MWRA Nutrient Indicator Workshop

held on January 20, 1994

by
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PREFACE

The workshop 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, workshop 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 workshop 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 have been implemented for 1994.

INTRODUCTION

The third MWRA nutrient issues workshop was held at Battelle on January 20, 1994. There were 47 attendees, including MWRA personnel, regulators, members of the academic community, environmental interest groups, and project scientists (see Appendix A). To provide an overview and some perspective, Mike Mickelson (MWRA) reviewed the goals of the Harbor and Outfall Monitoring Program and the program's activities. Carlton Hunt (Battelle) discussed the objectives of the workshop and the charge to participants (included in agenda handout). Project scientists made formal presentations that summarized their findings to date. 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 figures are included in Appendix C and written comments received after the workshop are included in Appendix D.

The goals of the workshop were to evaluate

- Questions posed in the monitoring plan.
- Progress towards identifying indicators of change, meaningful change, and endpoints.
- 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, Carlton Hunt presented the following series of questions:

- 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 parameters?
- Is spatial and temporal coverage provided by the monitoring plan adequate to meet its goals?
- What is the role of the various measurements in the monitoring program?
- What are meaningful levels of change for the system?
- Can monitoring questions now be phrased as quantitative hypotheses reflecting meaningful levels of change?

Workshop participants were 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.

- Help resolve meaningful levels of change for monitoring parameters.

- Provide justification for the level of meaningful change.

- Identify key parameters that may be considered indicators and their endpoints.

- Suggest alternate presentations of data.

- Generate statements that may be used as the basis for developing hypotheses.

In accordance with guidance provided in *Managing Troubled Waters* (NRC, 1991), an ongoing evaluation of information and understanding is necessary to develop an effective monitoring plan. This workshop is consistent with activities specifically defined in Step 4 of this guidance and is necessary before finalizing the specific issues that will be addressed. Discussions held during the workshop examined some of the following design issues:

- Are the resources at risk the same as identified in the monitoring plan?

- Have the sources (perturbations) changed sufficiently to modify the resources at risk?

- Have the proper spatial (areal and depth) and temporal scales been selected for the program? Should any be modified?

- Is the sampling design in the nearfield and farfield adequate to detect change? Should the sampling design be modified?

- Are the measurements being made adequate? Is anything missing?

- Is our concept of how the ecosystem functions adequate? What needs to be improved, added, or deleted?

- Are our expected responses different? Should the expected responses be redefined?

Summaries of the formal presentations are presented below, followed by a summary of the discussion issues and the workshop discussions.

MODEL PREDICTIONS — Jim Fitzpatrick (HydroQual)

- Results of the model calibrations and model projections were presented for water column parameters (chlorophyll *a*, nutrients, and dissolved oxygen) and for sediment parameters (dissolved oxygen and nutrients).
- With the new outfall in operation, it is expected that changes in the concentrations of chlorophyll will be minimal in both the nearfield and farfield.
- For the water column, the model predicts that (1) effects of the outfall on dissolved oxygen concentrations in the nearfield will be small (~0.5 mg/L depression in the nearfield); (2) dissolved inorganic nitrogen (DIN) will be exported from the Harbor in the spring; (3) dissolved organic nitrogen (DON) will be exported from the Harbor in the summer.
- In nearfield sediments, the model predicts that oxygen demand (SOD) and nitrogen flux could increase by a factor of four. Based on model predictions, no effects will be detected in the farfield.
- It was emphasized that more farfield monitoring was needed to describe the model's "boundary" conditions. HydroQual will try to use data from the eastern-most farfield stations to project conditions in the boundary area.

OVERVIEW OF WATER COLUMN MONITORING RESULTS — Jack Kelly (Battelle)

- In the nearfield (10 x 10 km^2), water column nutrients and other key parameters are highly variable, both spatially and temporally. A seasonal trend, however, is discernable.
- Spatial features of the monitoring parameters included a strong gradient of decreasing nutrient and chlorophyll concentrations out from Boston Harbor.
- Large year-to-year variability in temperature, and in nutrient and chlorophyll concentrations underscore the importance of baseline monitoring over several years.

- Monitoring results show that Massachusetts Bay and Cape Cod Bay function as distinct systems.

- Because of a continuous source of nutrients from the Harbor, chlorophyll concentrations are highest during the late summer, rather than during the late winter-spring bloom period.

- In the nearfield, chlorophyll concentrations are patchy during the development of the winter-spring bloom and into the summer. This patchiness should be recognized when characterizing plant biomass.

BENTHIC FLUX — Ann Giblin (MBL)

- The rates of benthic nutrient release, sediment oxygen demand, and denitrification are being measured to determine (1) how these processes influence the concentrations of oxygen and nutrients in the water near the outfall and (2) if the rates of these processes change when the outfall is operational. Benthic fluxes of oxygen, carbon dioxide, ammonium, nitrate, urea, phosphate, and silicate are measured. The data collected will help to calibrate the water quality model. Measured rates of nutrient release from the sediments will help the model predict the amount of nutrient recycling.

- Sediments in Massachusetts Bay are collected by box corer. Most of these sediments are coarse and rocky; few locations can actually be sampled. Because variability within nearfield box cores (CV=30%) is similar to variability between box cores (CV=28%), natural variabilities are probably being sampled. Fluxes of phosphate and nitrate are generally more variable than for other parameters. Urea fluxes are very low or not detectable. Silicate fluxes are higher in the Bay than in the Harbor (CV=20-30%). Oxygen uptake was generally similar among the nearfield stations (except one deep station).

- Harbor sediments are collected by divers. Spatial variability of fluxes in Harbor sediments is large. Flux rates are highest near the former sludge discharge site.

SEDIMENT DENITRIFICATION — Barbara Nowicki (URI)

- Denitrification is being measured to determine how much nitrogen is being lost (not available to phytoplankton) from the Harbor and Bay sediments.

- Denitrifying bacteria anaerobically convert nitrate to gaseous nitrogen (see Appendix C-6).

- Mean denitrification rates are significantly lower in the Bay compared to the Harbor. No clear seasonal trend is apparent. Denitrification rates correlate well with temperature in the Harbor but not in the Bay where the temperature range is smaller. Rates show considerable station-to-station and year-to-year variability.

- Based on preliminary calculations, approximate average annual loss of nitrogen from Massachusetts Bay may be $\approx$400 ($\pm$100) mM m^{-2} y.

EXPORT OF NUTRIENTS FROM THE HARBOR — Jack Kelly (Battelle)

- Nitrogen budget in the Harbor:
  ~8-12% lost to denitrification
  ~84-88% flushed into Massachusetts Bay
  ~2% buried
  ~2% dredged

- Most nitrogen (84-88%) entering Boston Harbor from the effluent outfall is already being transported to Massachusetts Bay. From a regional perspective, the new outfall is not expected to change the nutrient loads to the Bay; however, on a local scale, the source of the nutrient loading will shift.

PRIMARY PRODUCTIVITY MEASUREMENTS — Peter Doering (URI)

- Primary productivity (production vs irradiance response) is being monitored (1) as an indicator of change (PI curves/physiological status; integrated water column production), (2) to estimate primary production for carbon and dissolved oxygen budgets, and (3) because nutrients discharged from the outfall may increase productivity and lead to potential eutrophication. Productivity measurements are made in the nearfield and farfield at both the surface and at the chlorophyll maximum. In 1992, measurements were made by dissolved oxygen; in 1993, measurements were made by ^{14}C. The results from the oxygen method were presented as net productivity.

- P_{MAX}-V in Massachusetts Bay is primarily a function of phytoplankton biomass and temperature. Statistical relationships with nutrients are mostly negative suggesting that when productivity is high, ambient nutrient concentrations are low.

- To detect changes in annual average P_{MAX} between stations, P_{MAX} must change by at least 80%; to detect change between surveys, P_{MAX} must change by 40%; and to detect change between depths, P_{MAX} must change by 20%.

MODELING INTEGRATED PRIMARY PRODUCTIVITY — Jack Kelly (Battelle)

- Using primary productivity measurements, the integrated water column productivity can be calculated. Average production $\approx$ 1 g m^{-2} day.

- Primary productivity is strongly related to chlorophyll biomass. Knowing biomass, primary production over various spatial and temporal scales can be extrapolated (modeled).

DISSOLVED OXYGEN IN BOTTOM WATER — Jack Kelly (Battelle)

- In deep (>50 m) stratified water, dissolved oxygen saturation decreases gradually from winter through fall. However, no violations of state water quality standards were observed in any location during any period of the year.

- Over time, the slow decline in dissolved oxygen saturation in deep water implies low respiration rates and that a small fraction of the annual primary production is consumed in deep bottom waters.

PHYTOPLANKTON/ZOOPLANKTON — Jeff Turner (UMD)

- Measurements of phytoplankton and zooplankton abundance and composition indicate large seasonal and year-to-year variabilities; within a given sampling period, however, variability between stations was much smaller.

- Diatoms generally dominated the phytoplankton population in winter and spring, followed by increased contributions from microflagellates and dinoflagellates in late spring and summer, with an increase in the diatom population in the fall again.

- The largest bloom during the two-year sampling period was the diatom *Asterionellopsis glacialis* in October 1993. Other significant blooms of noxious or harmful algae included (1) *Phaeocystis pouchetti,* in April 1992 (2) *Ceratium longipes/C. tripos* during June-August 1992 and June-October 1993, and (3) *Prorocentrum micans* in August 1993.

The toxic species *Alexandrium tamarense* and *Pseudonitzschia pungens* were also detected in low numbers.

- The zooplankton population was generally dominated by copepod nauplii, copepodites, and small adults. The same general trends were found at all stations sampled. Although the large copepod *Calanus finmarchicus* appears to be an important food source for right whales in Cape Cod Bay, this copepod represents only a fraction of the total zooplankton abundance.

- Physical forcing functions causing the apparent high density of *Calanus* in parts of Cape Cod Bay are not well understood and should be studied.

SUMMARY OF DISCUSSIONS

Topics identified during presentations and discussed during the afternoon session included

- Monitoring objectives
- Boundary stations
- Productivity
- Respiration (water and sediment)
- Benthic flux
- Denitrification
- Nearfield-farfield trade offs
- Key indicators
- Status of the system relative to endpoints
- Meaningful change
- Temporal resolution
- Spatial coherence and resolution
- Physical forcing functions (broad-scale climatological factors affecting response of the system)
- Grazing by zooplankton
- Statistical design versus functional understanding and modeling
- Patchiness (*Calanus* and chlorophyll)
- Biomass measurements

There was a general agreement during the workshop discussions that the monitoring program objectives should address (1) compliance with permits, (2) blooms of toxic species, and (3) enhanced understanding of the ecosystem and ability to make predictions. It was also agreed among workshop participants that Massachusetts and Cape Cod Bays are decoupled. All workshop participants were encouraged to define benchmarks, endpoints, and indicators that the scientific and regulatory communities can agree on as soon as possible. In the absence of standards, consensus regarding meaningful change should be developed.

The following predictions were made by various participants during the workshop:

- Model suggests a minor depression of dissolved oxygen (not more than 0.5 mg/L) in the nearfield.
- Model indicates that DIN will increase slightly in nearfield bottom waters.
- Model indicates that chlorophyll *a* will decrease in the nearfield after the outfall comes on line.
- Model indicates that SOD will not change in the farfield after the outfall comes on line.
- Model predicts that the farfield will not be affected by the outfall.
- It is expected that a new steady state will develop in 4-5 years.
- There will be no change (functional or otherwise) to the Massachusetts Bay system when the outfall is relocated. Export of nutrients from Boston Harbor to Massachusetts Bay is 80-90% and the export is approximately 5% of the total input to the Massachusetts Bay system.
- Toxic dinoflagellate blooms will decrease in coastal areas. To quantify this, the need to systematize the monitoring in these areas was identified; the frequency of monitoring in these areas during periods of expected detectable response should be increased.
- Chlorophyll *a* will not increase to a level of concern (e.g., double) and may actually decrease.
- Sulfide measurements in the nearfield may be the best indicator of change in the sediments.
- Fluctuations in phytoplankton may have been bounded by the variability observed in 1992 and 1993.
- The outfall will not influence zooplankton patches near Provincetown because these are aggregated by physical forces.
- As now, unpredictable events may also happen after commissioning of the outfall.

