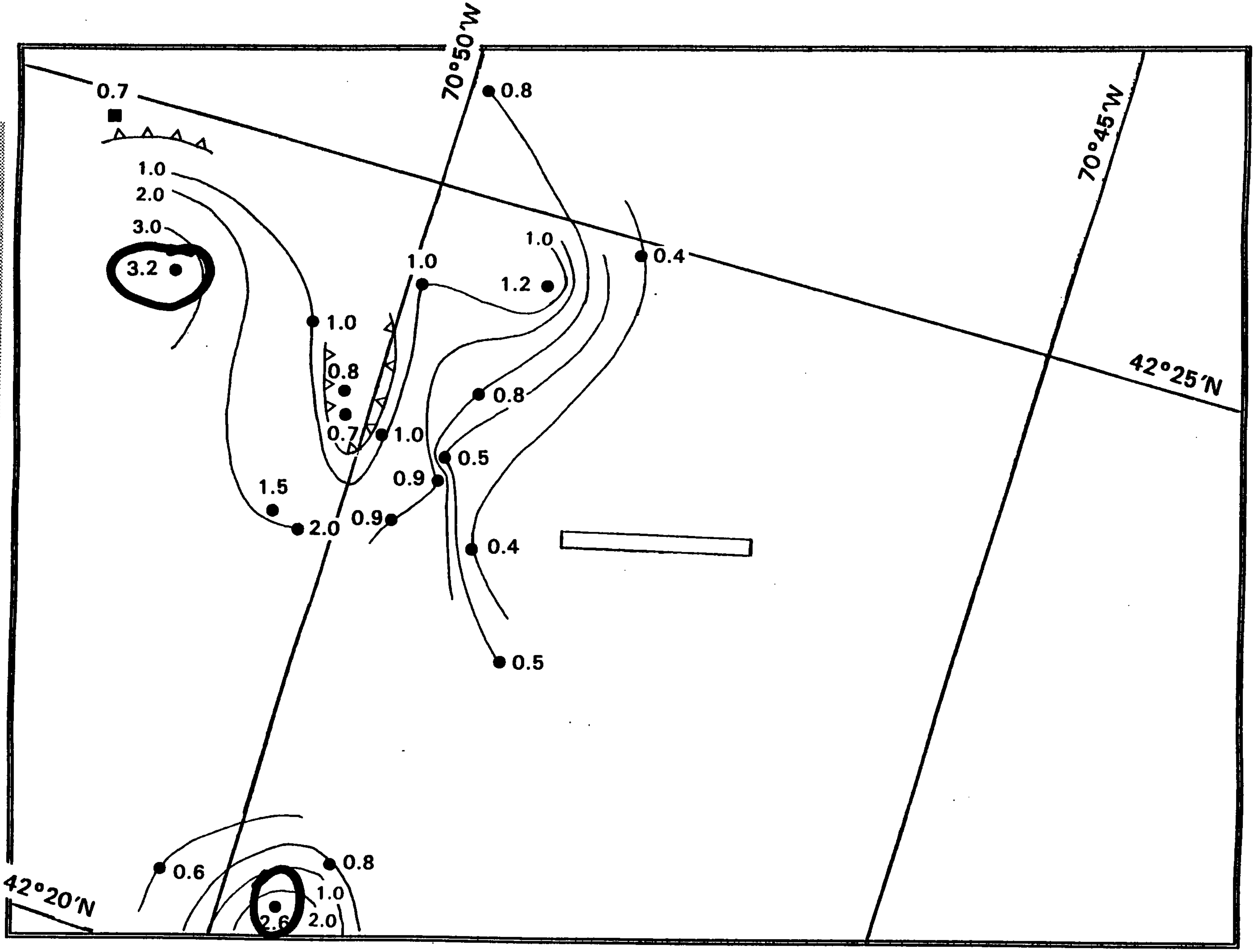


Figure 6. Distribution of Average Total Organic Carbon Contents (wt %) in the Nearfield. Note contour intervals are unequal.

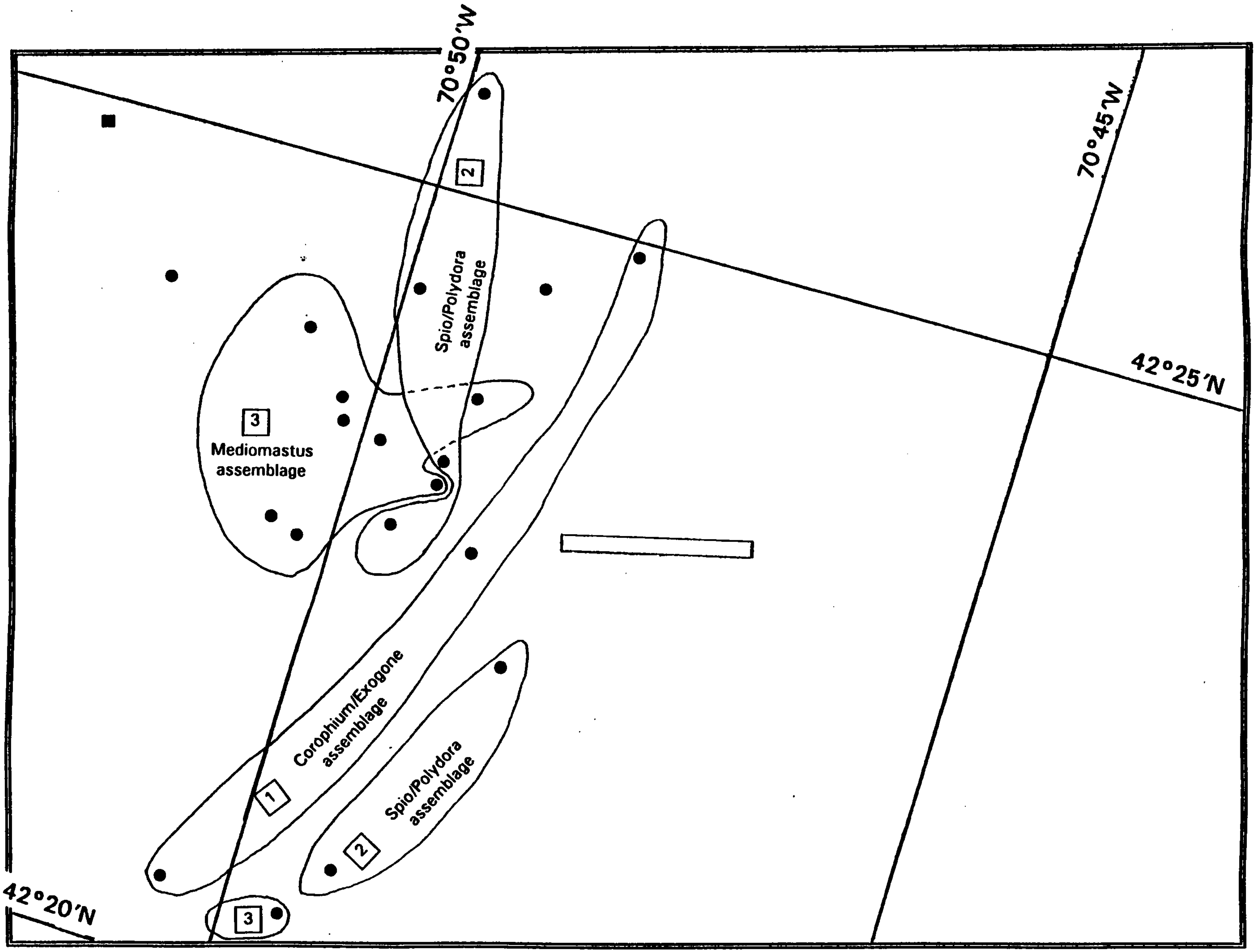


Figure 12. Infaunal Assemblages in the Nearfield.

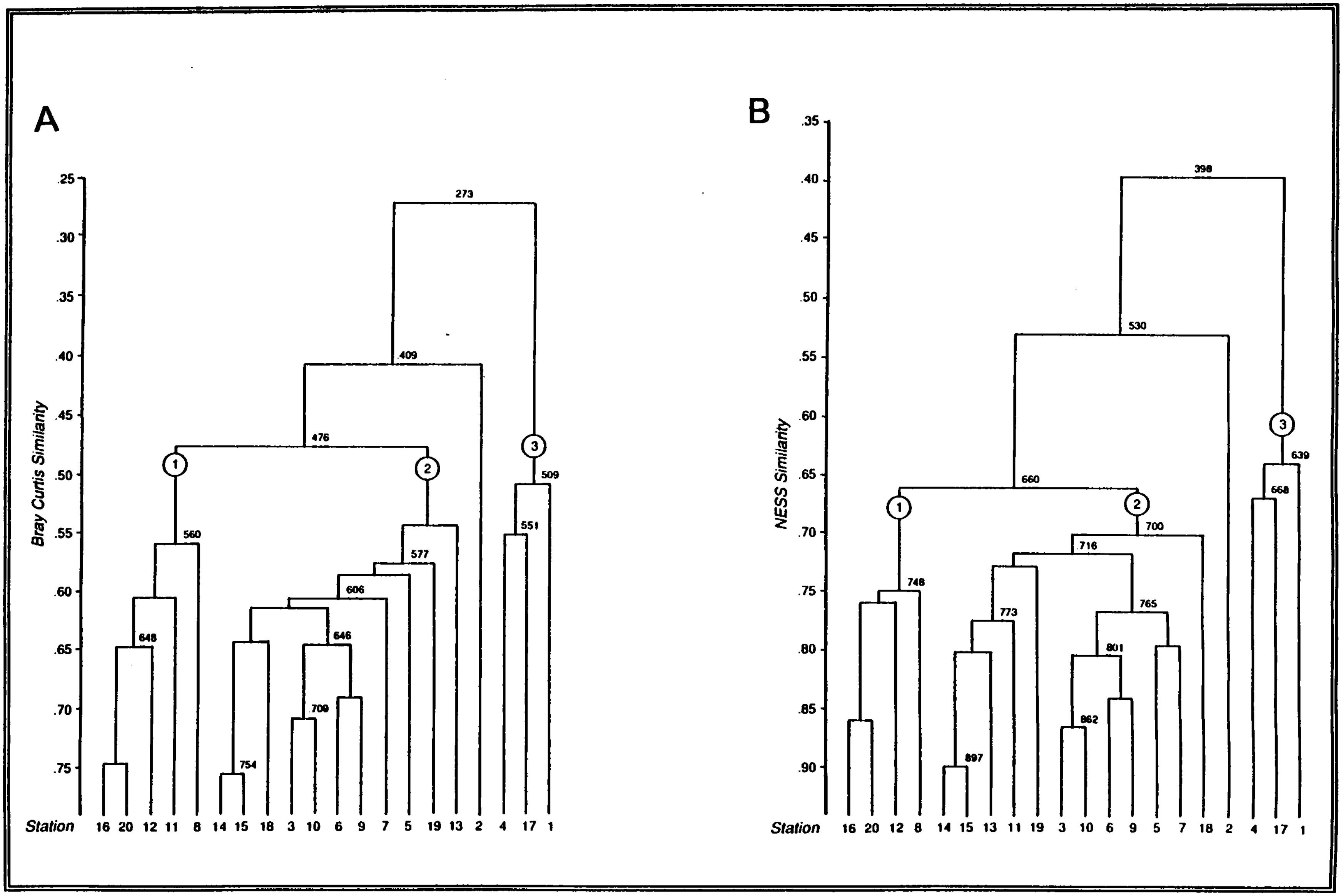
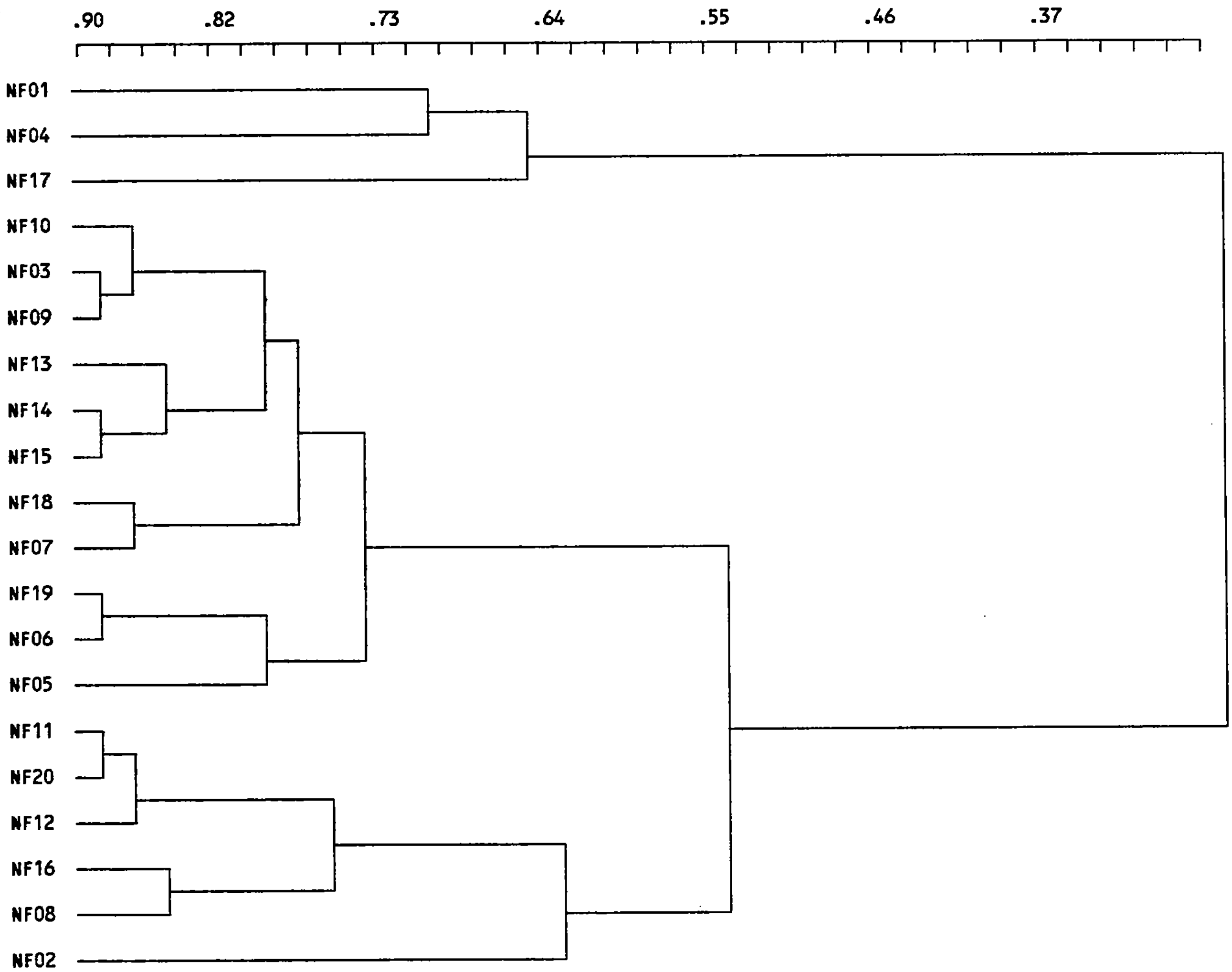


Figure 16. Similarity Among the Nearfield Stations. A, Bray-Curtis Similarity; B, NESS Similarity. Clustering with group average sorting (UPGMA).

Group-Average Clustering, Near-field August 1992 data using NNESS @ m = 10



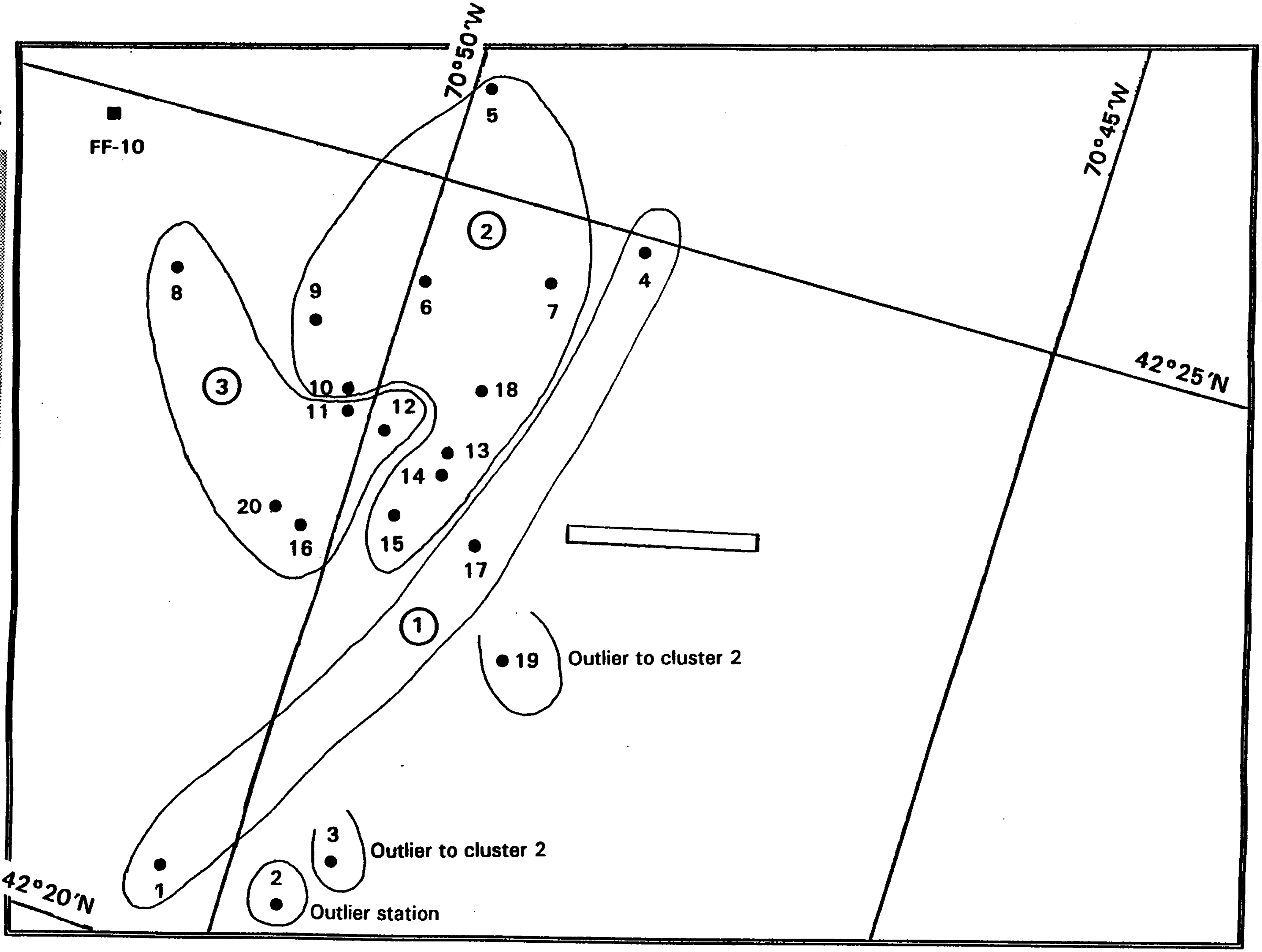


Figure 17. Geographical Distribution of the Station Clusters Defined by NESS and Group Average Sorting (UPGMA).