Recognizing the need that all monitoring programs must be grounded by indicators of change, clearly defined levels of meaningful change, and key end points, the workshop participants tentatively agreed on the following points.

STATEMENTS THAT COULD BECOME SPECIFIC HYPOTHESES

- Is Massachusetts Bay better/worse/unchanged from its predischarge status (1992 through 1995) as a result of the relocation of the discharge?

  Corollary: Is Boston Harbor improved/unchanged/worse as a result of the effluent discharge relocations?

INDICATORS OF CHANGE

- Chlorophyll *a*
- Sulfide in sediment pore waters
- Sediment oxygen demand
- Diatom fraction of phytoplankton
- Changes in benthic flux variability (outside of 30%)
- Light transmission (water clarity)
- Plume transport (dilution/direction)

MEANINGFUL CHANGE

- Defining meaningful change (and agreeing on what it is) for this system should be a high priority.

- Address use/loss of use from outfall relocation.

ENDPOINTS

- Oxygen in bottom waters—4 mg/L and 5 mg/L (state standard)—were discussed.

- Toxic phytoplankton species (no numbers suggested).

- Zooplankton species composition as related to the diet of whales (physics of the system).

- Swimmability of water.

- Fish and shellfish safety.

- Aesthetics.

MONITORING PLAN MODIFICATIONS DISCUSSED

Spatial Resolution

- Consider changing to an X-design sampling scheme in the nearfield.
- Maintain the parameters currently being measured.
- Retain all sampling depths for water quality parameters.
- Use gradients (water column) to determine changes (north-south along selected isobaths; from inside the Harbor to the Stellwagen Bank area; along shore).
- Decrease nearfield water column stations (relocate to the farfield).
- Relocate water column farfield stations to provide better coverage of major transport channels and Stellwagen Bank boundaries (for modeling efforts).
- Retain tow-yo data (extend tow-yos into the farfield through the gradient approach) and determine data analysis for these data.
- Add phyto/zooplankton stations in Boston Harbor.
- Decrease phyto/zooplankton stations in Massachusetts Bay.
- Decrease spatial coverage of zooplankton/phytoplankton sampling (spatial coherence is high; four subregions can be identified for zooplankton); Increase depth resolution for phytoplankton.
- Increase coastal monitoring for nuisance algae.
- Maintain the benthic flux measurements in the Harbor.
- Distribute the benthic flux effort at stations MB06 and MB04 to other stations or to other months of the year.
- Need to add stations in the sandy areas for benthic flux measurements; Add stations further south in Cape Cod Bay.
- Add more denitrification stations if mass balance is to be considered; current stations adequate to detect change.
- Modify productivity measurements as outlined below under "Science Issues."
- Evaluate adequacy of coastal station locations for detecting upwelling.

Temporal Resolution

- Temporal resolution in the farfield appears to be inadequate for a number of parameters; large scale factors affecting inputs and transport within the system are responsible for much of the observed variability.
- Increase the temporal coverage of the phyto/zooplankton sampling.
- Retain year-round sampling for water column and other nutrient measurements.
- Focus coastal monitoring for red tide organisms on seasons of expected response.
- Consider higher frequency resolution of hydrographic and chlorophyll information (moorings; imagery).
- Add more benthic flux sampling in Cape Cod Bay (station CCO1) in August.

SCIENCE ISSUES

- Deconvolute the nearfield tidal influences from other influences (48 h or longer sampling at one or two locations seasonally).
- Understand the functional relationships and dynamics of the system before conducting statistical analyses. Statistical analysis demands a clear statement of goals and specific questions.
- Use calculated productivity but ensure its utility by retaining higher frequency and depth sampling for C14 productivity measurements at fewer stations. Locate stations on gradients and in the nearfield to maximize detections of response. Sample at least 10 times, but preferably 16 times per year, at a limited number of stations. The issue is whether the carbon flow is changed as a result of the outfall relocation and the need to understand the vertical patterns in productivity (primary productivity below the pycnocline). Thus, integrated primary productivity is desired and the plan should be refocused. Modeled productivity will provide the best measure of this.
- Examine the benthic flux and denitrification in sandy areas.
- Determine where in the ecosystem particulate carbon is being oxidized.

- Decide whether zooplankton biomass should be measured.
- Understand the physical forces influencing *Calanus* patches.

Several workshop participants cautioned that design changes to the monitoring program must be examined carefully to ensure that continuity of the program is retained.

DISCUSSION OF DATA ANALYSIS

- Examine the hydrographic data in a manner similar to the nutrients data; evaluate water quality variables in light of the hydrographic variables.
- Examine dissolved oxygen percent saturation plots versus hydrographic data to determine if water advection is causing some of the variability.
- Use oxygen concentration rather than percent saturation to evaluate respiration in deep waters. Evaluate the effect of the two calculations on the conclusions drawn.
- Conduct coherence analyses of farfield and nearfield station data.
- Further examine "patchiness" issues:
  - Conduct spectral analysis of the tow-yo data.
  - Compare tow data to profile data.
- Quantify variability scales.
- Determine whether the productivity data are normally or log-normally distributed before performing statistical analyses.
- Examine autocorrelation among the various parameters.
- Conduct statistical analyses (e.g., cluster analysis, principal component analysis) of primary productivity to examine light limitations.
- Examine and interpret the light profiles more extensively.
- Examine zooplankton grazing issue through modeling.

APPENDIX A

WORKSHOP PARTICIPANTS

MWRA NUTRIENT INDICATOR WORKSHOP

JANUARY 20, 1994

BATTELLE OCEAN SCIENCES
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ATTENDANCE LIST

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Signed

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APPENDIX B

WORKSHOP AGENDA AND OVERHEAD SLIDES

MASSACHUSETTS WATER RESOURCES AUTHORITY

NUTRIENT INDICATOR WORKSHOP

JANUARY 20, 1994

BATTELLE OCEAN SCIENCES
DUXBURY, MA

AGENDA
NUTRIENT INDICATOR WORKSHOP
JANUARY 20, 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
   Mike Mickelson, MWRA: Overview of monitoring design
   Carlton Hunt: Workshop Goals, Process, Charge, Product

3. Water column: 0915 - 1400

   0915 Model Predictions - Dom DiToro/Jim Fitzpatrick - HydroQual

   0945 Overview of water column results - Jack Kelly
   - Major spatial features
   - Gradients (Nutrients, Chl a, primary production)
   - Expected change along gradients
   - Bay differences
   - Annual differences
   - Patchiness

   1045 Nutrient transfer
   - Benthic flux - Anne Giblin
   - Denitrification - Barb Nowicki
   - Harbor Export - Jack Kelly

   1145 Productivity
   - P.P. and PI measurements - Peter Doering
   - Modeling integrated P.P. - Jack Kelly
   - Oxygen in bottom waters; time trends in metabolic rate - Jack Kelly

Lunch - Provided 1230 - 1315

   1315 Phytoplankton/Zooplankton - Jeff Turner
   - Major features
   - Nuisance algal
   - Present design and detectable changes

5. Discussion 1400 - 1630
   Detectable/meaningful change
   Monitoring Questions and Hypothese statements

6. Wrap up 1630 - 1700

   Prioritization of issues and hypotheses

PERTURBATIONS RELATED TO NUTRIENT ISSUES

R-3 Will nutrient enrichment in the water column contribute to an increase in primary production?

R-4 Will enrichment of organic matter contribute to an increase in the benthic respiration and nutrient flux to the water column?

R-5 Will increased water-column and benthic respiration contribute to depressed oxygen levels in the water?

R-6 Will increased water-column and benthic respiration contribute to depressed oxygen levels in the sediment?

R-7 Will nutrient enrichment in the water column contribute to changes in plankton community structure (species composition, biomass, and vertical distribution)?

R-15 Will changes in water clarity and/or color result from the direct input of effluent particles or other colored constituents, or indirectly through nutrient stimulation of nuisance plankton species?

SPECIFIC QUESTIONS

R-3 WILL NUTRIENT ENRICHMENT IN THE WATER COLUMN CONTRIBUTE TO AN INCREASE IN PRIMARY PRODUCTION?

Nutrients and Hydrography

Nearfield

Have nutrient concentrations changed in the water near the outfall? (R-3, R-7)

Have the concentrations (or percent saturation) of dissolved oxygen in the water changed relative to pre-discharge baseline or a reference area and, if so, can changes be correlated with effluent or ambient water nutrient concentrations? (R-5) [NPDES]

Do the concentrations (or percent saturation) of dissolved oxygen in the water column meet the State Water Quality Standard? (R-5) [NPDES]

Has the phytoplankton biomass changed and, if so, can changes be correlated with effluent or ambient water nutrient concentrations? (R-3, R-7)

Farfield

Have water-column nutrient concentrations changed at selected farfield stations in Massachusetts Bay or Cape Cod Bay and, if so, are they correlated with changes in the nearfield? (R-3, R-7)

Have the water-column concentrations (or percent saturation) of dissolved oxygen changed at selected farfield stations in Massachusetts Bay or Cape Cod Bay and, if so, are the changes correlated with changes in the nearfield or changes in nutrient concentrations in the farfield? (R-5)

Do the water-column concentrations (or percent saturation) of dissolved oxygen at selected farfield stations meet the State Water Quality Standard? (R-5)

Has the phytoplankton biomass changed at selected farfield stations in Massachusetts Bay or Cape Cod Bay and, if so, are the changes correlated with changes in the nearfield or changes in nutrient concentrations in the farfield? (R-3, R-7)

R-3 WILL NUTRIENT ENRICHMENT IN THE WATER COLUMN CONTRIBUTE TO AN INCREASE IN PRIMARY PRODUCTION?

Biology and Productivity

Nearfield

Have the phytoplankton production rates changed in the vicinity of the outfall and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations? (R-3)

Has the species composition of phytoplankton or zooplankton changed in the vicinity of the outfall and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations? (R-7)

Has the abundance of nuisance or noxious phytoplankton species changed? (R-7)

Farfield

Has the phytoplankton and zooplankton species composition changed at selected farfield stations in Massachusetts Bay or Cape Cod Bay and, if so, are the changes correlated with changes in the nearfield or changes in nutrient concentrations in the farfield? (R-3, R-7)

Has the primary production at selected farfield stations in Massachusetts Bay or Cape Cod Bay changed and, if so, are the changes correlated with changes in the nearfield or changes in nutrient concentrations in the farfield? (R-3)

R-4 WILL ENRICHMENT OF ORGANIC MATTER CONTRIBUTE TO AN INCREASE IN THE BENTHIC RESPIRATION AND NUTRIENT FLUX TO THE WATER COLUMN?

How do the sediment oxygen demand, the flux of nutrients from the sediment to the water column, and denitrification influence the levels of oxygen and nitrogen in the water near the outfall? (R-5, R-6)

Have the rates of these processes changed? (R-4)

R-5 WILL INCREASED WATER-COLUMN AND BENTHIC RESPIRATION CONTRIBUTE TO DEPRESSED OXYGEN LEVELS IN THE WATER?