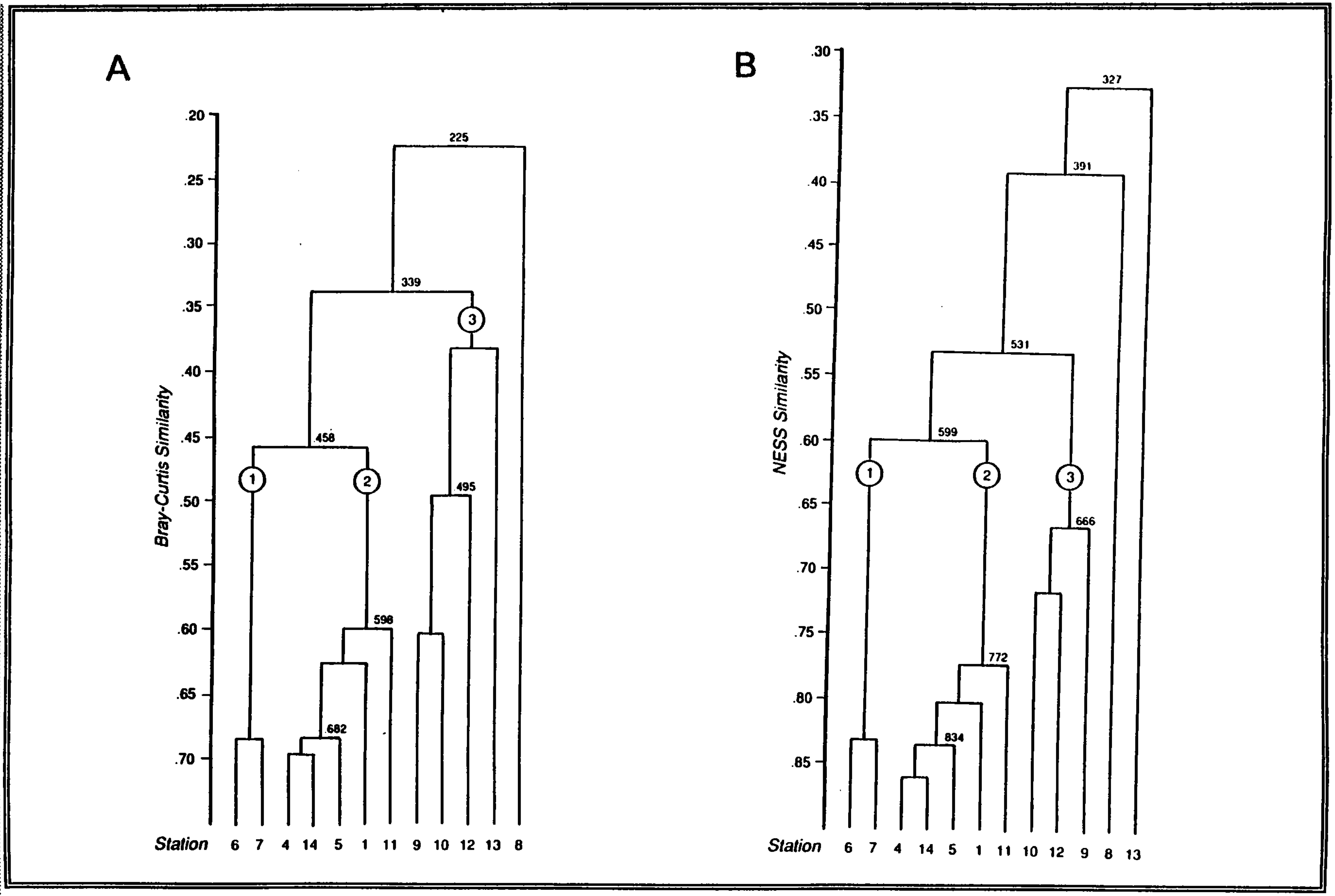
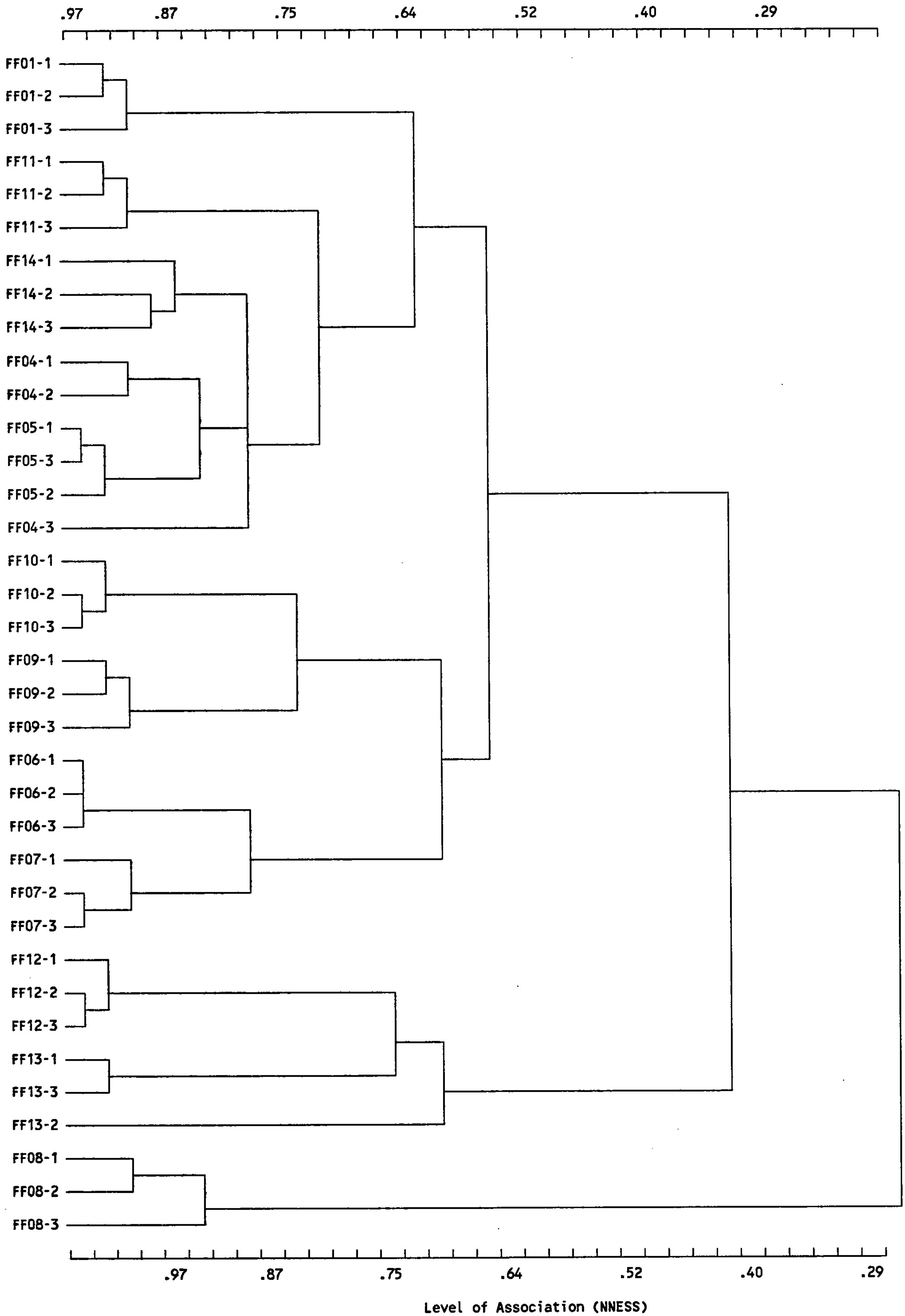


Figure 36. Similarity Among the Farfield Stations, August 1992. A, Bray-Curtis Similarity; B, NESS Similarity. Clustering with group average sorting (UPGMA).

Group Averge clustering, Far-field August 1992 data NNESS @ m = 10



OMTF Decisions re Soft-Bottom Benthic Monitoring
Meeting of July 15, 1993

OMTF Mandate

- MWRA was directed to change from a 20 station, 1 replicate/station design in the near-field to a replicated design using roughly the same level of effort. This roughly equated to 8 stations, sampled as are far-field reference stations (3 biology, 2 chemistry).

- MWRA was given approval to cease sampling at station FF-8 (east of Stellwagen Bank) and to re-allocate those sample analysis resources to the near-field study. This resulted in a total of 9 near-field stations.

OMTF Guidance The following technical concerns were voiced by OMTF members for MWRA to consider in selecting near-field stations for continued monitoring:

- Attempt to capture the range in community types and habitat seen in the 1992 survey.

- Focus effort in the most stable, depositional areas.

- Attempt to maintain a gradient in distance from the Future Effluent Outfall.

Resulting station list Following consultation with OMTF members, and working with our consultants, we selected Stations NF08, NF02, NF16, NF12, NF09, NF10, NF14, NF04, & NF17 for continued sampling. This list includes:

- All stations with more than 70% silt + clay in 1992 samples.

- At least 2 representatives from each of the 3 faunal station clusters identified in 1992 sampling.

- Both of the USGS long-term sediment monitoring stations in the near-field, WH-3 (=NF12) and WH-2 (=NF17).

- A range in distance and direction from the Future Effluent Outfall.

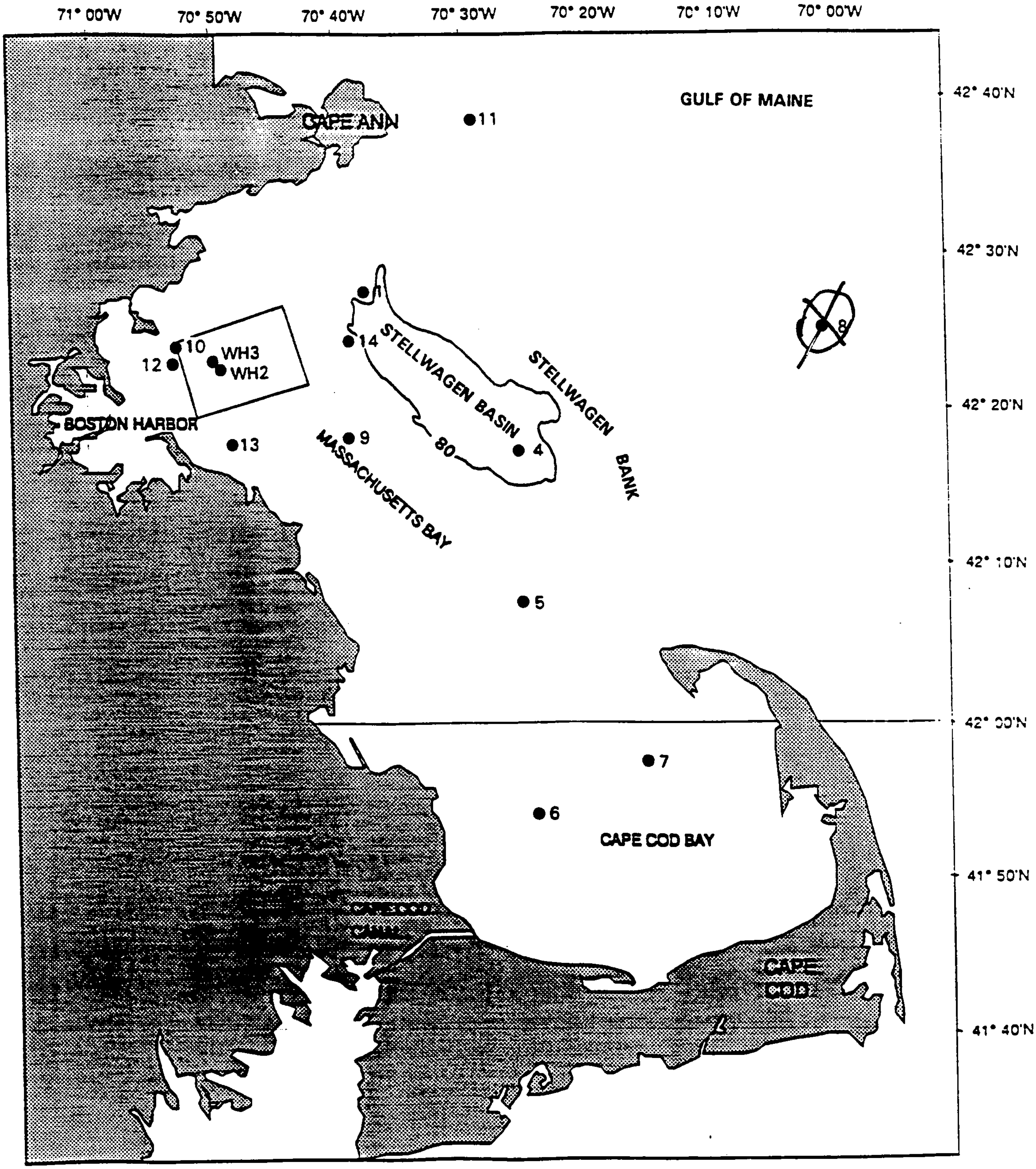


Figure 1. Location of Farfield Stations Sampled in May and August 1992. The rectangular box represents the nearfield area shown in detail in Figure 2.

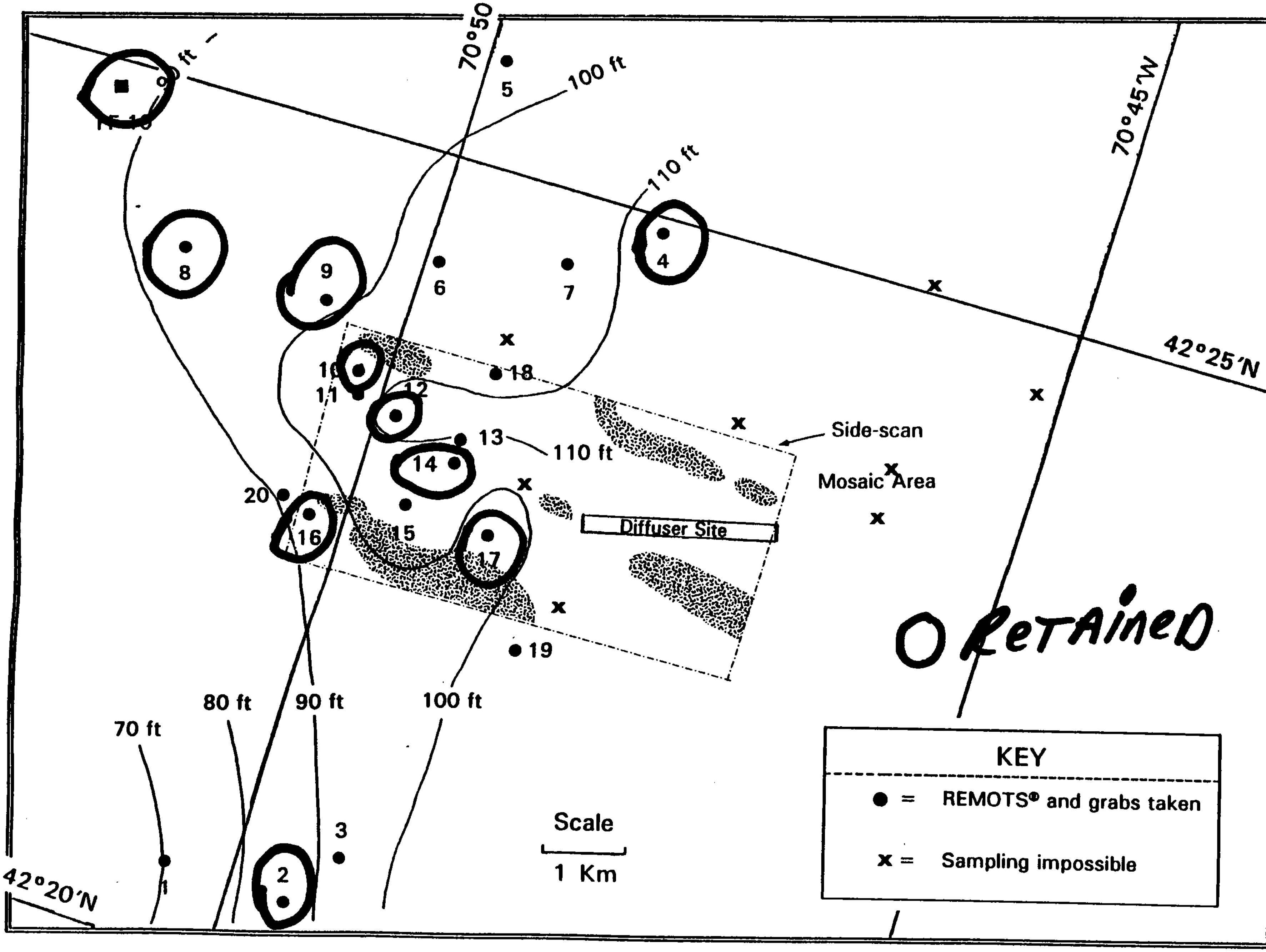
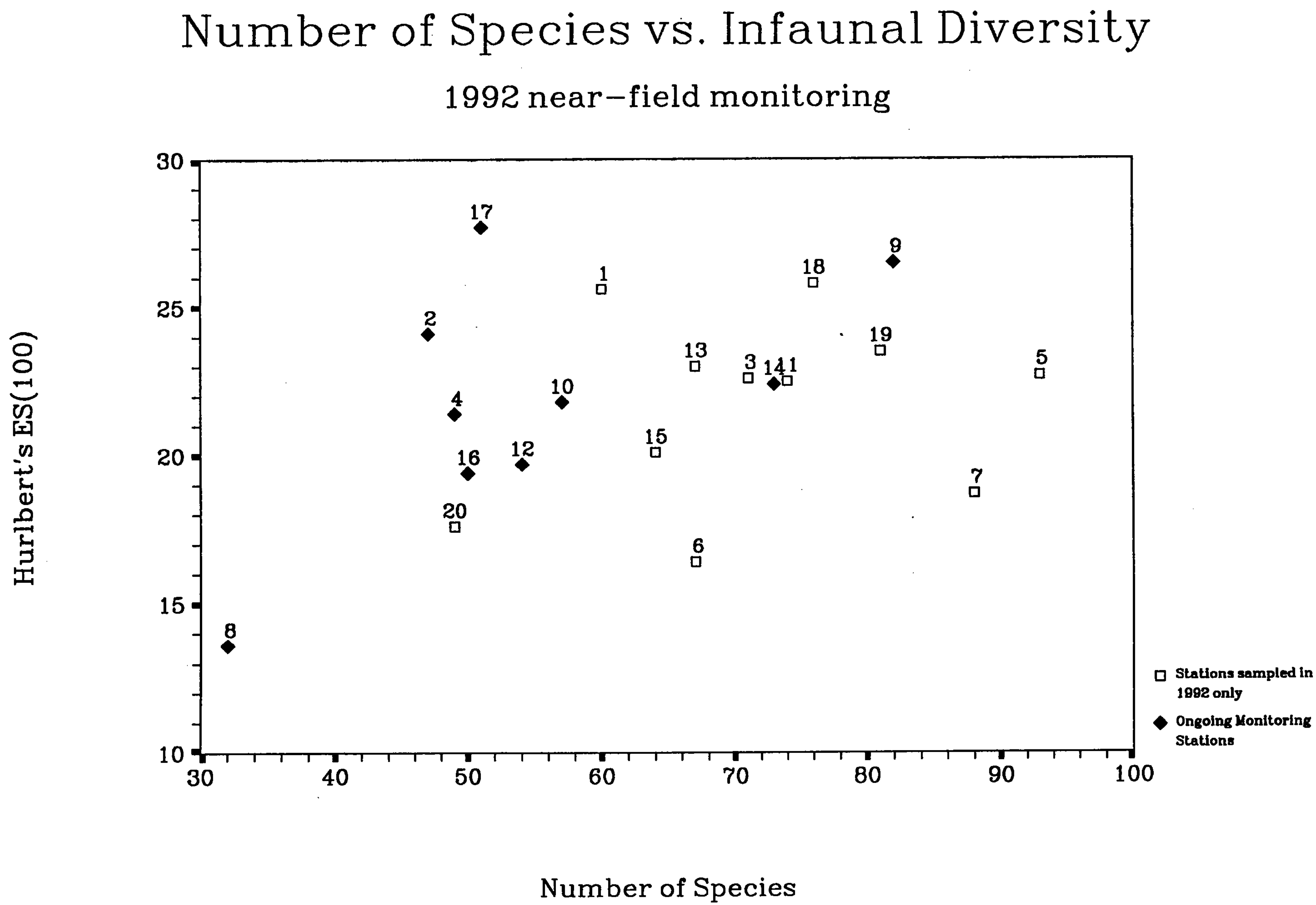


Figure 2. Locations of Nearfield Stations. Depth contours are in feet below MLW. Side scan mosaic area (dashed box) after Butman *et al.*, 1992. Shaded areas within the box are drumlins. Station FF10 has been included to facilitate contouring of data.

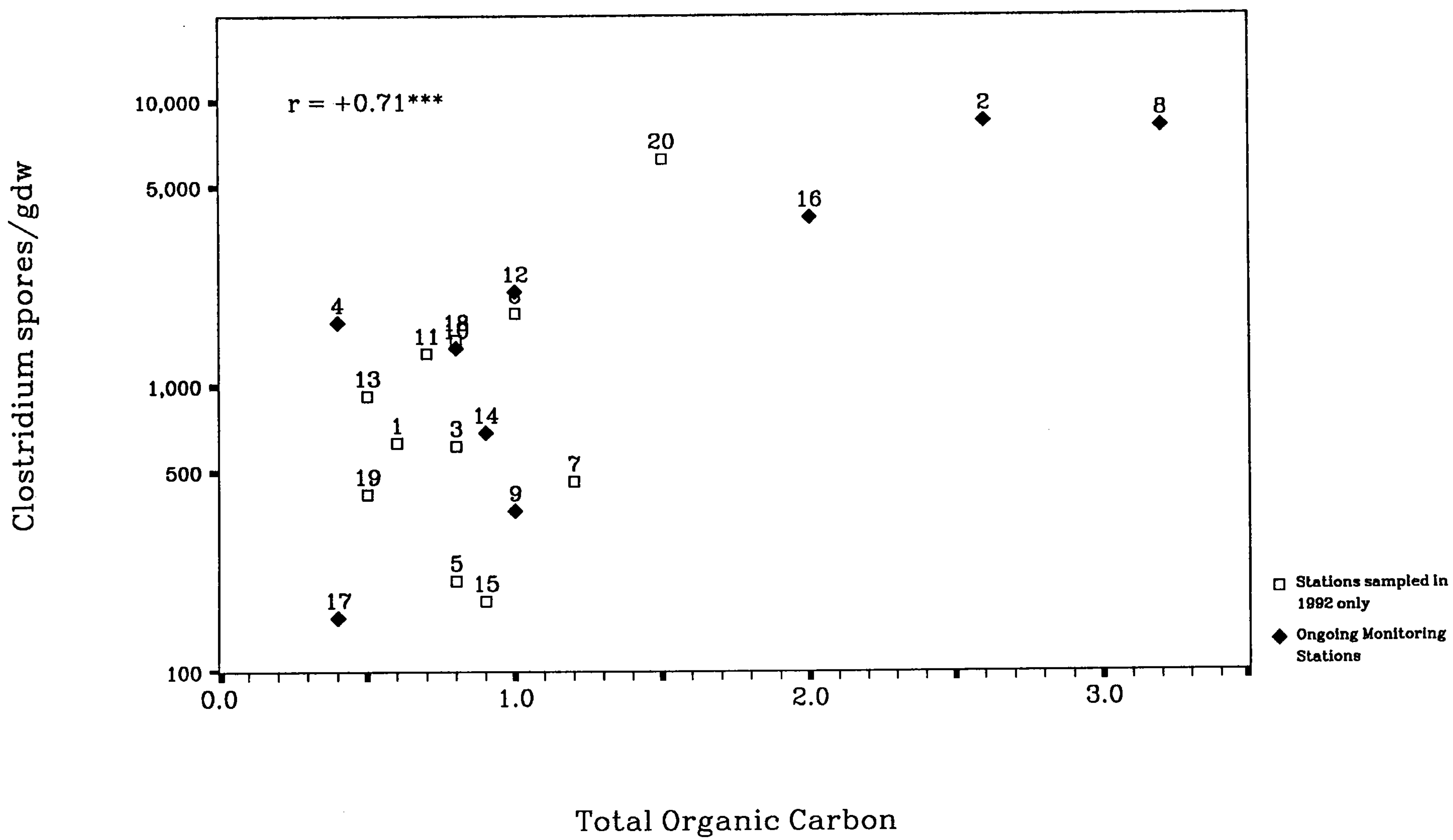
Partial summary of 1992 Near-field data, sorted in increasing order on % silt + clay.