How do the sediment oxygen demand, the flux of nutrients from the sediment to the water column, and denitrification influence the levels of oxygen and nitrogen in the water near the outfall? (R-5, R-6)1

Have the rates of these processes changed? (R-4)

R-6 WILL INCREASED WATER-COLUMN AND BENTHIC RESPIRATION CONTRIBUTE TO DEPRESSED OXYGEN LEVELS IN THE SEDIMENT?

How do the sediment oxygen demand, the flux of nutrients from the sediment to the water column, and denitrification influence the levels of oxygen and nitrogen in the water near the outfall? (R-5, R-6)

Have the rates of these processes changed? (R-4)

R-7 WILL NUTRIENT ENRICHMENT IN THE WATER COLUMN CONTRIBUTE TO CHANGES IN PLANKTON COMMUNITY STRUCTURE (SPECIES COMPOSITION, BIOMASS, AND VERTICAL DISTRIBUTION)?

Has the phytoplankton biomass changed and, if so, can changes be correlated with effluent or ambient water nutrient concentrations? (R-3, R-7)

Has the phytoplankton biomass changed at selected farfield stations in Massachusetts Bay or Cape Cod Bay and, if so, are the changes correlated with changes in the near-field or changes in nutrient concentrations in the farfield? (R-3, R-7)

Have the phytoplankton production rates changed in the vicinity of the outfall and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations? (R-3)

Has the species composition of phytoplankton or zooplankton changed in the vicinity of the outfall and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations? (R-7)

Has the abundance of nuisance or noxious phytoplankton species changed? (R-7)

Has the phytoplankton and zooplankton species composition changed at selected farfield stations in Massachusetts Bay or Cape Cod Bay and, if so, are the changes correlated with changes in the nearfield or changes in nutrient concentrations in the farfield? (R-3, R-7)

Has the primary production at selected farfield stations in Massachusetts Bay or Cape Cod Bay changed and, if so, are the changes correlated with changes in the nearfield or changes in nutrient concentrations in the farfield? (R-3)

R-15 WILL CHANGES IN WATER CLARITY AND/OR COLOR RESULT FROM THE DIRECT INPUT OF EFFLUENT PARTICLES OR OTHER COLORED CONSTITUENTS, OR INDIRECTLY THROUGH NUTRIENT STIMULATION OF NUISANCE PLANKTON SPECIES?

SPECIAL STUDIES

WATER CIRCULATION AND PARTICLE FATE

What are the nearfield and farfield water circulation patterns?

What is the farfield fate of dissolved, conservative, or long-lived effluent constituents?

ACTIONS NEEDED TO COMPLETE REVISION OF THE MONITORING PLAN

1. Determine the role of each parameter/metric in the measurement program

    - Interpretive support
    - Diagnostic (Alert)
    - Trigger (Action)

2. Determine meaningful levels of change for diagnostic and action levels for triggers.

    Note: This activity is highly interactive with the ability to detect change within the current design. However, we believe that the pragmatic approach of identifying action levels (change measures relative to current conditions and absolute criteria) will move the program forward in a more effective manner.

3. Prepare statistical design necessary to measure the change levels agreed upon.
    - Determine power level for the program (e.g., 0.7, 0.8)
    - Determine the frequency, replicates, pooling, etc. necessary to detect the change or trigger level

4. Develop management actions and actions plans.

5. Revise the monitoring plan.

THE PROCESS

Step 1: Develop a matrix of parameters arrayed against the various characterizations of the parameter.

Parameter/Metric: Monitoring parameter or metric used to present the data
Environmental media: water, sediments, tissue
Role: Interpretive support, Diagnostic (Indicator/Alert), Endpoint (Trigger)
Frequency/Duration: How often and how long before say has exceeded our change/trigger?
Seasonality: Is there a seasonal component to the variable that should be considered?
Meaningful change level: (possibly two or three levels)
Rational: first order justification for role and trigger value (e.g., high correlation to nutrient loading, water quality criteria, FDA Action level, known level for tumor inducement or impairment of reproductive success,

Step 2: Populate the table with values that represent our best scientific judgement of meaningful change, that is diagnostic and trigger levels that reflect the current status of the Mass Bay system, and provide a first order rational for these levels.

Step 3: Submit the matrix for reviewed by MWRA

Step 4: Revise matrix based on input from Science Review workshop

Step 5: Deliver draft matrix, with recommendations for the next steps, for review and comment by OMTF (early February 1994)

OBJECTIVES
KEY NUTRIENTS INDICATORS WORKSHOP
JANUARY 20, 1994

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

  - to determine those that have been answered by recent baseline studies,
  - to determine if the questions should (can) be modified
  - 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 (annual average, rate of change, total versus species, 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?

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?

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 help resolve meaningful change levels

To provide justification for the level of meaningful change

To identify key parameters that are considered to be triggers and trigger levels

To identify other ways to present data, other relationships

APPENDIX C

PRESENTATIONS

APPENDIX C-1

M. MICKELSON
MWRA

Monitoring activities	relative cost
water column	51
soft-bottom benthic monitoring	23
benthic nutrient flux	19
fish & shellfish	5
effluent characterization	2

	100

Figure 4.1 of Managing Troubled Waters (NRC, 1990)

How many samples? Method #1

judgement of cost or effort

↓

n number of samples

How many samples? Method #2

μ_1 mean
s standard deviation
μ_2 level of concern

$$\frac{\mu_2 - \mu_1}{s}$$ effect size

effect size, alpha, beta --> n

Assume α=5% (1 tailed) and β=20%

$\frac{\mu_2 - \mu_1}{s}$	n
1/2	50
1	13
2	4

M.Mickelson overheads

comparisons & controls

time

before vs after
cycles, trends

space

understanding

Making hypotheses more quantitative

"has the chlorophyll increased?"

↓

"has the chlorophyll doubled?" or

"has the chorophyll increased by 2 standard deviations?"

Making hypotheses more sensitive

"has the chlorophyll at place __ and depth __ during time __ doubled?" or

"has the chlorophyll doubled, after subtracting the 'natural' variability that we can explain?"

APPENDIX C-2

C. HUNT
BATTELLE

MWRA

NUTRIENT INDICATOR WORKSHOP

JANUARY 20, 1994

BATTELLE OCEAN SCIENCES
DUXBURY, MA

BASELINE MONITORING PROGRAM
OBJECTIVES

OVERALL MONITORING PLAN

- Test for compliance with the future NPDES permit requirements.
- Test whether the impact of the discharge on the environment is within the bounds projected by the Supplemental Environmental Impact Statement.

PHASE I

- Provide an adequate baseline from which outfall-caused change across a diversity of meaningful potential changes can be detected.
- Provide a baseline from which meaningful change (indicators) at levels far below, and prior in time to those changes that may be of great concern (e.g. endpoints).

BASELINE MONITORING PROGRAM
STUDY ELEMENTS

HARBOR

CSO Studies
Benthic Recovery
Water Quality - Dissolved oxygen, turbidity
Reconnaissance Studies

OUTFALL

Effluent Characterization
Water Column
Sediment Chemistry
Benthic Community
Fish and Shellfish
Special Studies
- Nutrient flux from sediments
- Denitrification
- Treatment plant efficiency studies
- Hard-bottom communities

MODELING

Transport
Ecological

SCIENCE AND TECHNICAL REVIEW

PUBLIC OUTREACH

PERTURBATIONS RELATED TO NUTRIENT ISSUES

R-3 Will nutrient enrichment in the water column contribute to an increase in primary production?

R-4 Will enrichment of organic matter contribute to an increase in the benthic respiration and nutrient flux to the water column?

R-5 Will increased water-column and benthic respiration contribute to depressed oxygen levels in the water?

R-6 Will increased water-column and benthic respiration contribute to depressed oxygen levels in the sediment?

R-7 Will nutrient enrichment in the water column contribute to changes in plankton community structure (species composition, biomass, and vertical distribution)?

R-15 Will changes in water clarity and/or color result from the direct input of effluent particles or other colored constituents, or indirectly through nutrient stimulation of nuisance plankton species?

MEASUREMENTS INCLUDED IN THE MWRA MONITORING PROGRAM

WATER COLUMN — NUTRIENTS

PARAMETER	STATIONS NEARFIELD 5 Depths	FARFIELD 5 Depths	BIO/PROD[a] 2 depths	EFFLUENT Bimonthly
Chlorophyll a/Phaeopigments	21	25	10	
Dissolved inorganic nutrients NH_3, NO_2, NO_3, PO_4, Si	21	25	10	X
Dissolved Organic Carbon	21	25	10	X
Dissolved Organic Nitrogen	21	25	10	X
Dissolved Organic Phosphorous	21	25	10	X
Particulate Organic Phosphorous				X
Particulate Organic Carbon	21	25	10	X
Particulate Organic Nitrogen	21	25	10	X
Total Phosphorous	21	25	10	X
Total Nitrogen	21	25	10	X
Biogenic Silica				X
Dissolved Inorganic Carbon			10	
Primary Production			10	
Dissolved Oxygen				
Respiration (Oxygen)[b]			10	
Total Suspended Solids	21	25	10	
Particulate ^{15}N				X
Particulate ^{34}S				X
Zooplankton species[c]			10	
Phytoplankton species			10	

[a]Subset of stations from near and farfield stations
[b]Summer only
[c]Vertical tow

MEASUREMENTS INCLUDED IN THE MWRA MONITORING PROGRAM

WATER COLUMN — HYDROGRAPHIC PROFILES AND TOW-YOs

PARAMETER	NEARFIELD[a]	FARFIELD
Depth	21	25
Salinity	21	25
Temperature	21	25
Density	21	25
Dissolved oxygen	21	25
Transmissometry	21	25
Chlorophyll a - Fluorescence	21	25
Light extinction[b]		
Irradiance surface		
Irradiance *In situ*	21	25

[a]Tow-yo activities are conducted only in the nearfield
[b]Profile day only

MEASUREMENTS INCLUDED IN THE MWRA MONITORING PROGRAM

BENTHIC FLUX STUDIES[a]

PARAMETER	FLUX	PORE WATER
O_2	X	
Total CO_2	X	
NH_4	X	X
$NO_2 + NO_3$	X	X
PO_4	X	X
Si	X	X
N_2	X	
Sulfide		X
pH		X
Eh		X
Alkalinity		X

[a]1 to 3 stations in the Harbor plus 3 to 5 stations in Mass Bay depending on season

STEPS NEEDED TO REVISE THE MONITORING PLAN

1. Determine the role of each parameter/metric in the measurement program

   - Interpretive support
   - Diagnostic (Alert)
   - Endpoints (Action)

2. Determine meaningful levels of change for diagnostic and action levels.

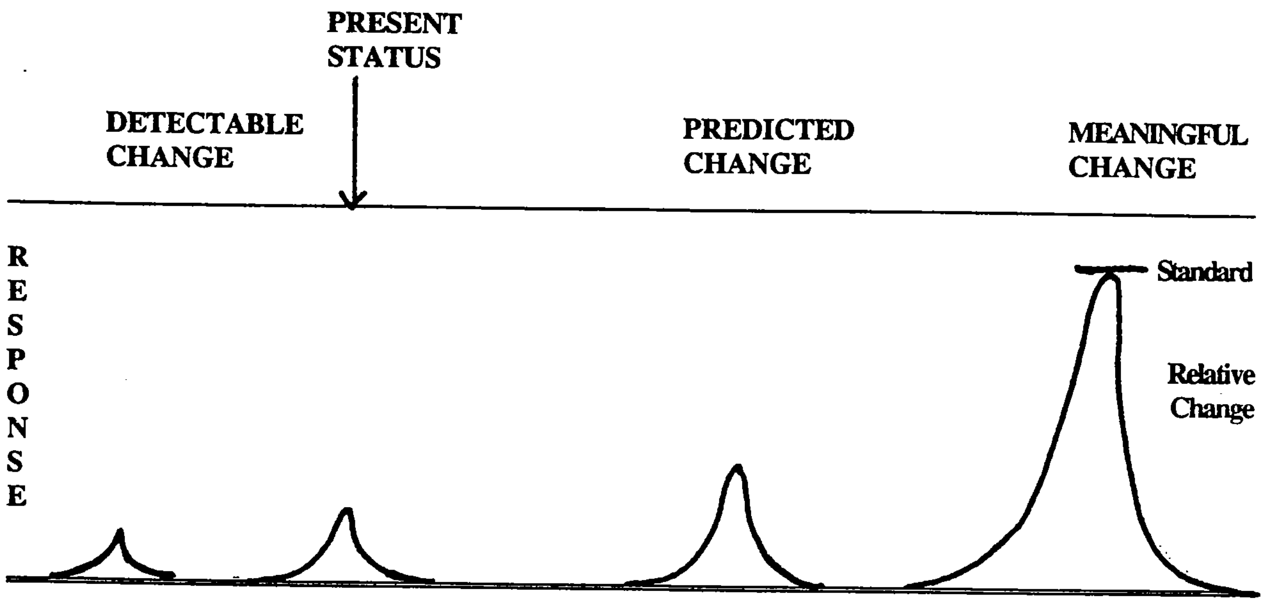
   Note: This activity is highly interactive with the ability to detect change within the current design. However, I believe that the pragmatic approach of identifying action levels (change measures relative to current conditions and absolute criteria) will move the program forward in a more effective manner.