Station	Sand + Gravel, %	Silt + Clay, %	Total Organic Carbon, %	Apparent RPD, cm	Distance, SW end of Outfall, km	Number of Species	Infaunal Abundance	ES(100)	ES(500)	H'	Cluster Membership
NF-17	99	1	0.4		1.69	51	13,600	27.7	[illegible]	4.36	3
NF-04	96	4	0.4		3.47	49	18,900	21.4	42	3.67	3
NF-13	96	4	0.5	2.15	1.67	67	31,850	23	46.7	3.89	2
NF-19	94	6	0.5		1.40	81	100,100	23.5	46.9	3.56	2
NF-01	93	7	0.6		5.90	60	26,975	25.6	47.8	4.21	3
NF-18	90	10	0.8	2.28	1.97	76	45,525	25.8	48.9	4.17	2
NF-14	87	13	0.9	2.62	1.37	73	57,825	22.4	44.2	4.05	2
NF-15	81	19	0.9	2.02	1.99	64	67,350	20.1	40.9	3.71	2
NF-05	79	21	0.8	4.05	5.35	93	71,600	22.7	51.8	3.69	2
NF-11	75	25	0.7	2.79	2.84	74	39,300	22.5	47.4	3.68	1
NF-03	65	35	0.8	1.65	4.67	71	77,725	22.6	42.8	3.97	2
NF-06	63	37	1	2.32	3.34	67	83,325	16.4	35.5	2.81	2
NF-10	60	40	0.7	2.79	2.98	57	45,850	21.8	38.3	3.76	2
NF-07	59	41	1.2	2.88	3.00	88	141,225	18.7	40.1	3.41	2
NF-09	56	44	0.8	4.09	3.79	82	57,375	26.5	49.8	4.23	2
NF-20	42	58	1.5	3.6	3.43	49	31,925	17.6	35.4	3.34	1
NF-12	29	71	1.0	4.75	2.29	54	29,050	19.7	39.7	3.67	1
NF-16	23	77	2.0	2.31	2.86	50	31,625	19.4	37.1	3.55	1
NF-02	23	77	2.6	0.92	5.46	47	16,400	24.1	43.1	4.10	Outlier to groups 1,2
NF-08	18	82	3.2	1.71	5.20	32	31,550	13.6	34.1	2.72	1


Number of Species vs. Infaunal Diversity
1992 near–field monitoring
Hurlbert's ES(100)
30
25
20
15
10
30
40
50
60
70
80
90
100
Number of Species
17
9
1
18
2
19
13
3
14
11
5
4
10
15
16
12
7
20
6
8
Stations sampled in 1992 only
Ongoing Monitoring Stations

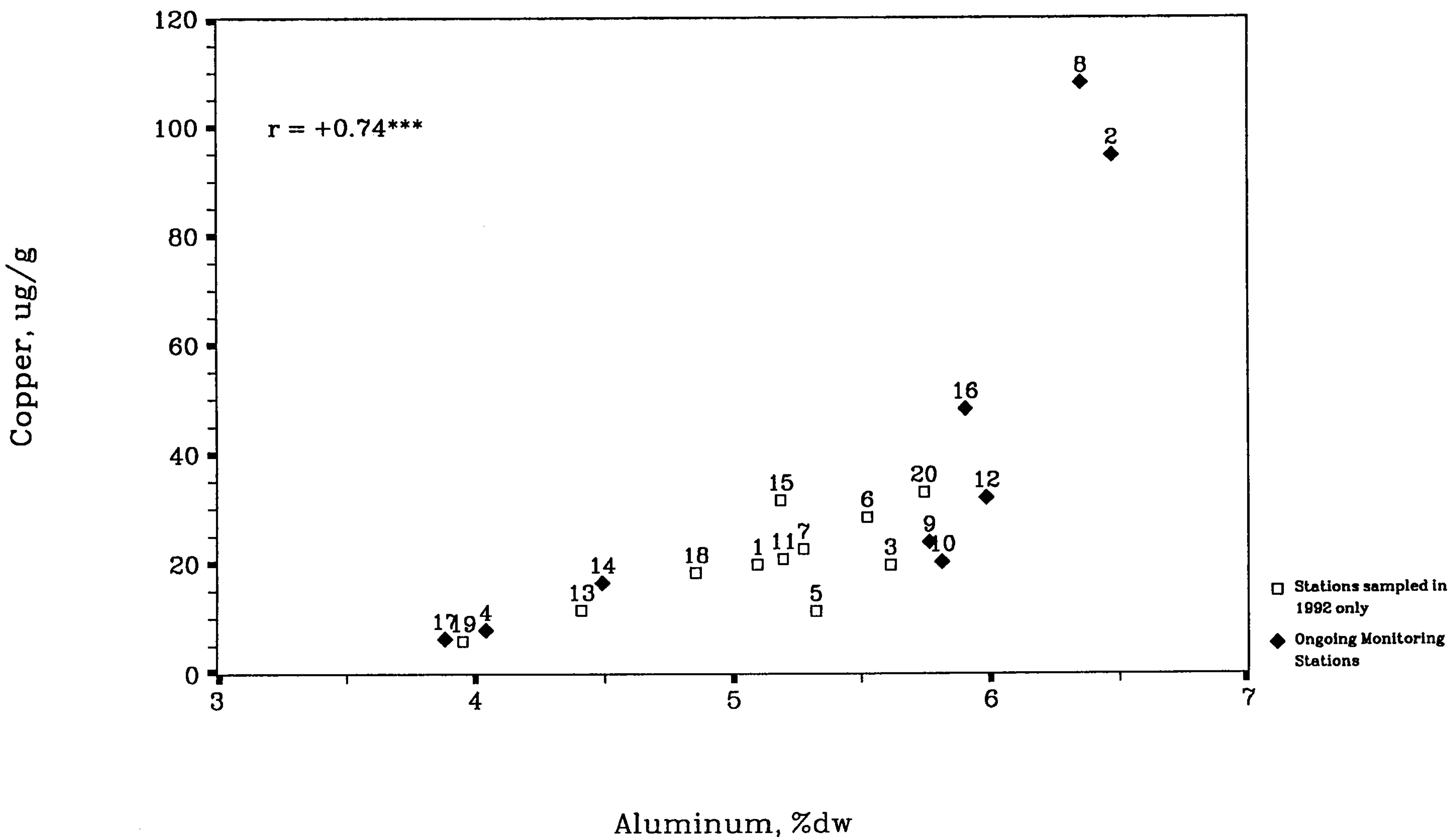
Clostridium Spore Counts vs. % TOC

1992 near-field monitoring

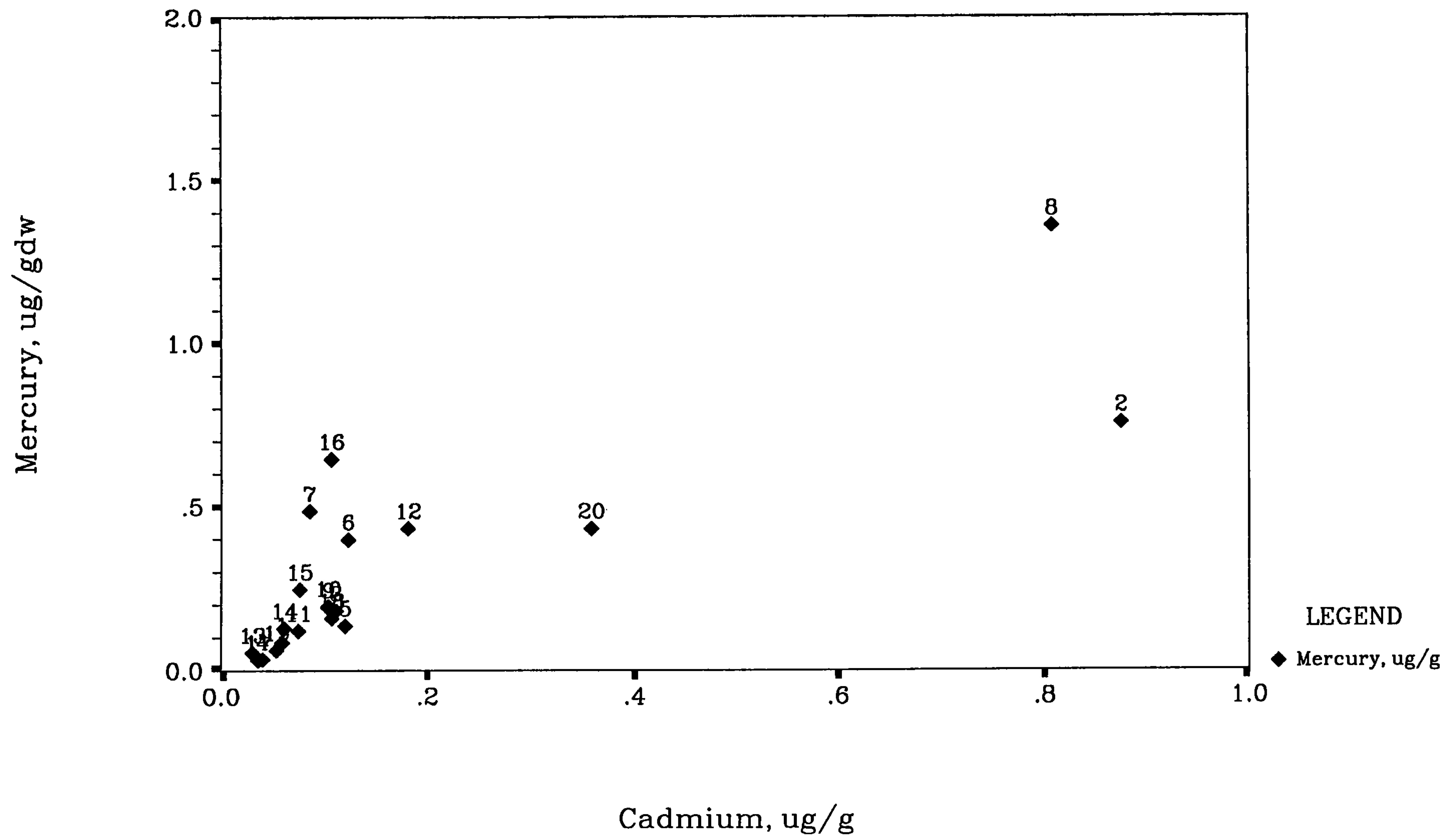


Copper vs. Aluminum in sediments

1992 near–field monitoring



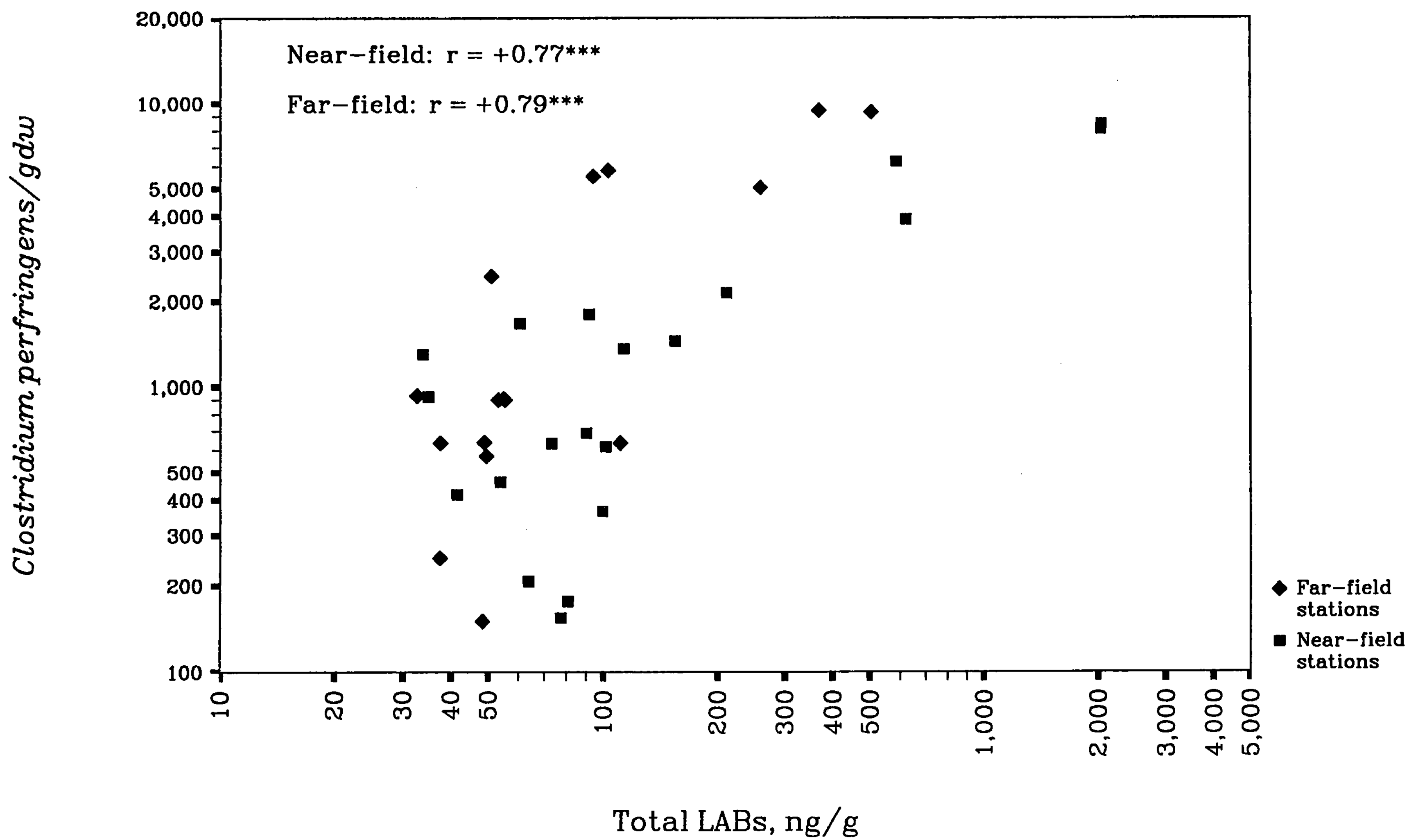
Mercury vs. Cadmium, near–field 1992 data



Clostridium perfringens

Spore counts vs. Total Linear Alkyl Benzenes

MWRA August 1992 benthic outfall monitoring



Set-up of Correlation analyses

Dependent Variables:	Hurlbert's rarefaction @ $E(S_{100})$, $E(S_{10})$. Shannon-Wiener diversity, H'
Predictor variables	Silt+Clay (% dw) Total Organic Carbon (% dw) Log_{10}(*Clostridium perfringens*) (spores/gdw) Trace metals Ag, Cr, CU, Hg, Ni, Pb, Zn (μg/gdy) Major Metals Al, Fe (% dw) Total LABs (ng/gdw) Total PAHs (ng/gdw) Total PCBs (ng/gdw) Total DDTs (ng/gdw) Distance from D. I. discharge (km) Station depth (m)

Near-field For the near-field analyses, the diversity estimates were based upon the one faunal sample per station. The contaminant and physical sediment parameters were also based upon a single sample per station.

The near-field correlation analyses are based upon 18 degrees of freedom.

Far-field For the far-field analyses, $E(S_n)$ values were the mean of diversity estimates for each of the 3 faunal samples per site, while H' was based upon pooled data from the 3 samples. The physical sediment parameters, and metals were the mean of 2 samples per site. The organic contaminant estimates for stations FF01, FF10, FF12, and FF13 were the mean of duplicate field samples. Organic contaminant estimates from FF04 - FF09, FF11 & FF14 were based upon a single analysis per station. Results of organic contaminant analyses on samples taken at these stations in May 1992 were not included.

Far-field correlation analyses are based upon 10 degrees of freedom.

Partial correlation analyses

Following the initial correlation analyses, carried out 2 series of first-order partial correlation analyses, controlling for the effects of silt plus clay in one set, and total organic carbon in the second. The same dependent and predictor variable lists were used, with the exclusion of TOC or SPC where those parameters were the control variables. These partial correlations have 9 df for the far-field data, 17 df for the near-field samples.

Synopsis of Results, Far-field

Correlation analyses

- None of the 3 diversity metrics showed a significant correlation with any of the predictor variables.

Partial correlation analyses

- Chromium and ΣDDTs showed significant ($p < 0.05$) positive partial correlations with all diversity indices when controlling for either silt + clay or TOC. PAHs had a positive, significant partial correlation with $E(S_{10})$ in both partial correlation analyses.

- None of the diversity indices showed a significant negative partial correlation with any of the predictor variables.

Synopsis of Results, Near-field

$E(S_{100})$
Correlation analyses

- ΣPAH, HG, ΣDDT, ΣPCB, % Silt+clay, and chromium showed negative correlations with $E(S_{100})$ significant at $p < 0.01$. % TOC, *C. perfringens* spore counts, aluminum, copper, zinc and lead were significant at $p < 0.05$.

- No parameters were significantly positively correlated with $E(S_{100})$.

Partial correlation analyses

- ΣPAHs were the only parameter to have a significant negative partial correlation ($p < 0.05$) with $E(S_{100})$ when controlling for % Silt + Clay. Mercury and ΣPAH were negatively correlated ($p < 0.05$) with $E(S_{100})$ when correcting for % TOC.

- Nickel had a positive partial correlation ($p < 0.05$) with $E(S_{100})$ when correcting for effect of silt+ clay, and silver had a positive partial correlation when correcting for the effect of TOC.

$E(S_{10})$
Correlation analyses

- ΣPAHs were significantly negatively correlated with $E(S_{10})$ at $p < 0.01$. HG, ΣPCBs and ΣDDTs were negatively correlated with $E(S_{10})$ at $p < .05$.

- No parameters were significantly positively correlated with $E(S_{10})$.

Partial correlation analyses

- ΣPAHs were the only parameter to have a significant negative partial correlation ($p < 0.05$) with $E(S_{10})$ when controlling for % Silt + Clay. Mercury and ΣPAH were negatively correlated ($p < 0.05$) with $E(S_{100})$ when correcting for % TOC.

- Nickel had a positive partial correlation ($p < 0.01$) with $E(S_{100})$ when correcting for effect of silt+ clay. Nickel and silver had positive partial correlations ($P < .05$) when correcting for the effect of TOC.

Synopsis of Results, Near-field

H'

Correlation analyses

- ΣPAHs, Mercury, ΣPCBs, and ΣDDTs were negatively correlated with Shannon-Wiener diversity at $P < 0.01$. Chromium, TOC, and silt-clay were negatively correlated with H' at $p < 0.05$.

- No parameters showed significant positive correlations with H'.

Partial correlation analyses

- ΣPAHs were the only parameter to have a significant negative partial correlation ($p < 0.05$) with H' when controlling for % Silt + Clay. Mercury and ΣPAH were negatively correlated ($p < 0.05$) with H' when correcting for % TOC.

- Nickel had a positive partial correlation ($p < 0.01$) with H' when correcting for effect of silt+ clay. Nickel and silver had positive partial correlations ($P < .05$) when correcting for the effect of TOC.

Results, correlation and partial correlation analyses
1992 MWRA Outfall Monitoring Program benthic monitoring data

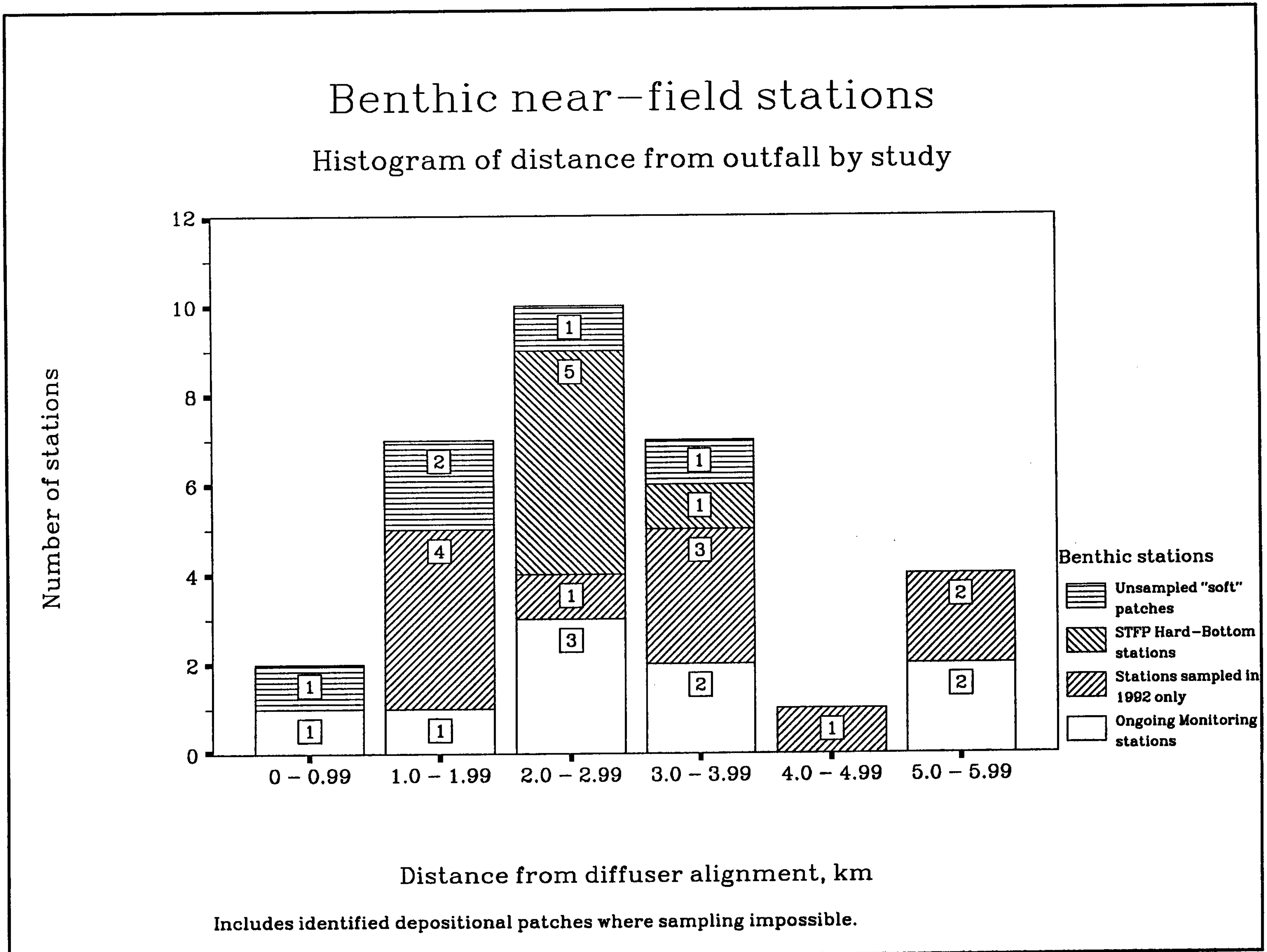
Near-field:

Correlation Analyses	Hurlbert's		Shannon-Wiener
	$E(S_{100})$	$E(S_{10})$	H'
% silt+clay	-.5912**	-.3519	-.4461*
% TOC	-.5485*	-.3429	-.4531*
D.I. distance	.1255	-.0962	-.0114
Depth	.2310	.1988	.2163
Log_{10}(*C. perfringens*)	-.5226*	-.3356	-.4422
AL	-.4828*	-.2605	-.3326
AG	-.3043	-.1258	-.2319
CD	-.3628	-.2074	-.3100
CR	-.5762**	-.4014	-.5027*
CU	-.4800*	-.2741	-.3924
FE	-.3182	-.1019	-.2046
HG	-.6876**	-.4952*	-.6055**
NI	-.3173	-.0119	-.1355
PB	-.4506*	-.1988	-.3262
ZN	-.4637*	-.2674	-.3786
Σ(PAH)	-.7885**	-.6326**	-.6976**
Σ(LAB)	-.3564	-.1849	-.2979
Σ(PCB)	-.6128**	-.4586*	-.5702**
Σ(DDT)	-.6160**	-.4503*	-.5641**

Open Issues

These have been brought up by reviewers or members of our Outfall Monitoring Task Force, and not been brought to resolution.