3. Prepare statistical design necessary to measure the change levels agreed upon.

   - Determine power level for the program (e.g., 0.7, 0.8)
   - Determine the frequency, replicates, pooling, etc. necessary to detect the change or endpoint.

4. Revise the monitoring plan.

REPRESENTATION OF CHANGE ISSUES



EXAMPLE — Summer Chlorophyll

2±2 μg/L 3±3 μg/L 4±3 μg/L 10 μg/L Standard
10±4 μg/L Relative

OBJECTIVES
KEY NUTRIENTS INDICATORS WORKSHOP
JANUARY 20, 1994

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

  - to determine if the questions should (can) be modified
  - 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 (annual average, rate of change, total versus species, 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 statements that can lead to clear hypotheses
  - to develop testable hypotheses where possible

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 help resolve meaningful change levels

To provide justification for the level of meaningful change

To identify key parameters that are considered to be endpoints and action levels

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

QUESTIONS FOR DISCUSSION SESSION

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?

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?

What statements can be made regarding expected change that can be used as a foundations for an hypotheses?

ROLE OF PRIMARY PRODUCTION

1) To detect change in productivity

2) To estimate primary production for carbon and oxygen budgets.

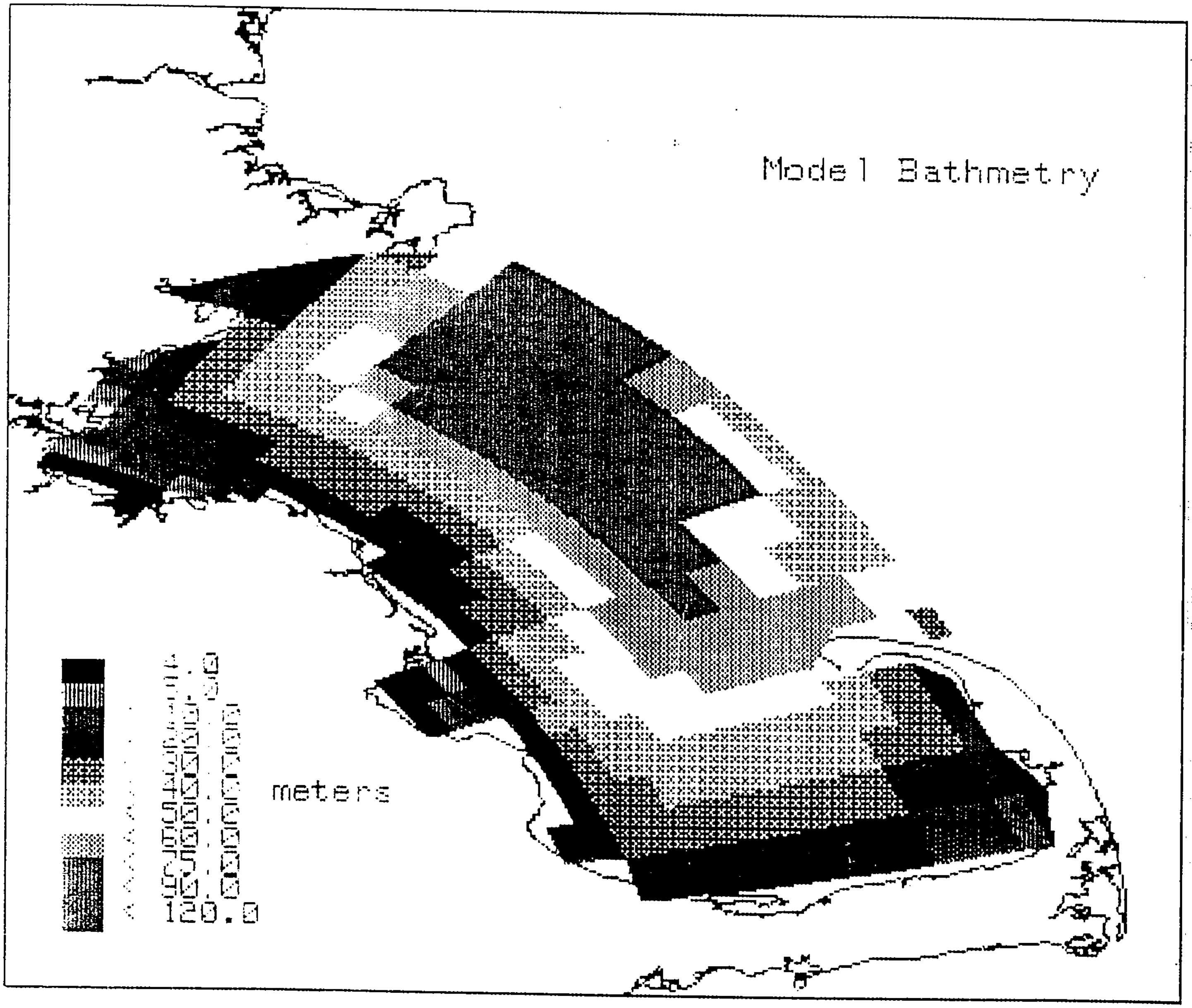
3) Others??