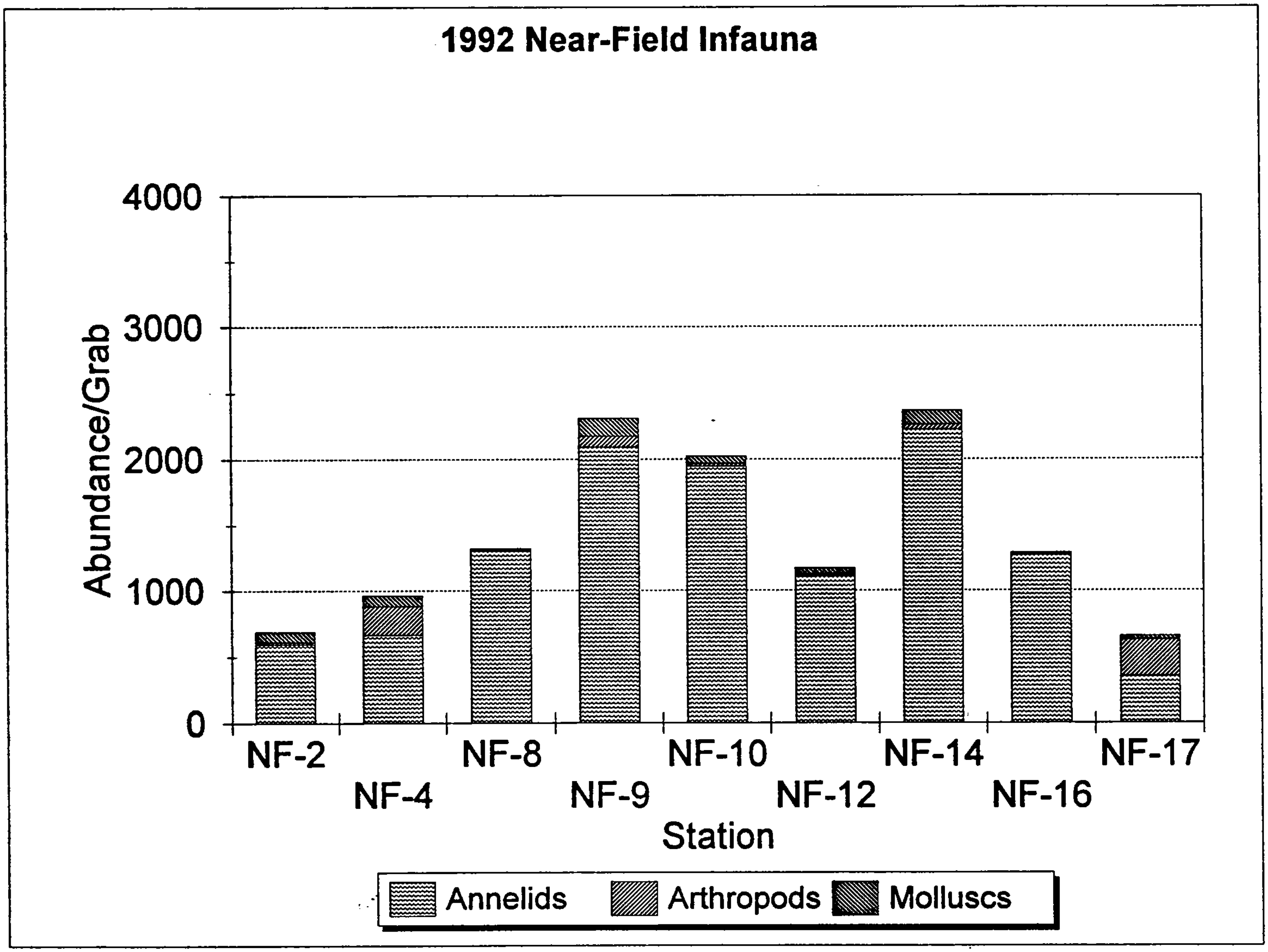
- Would the program benefit from the addition of infaunal biomass?
- Revisit issue of inclusion of hard-bottom component in light of lack of soft sediments in the extreme near-field (w/in 1 km).
- Change grain size analysis from Gravel-sand-silt-clay to full phi analysis.
- Sieve size: whether to retain nested 500 and 300μm sieves or to switch to only 500 μm sieved samples or only 300 μm samples.
- Is there need to further study within-year temporal replication, either within seasons or within the summer sampling period?
- Is annually the proper frequency to sample the full list of sediment contaminants?
- Should measurements of contaminants in benthos be pursued as a possible monitoring tool?



Benthic near–field stations
Histogram of distance from outfall by study
Number of stations
0
2
4
6
8
10
12
0 – 0.99
1.0 – 1.99
2.0 – 2.99
3.0 – 3.99
4.0 – 4.99
5.0 – 5.99
Distance from diffuser alignment, km
Benthic stations
Unsampled "soft" patches
STFP Hard–Bottom stations
Stations sampled in 1992 only
Ongoing Monitoring stations
Includes identified depositional patches where sampling impossible.