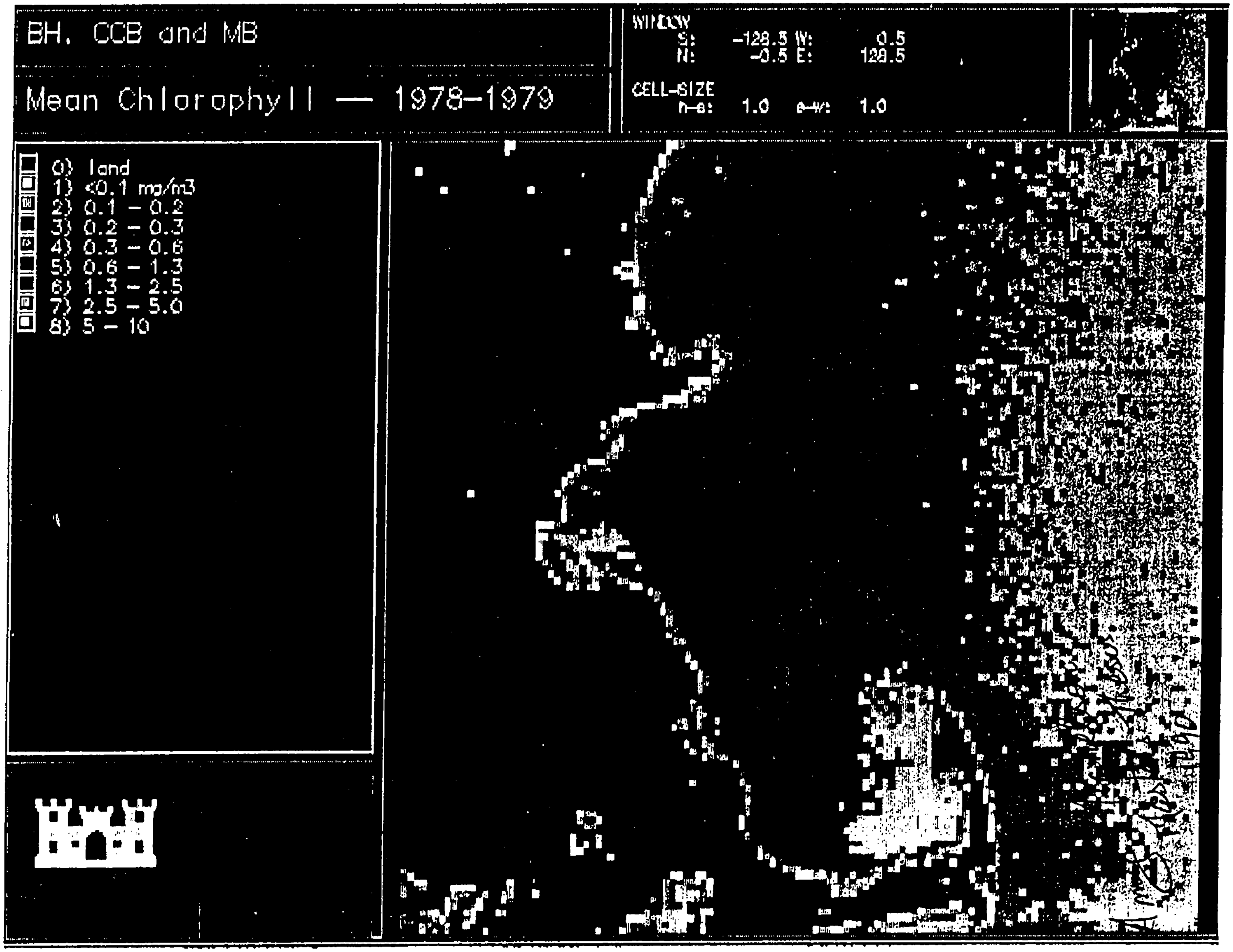
PRIMARY PRODUCTION MEASUREMENTS

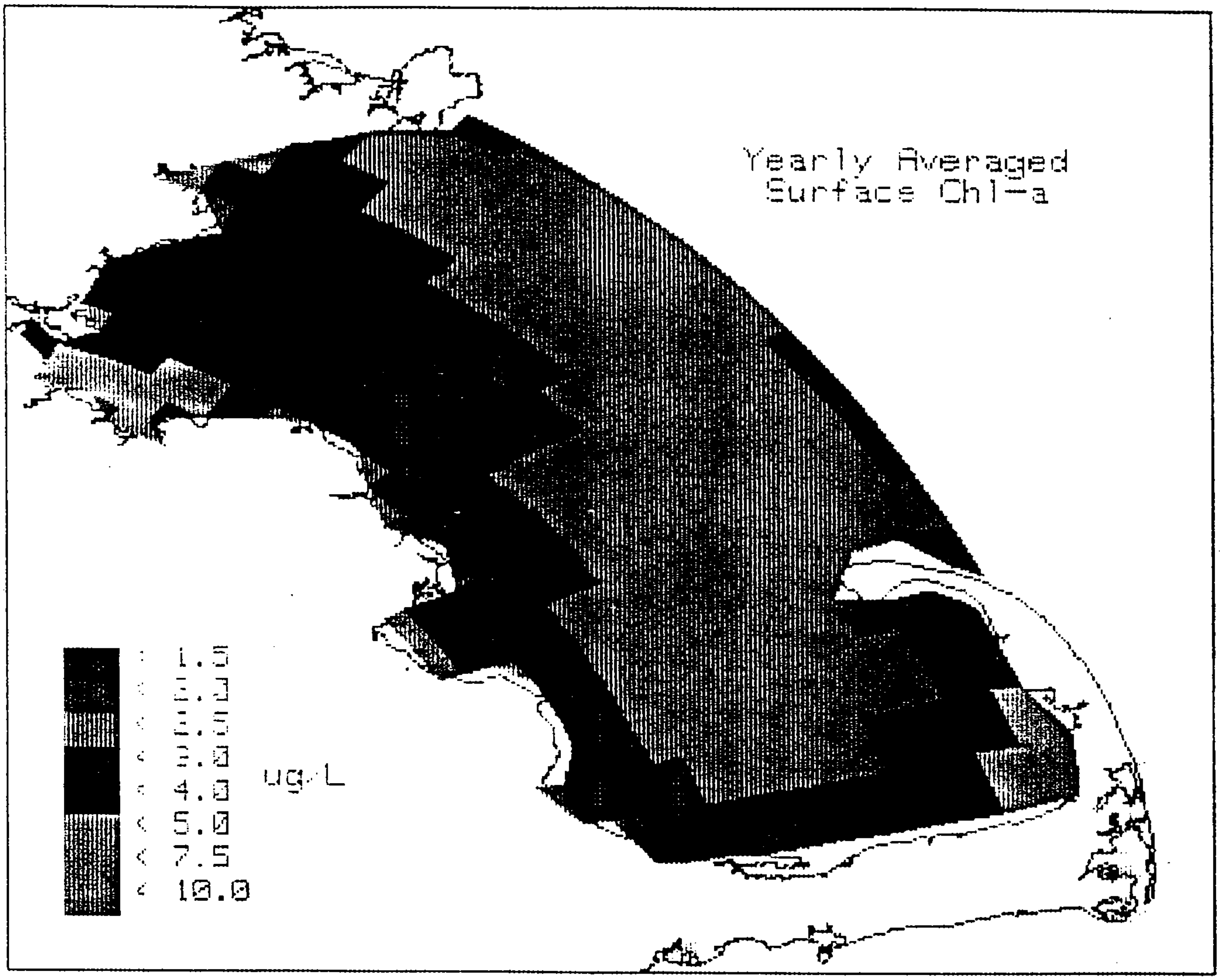
- INDICATOR OF CHANGE
  - PI curves/physiological status
  - Integrated water column production
- UNDERSTANDING OF THE SYSTEM
  - Carbon budgets
  - Oxygen budgets

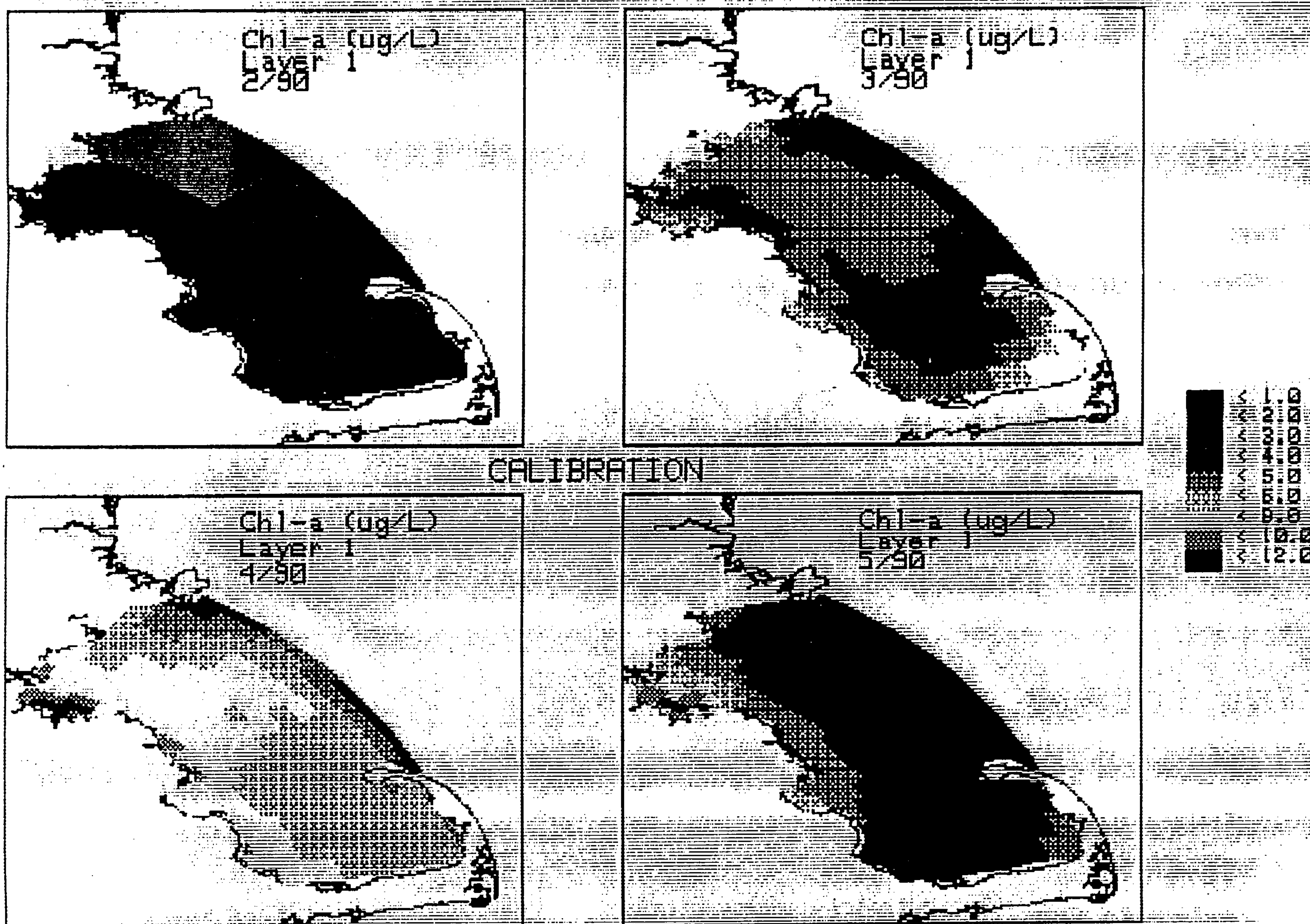
APPENDIX C-3

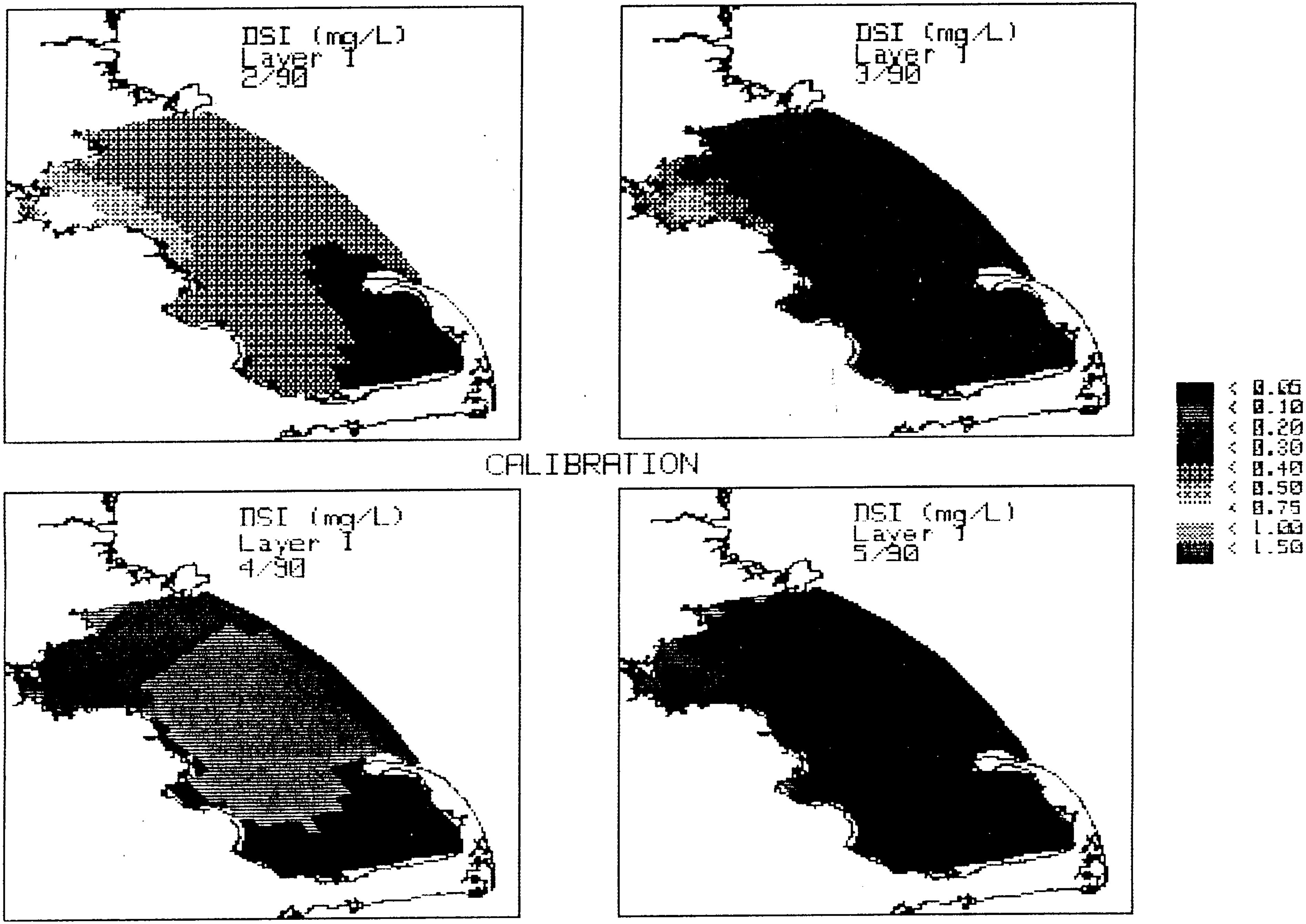
J. FITZPATRICK
HYDROQUAL


Model Bathmetry
meters
120.0

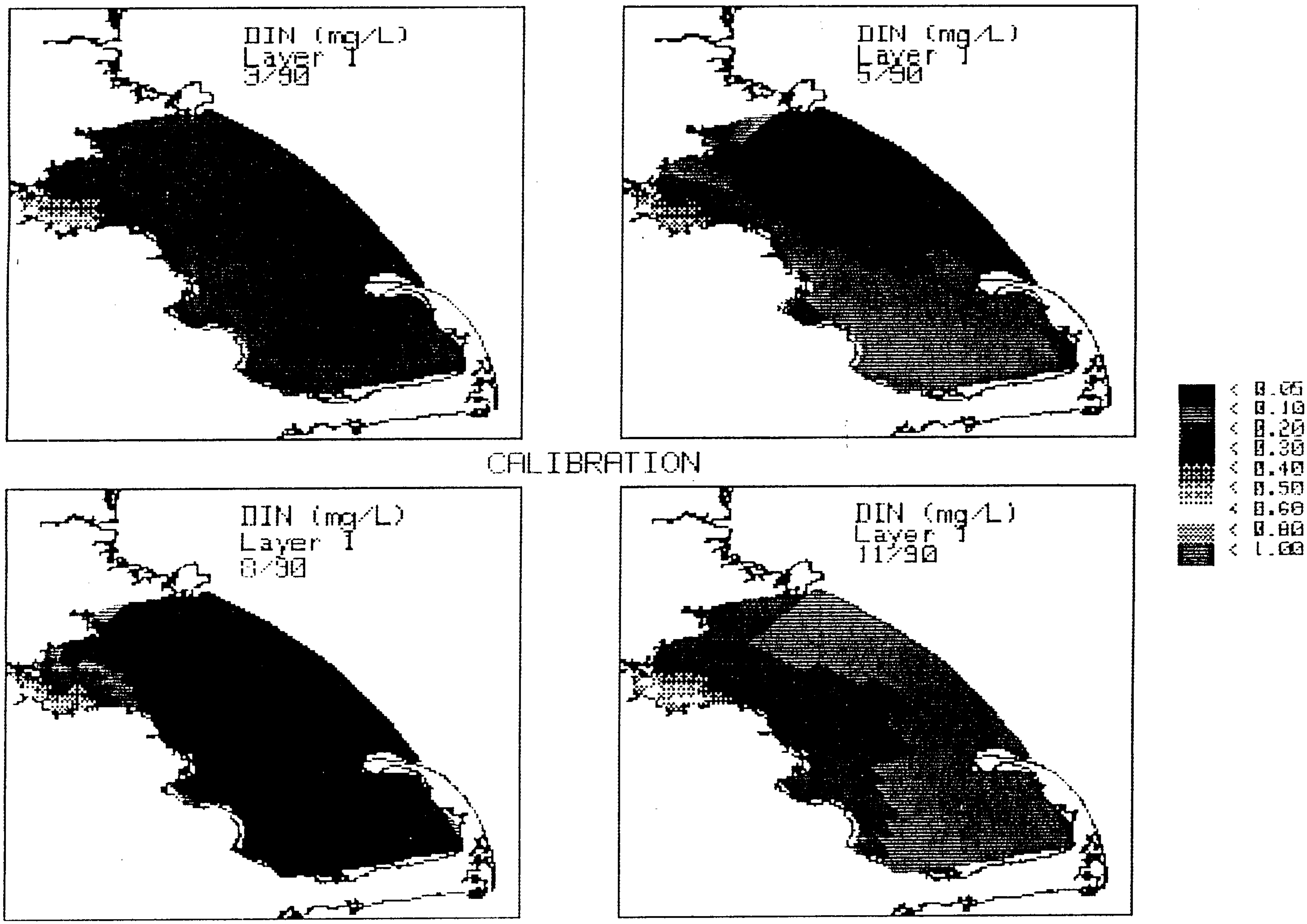

BH, CCB and MB
Mean Chlorophyll — 1978–1979
WINDOW
S: -128.5 W: 0.5
N: -0.5 E: 128.5
CELL-SIZE
n-s: 1.0 e-w: 1.0
0) land
1) <0.1 mg/m3
2) 0.1 - 0.2
3) 0.2 - 0.3
4) 0.3 - 0.6
5) 0.6 - 1.3
6) 1.3 - 2.5
7) 2.5 - 5.0
8) 5 - 10

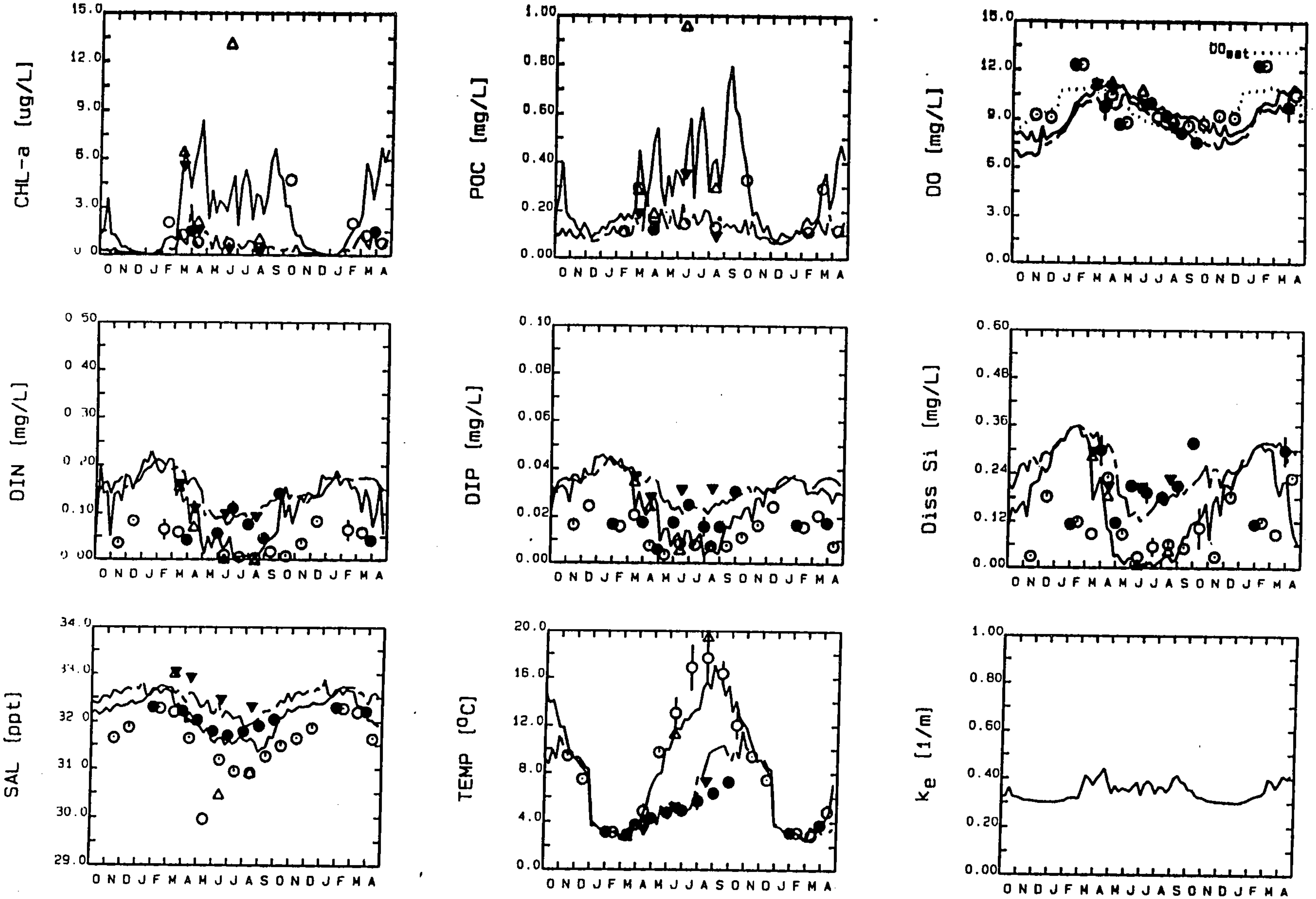

Yearly Averaged
Surface Chl-a
1.5
< 4.0
< 5.0
< 7.5
< 10.0
ug/L


Chl-a (ug/L)
Layer 1
2/90
Chl-a (ug/L)
Layer 1
3/90
CALIBRATION
Chl-a (ug/L)
Layer 1
4/90
Chl-a (ug/L)
Layer 1
5/90
< 1.0
< 2.0
< 3.0
< 4.0
< 5.0
< 6.0
< 8.0
< 10.0
< 12.0


DSI (mg/L)
Layer 1
2/90
DSI (mg/L)
Layer 1
3/90
CALIBRATION
DSI (mg/L)
Layer 1
4/90
DSI (mg/L)
Layer 1
5/90
< 0.05
< 0.10
< 0.20
< 0.30
< 0.40
< 0.50
< 0.75
< 1.00
< 1.50

00035


DIN (mg/L)
Layer 1
3/90
DIN (mg/L)
Layer 1
5/90
CALIBRATION
DIN (mg/L)
Layer 1
8/90
DIN (mg/L)
Layer 1
11/90
< 0.05
< 0.10
< 0.20
< 0.30
< 0.40
< 0.50
< 0.60
< 0.80
< 1.00