APPENDIX C-4

Roy Kropp



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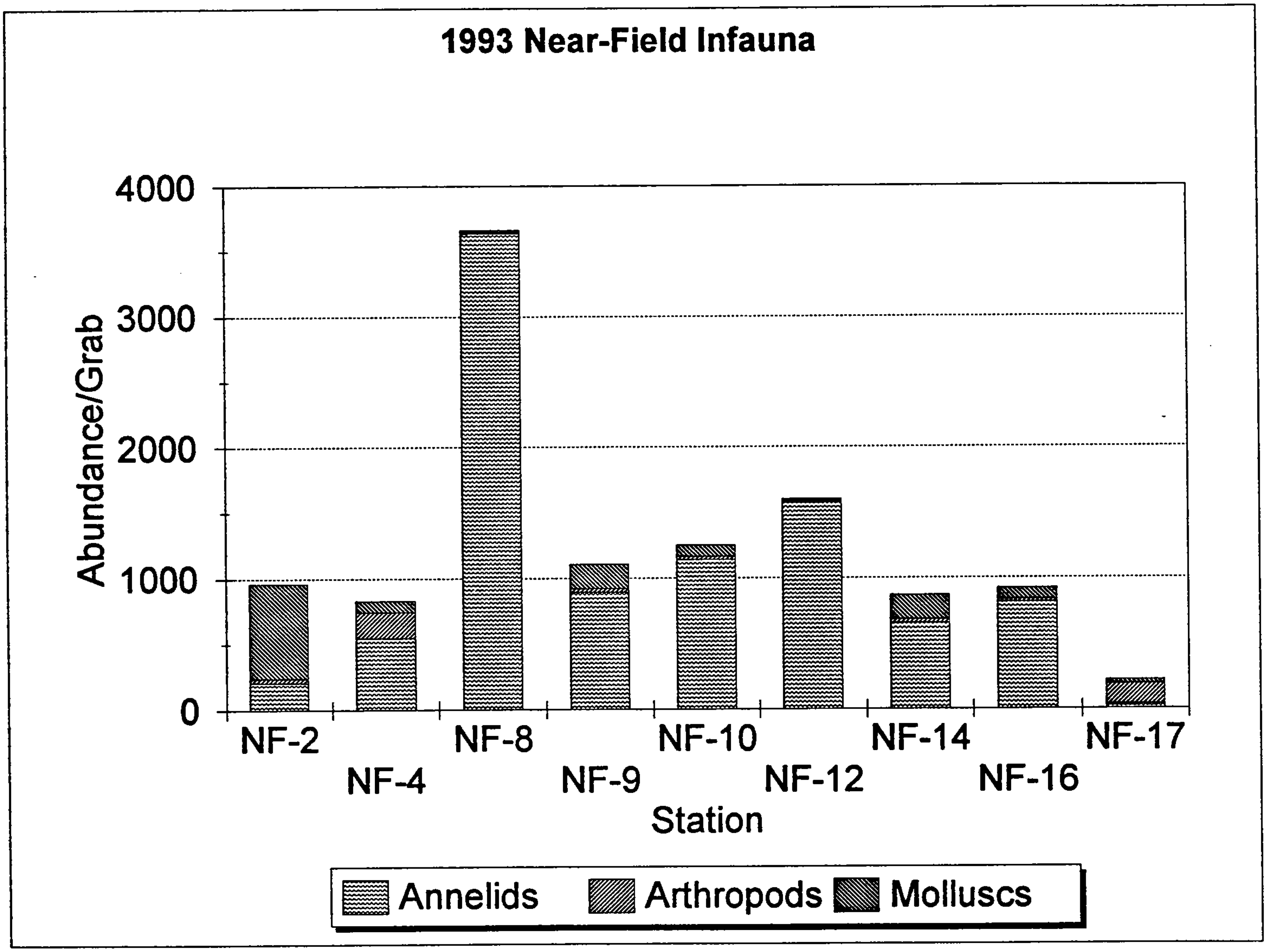
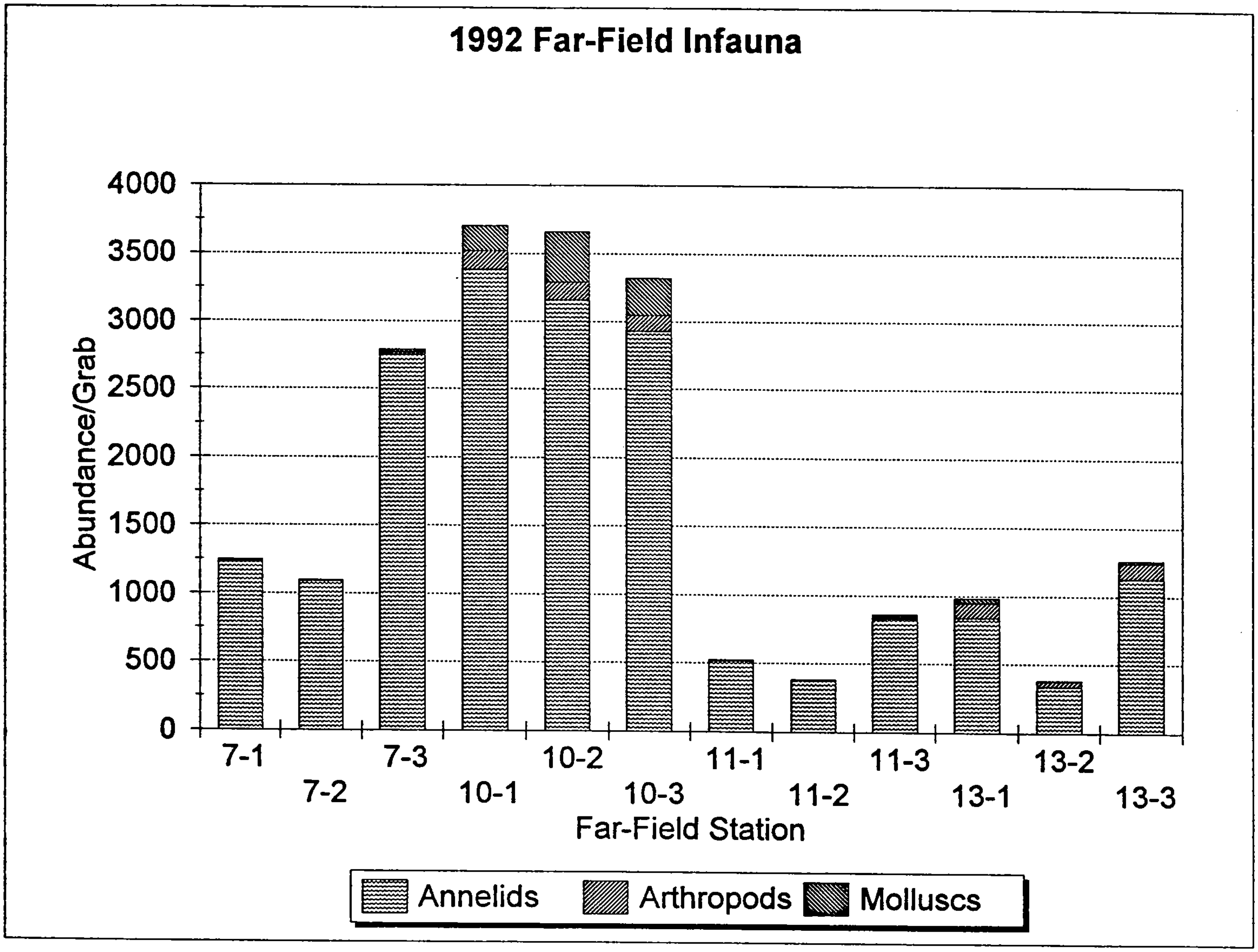
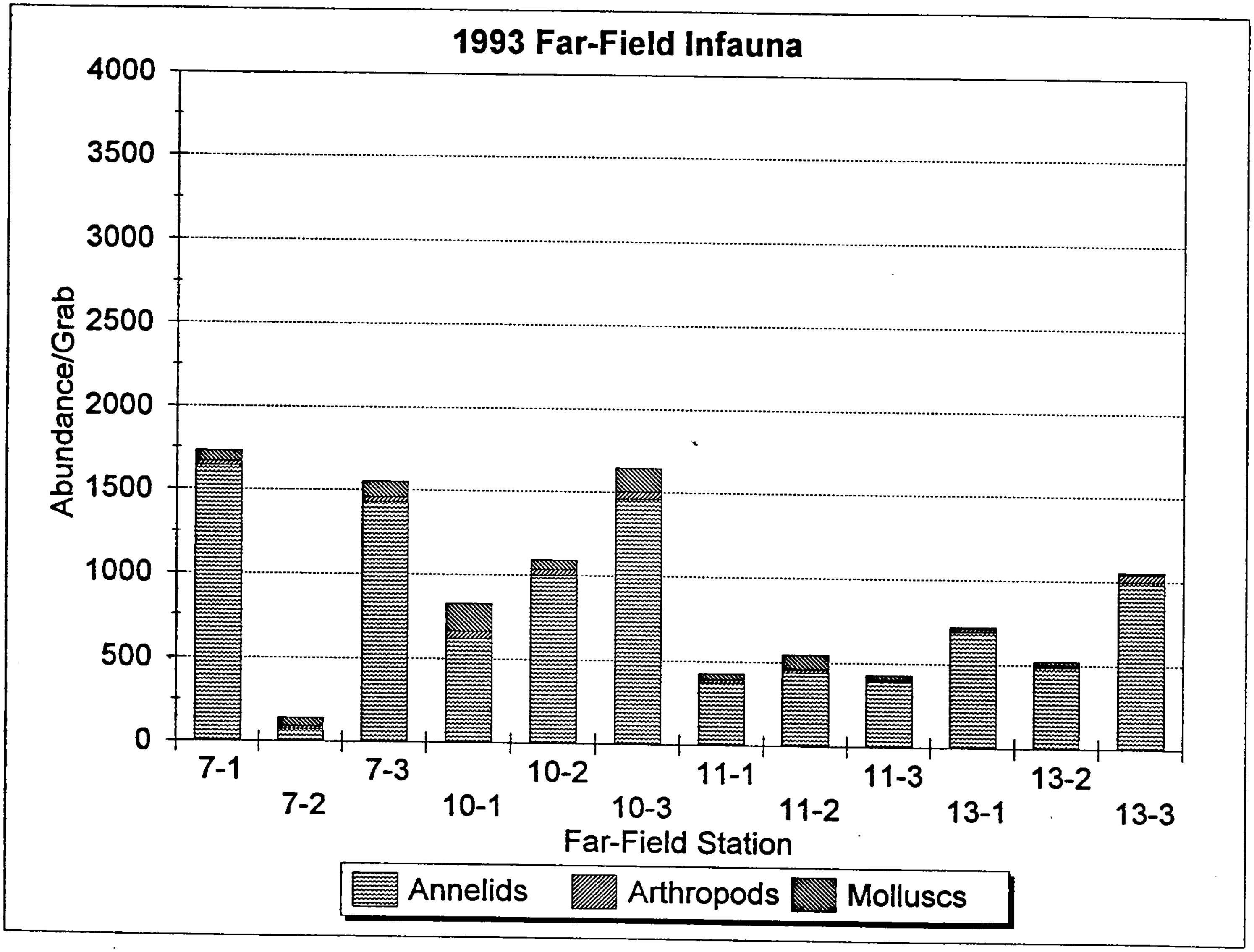


1993 Near-Field Infauna
4000
3000
2000
1000
0
Abundance/Grab
NF-2
NF-4
NF-8
NF-9
NF-10
NF-12
NF-14
NF-16
NF-17
Station
Annelids
Arthropods
Molluscs



1992 Far-Field Infauna
Abundance/Grab
4000
3500
3000
2500
2000
1500
1000
500
0
7-1
7-2
7-3
10-1
10-2
10-3
11-1
11-2
11-3
13-1
13-2
13-3
Far-Field Station
Annelids
Arthropods
Molluscs



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Near Field
Grain Size (%)

	1992				1993			
	Gravel	Sand	Silt	Clay	Gravel	Sand	Silt	Clay
NF-2	0	22.8	47	30.2	0	96.08	2.45	1.47
NF-4	37.7	58.6	2.1	1.5	1.89	94.05	2.29	1.77
NF-8	0	18	59.1	22.9	0	42.43	47.05	10.51
NF-9	0.1	56	33.6	10.3	5.36	56.46	29.38	8.81
NF-10	0.1	60.2	31.7	7.9	0	65.89	28.82	5.29
NF-12	0	29.2	57.4	13.3	0	44.77	46.81	8.43
NF-14	8.9	77.9	9.3	3.9	1.64	32.97	56.45	8.95
NF-16	0	23.5	59.8	16.7	0	70.52	26.67	2.81
NF-17	0.1	98.7	0.8	0.4	0.05	98.03	0.26	1.66

Far Field
Grain Size (%)

	1992 (Ave)				1993 (Ave)			
	Gravel	Sand	Silt	Clay	Gravel	Sand	Silt	Clay
FF-7	0	21	65	14	0	34	57	20
FF-10	1	68	27	4	0	66	31	3
FF-11	0	22	63	14	0	28	58	14
FF-13	39	34	20	7	0	72	23	5

Near-Field Infauna

	1992			1993 (ave 0.05)			1993 (ave total)		
	Annelids	Arthropod	Molluscs	Annelids	Arthropod	Molluscs	Annelid	Arthropod	Mollusc
NF-2	593	16	77	120	29	533	207	33	721
NF-4	661	221	81	389	183	38	542	201	86
NF-8	1314	0	6	2129	2	12	3641	3	18
NF-9	2091	83	134	634	20	63	889	30	186
NF-10	1946	17	59	925	16	44	1139	24	86
NF-12	1109	16	48	1333	2	17	1574	4	23
NF-14	2223	41	102	507	21	82	651	29	184
NF-16	1269	1	18	683	17	27	813	20	86
NF-17	353	275	27	28	126	17	32	159	27

Near-Field Infauna

	1993 (grab)			1993 (0.3&0.5)		
	Annelids	Arthropod	Molluscs	Annelids	Arthropod	Mollusc
2-1	83	28	393	122	28	505
2-2	158	39	939	315	49	1364
2-3	119	21	267	184	21	295
4-1	394	81	25	575	96	75
4-2	361	39	26	470	43	34
4-3	413	429	64	581	464	150
8-1	2416	3	25	4819	3	40
8-2	2025	2	2	3345	2	4
8-3	1947	1	9	2758	5	9
9-1	662	11	45	859	12	68
9-2	718	31	109	973	44	361
9-3	521	17	34	835	33	129
10-1	889	24	58	1106	42	107
10-2	635	8	22	808	10	36
10-3	1251	17	51	1503	20	114
12-1	1097	1	15	1247	3	17
12-2	1107	2	16	1254	4	30
12-3	1794	3	19	2220	4	23
14-1	695	20	52	884	31	196
14-2	218	24	89	374	32	200
14-3	609	19	105	696	23	156
16-1	455	8	5	523	10	56
16-2	1032	12	15	1186	14	72
16-3	562	31	60	729	36	130
17-1	32	91	7	32	96	10
17-2	21	74	37	26	85	48
17-3	30	214	6	37	297	24

Far-Field Infauna

	1992			1993		
	Annelids	Arthropod	Molluscs	Annelids	Arthropod	Molluscs
7-1	1231	0	16	1638	27	65
7-2	1089	4	7	74	15	51
7-3	2750	19	22	1427	27	96
10-1	3379	139	184	619	43	163
10-2	3156	130	374	998	37	57
10-3	2928	120	270	1454	48	142
11-1	516	4	4	375	18	37
11-2	376	4	5	437	21	90
11-3	830	2	28	387	11	35
13-1	836	112	36	694	19	7
13-2	334	44	3	487	13	20
13-3	1131	114	17	995	46	11