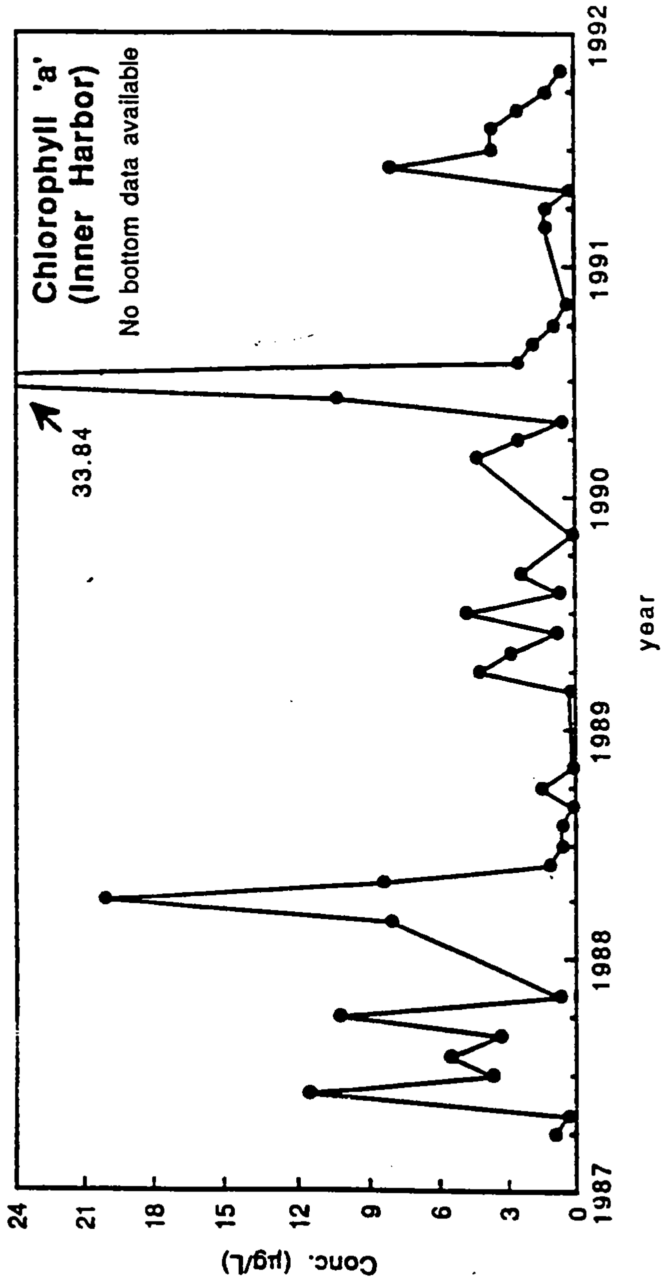


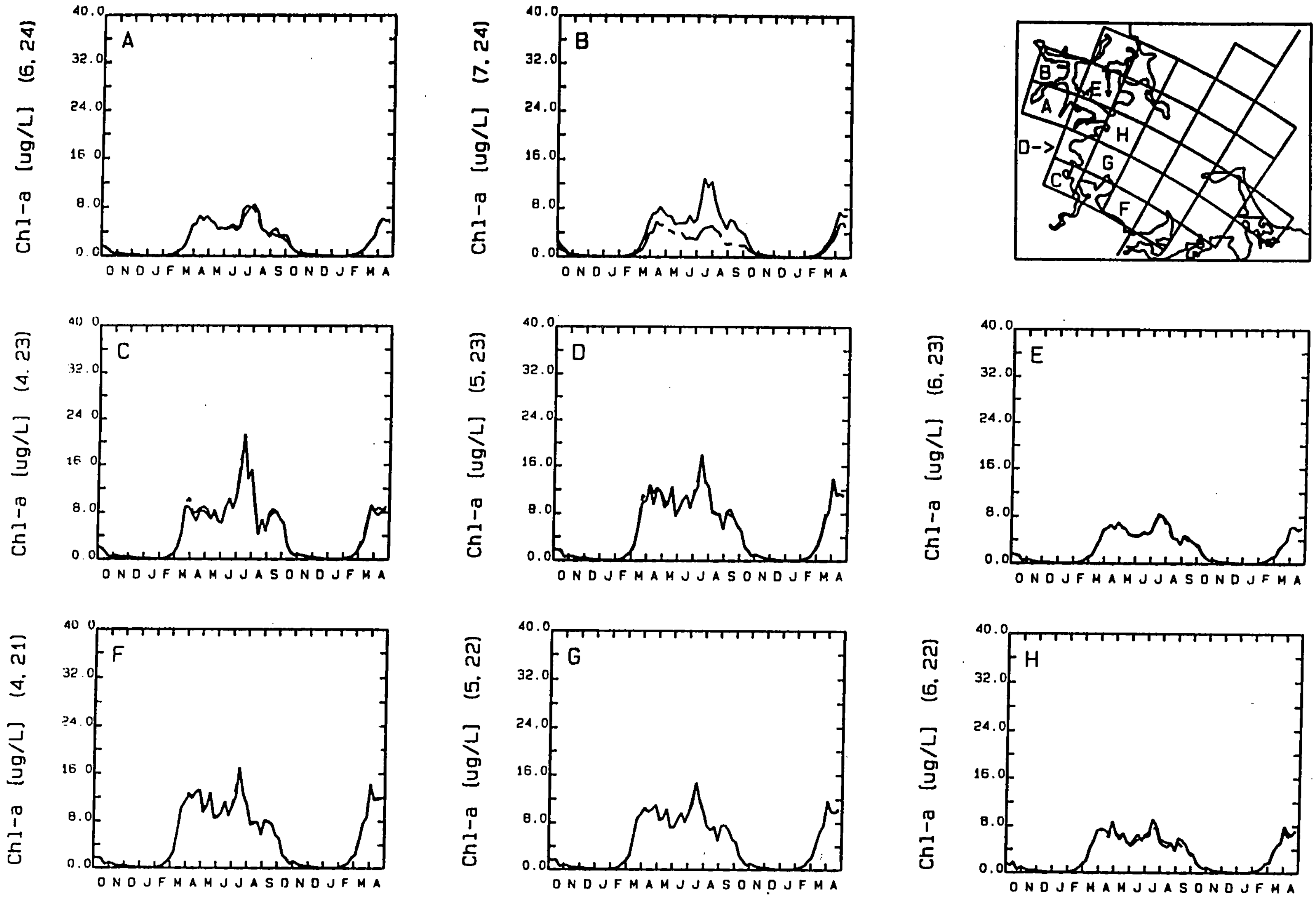
1989-1991 Calibration Results for Row/Column 11/18

------ LEGEND ---------
▲ +/- range Surface Data
▼ Bottom Data
——— Surface Model
— — — Bottom Model
○ Surface Data 1992
● Bottom Data 1992

DATE: Tue Jan 18 TIME: 14:34:09
ɟroQual - Mass Bays Study

New England Aquarium data – all at same stage of tide – average of Inner Harbor stations for monthly samples. We will have 1993 data soon (MWRA is doing this work now)





00039

1989-1991 Calibration Results for Boston Harbor Data

------ LEGEND ---------
▲ +/- range ▼ Surface Data
Bottom Data
——— Surface Model
— — — Bottom Model

DATE: Tue Jan 18 TIME: 12:48:08
HydroQual - Mass Bays Study

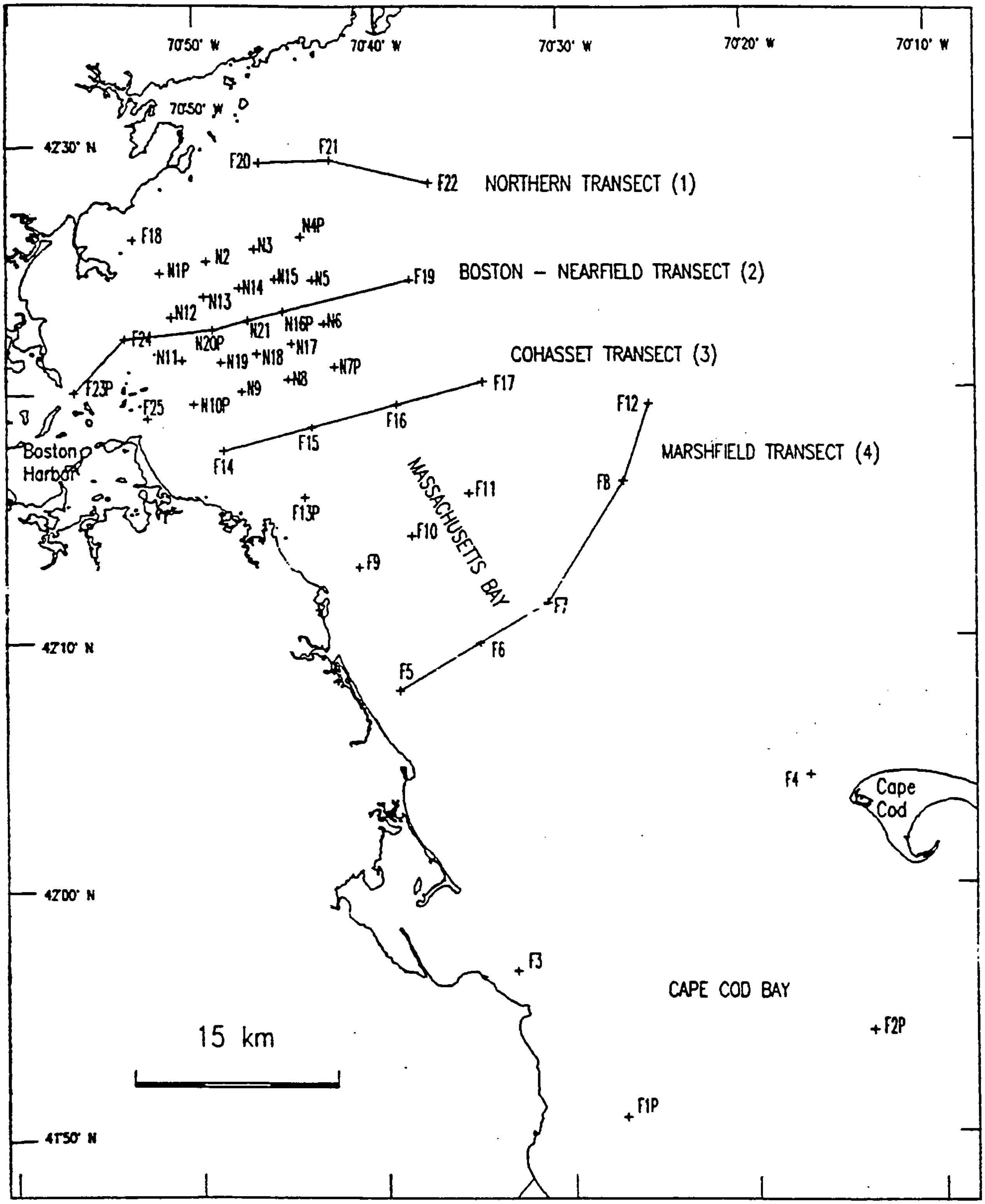
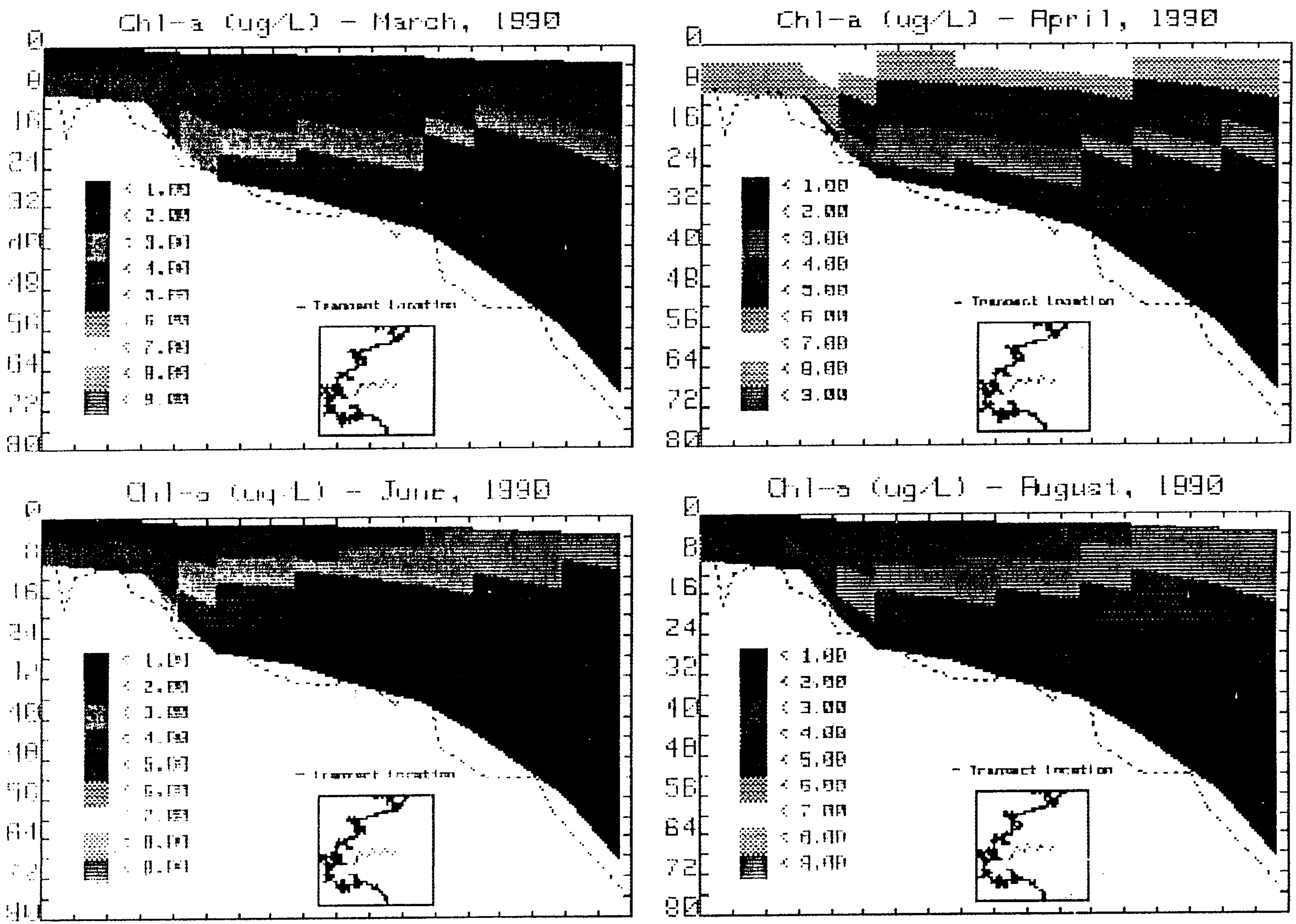
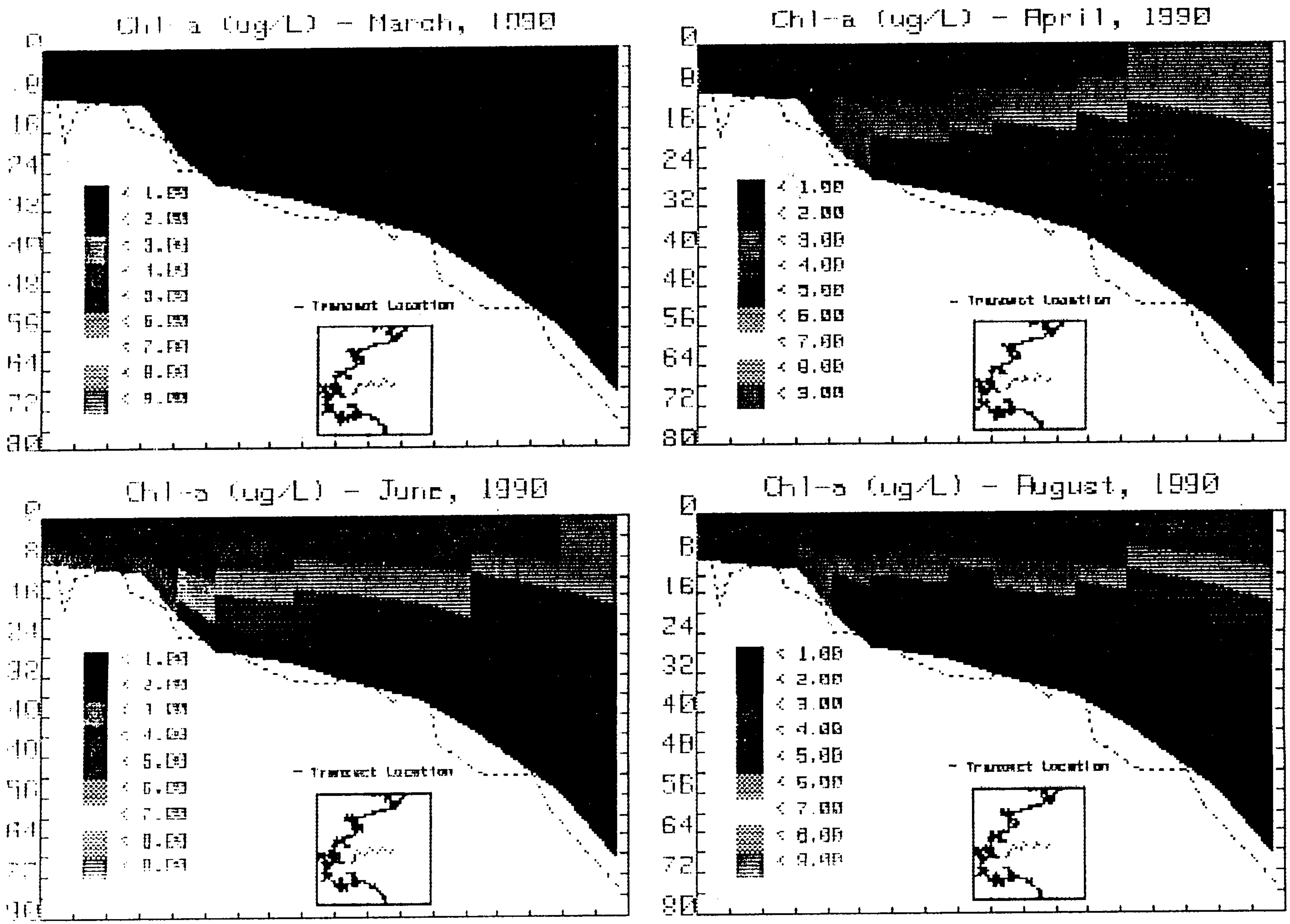


Figure 3-9. Map showing position of four standard transects for which vertical contour plots were produced in following Figures 3-10 to 3-14.

CALIBRATION

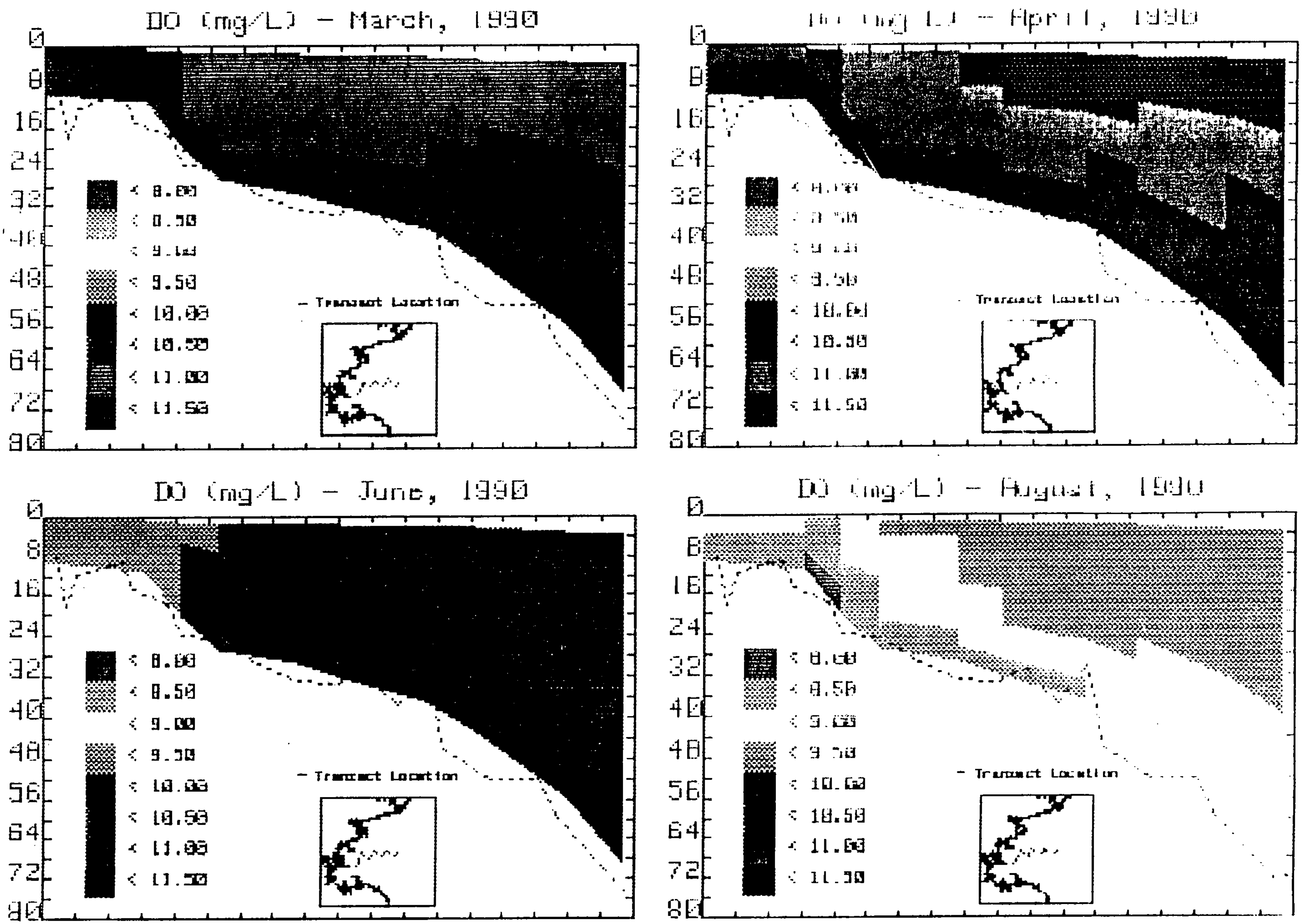


PROJECTION

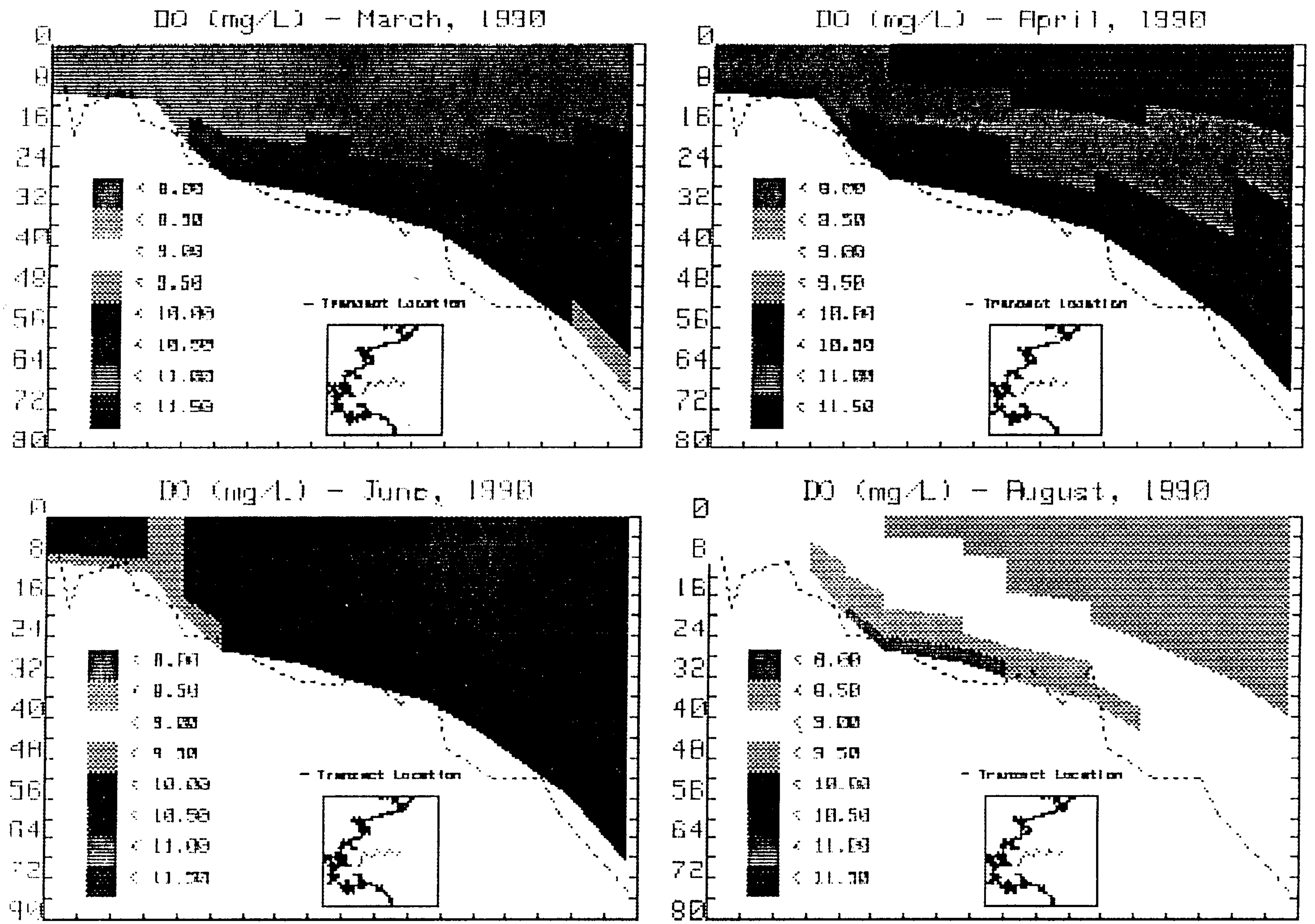


00042

CALIBRATION

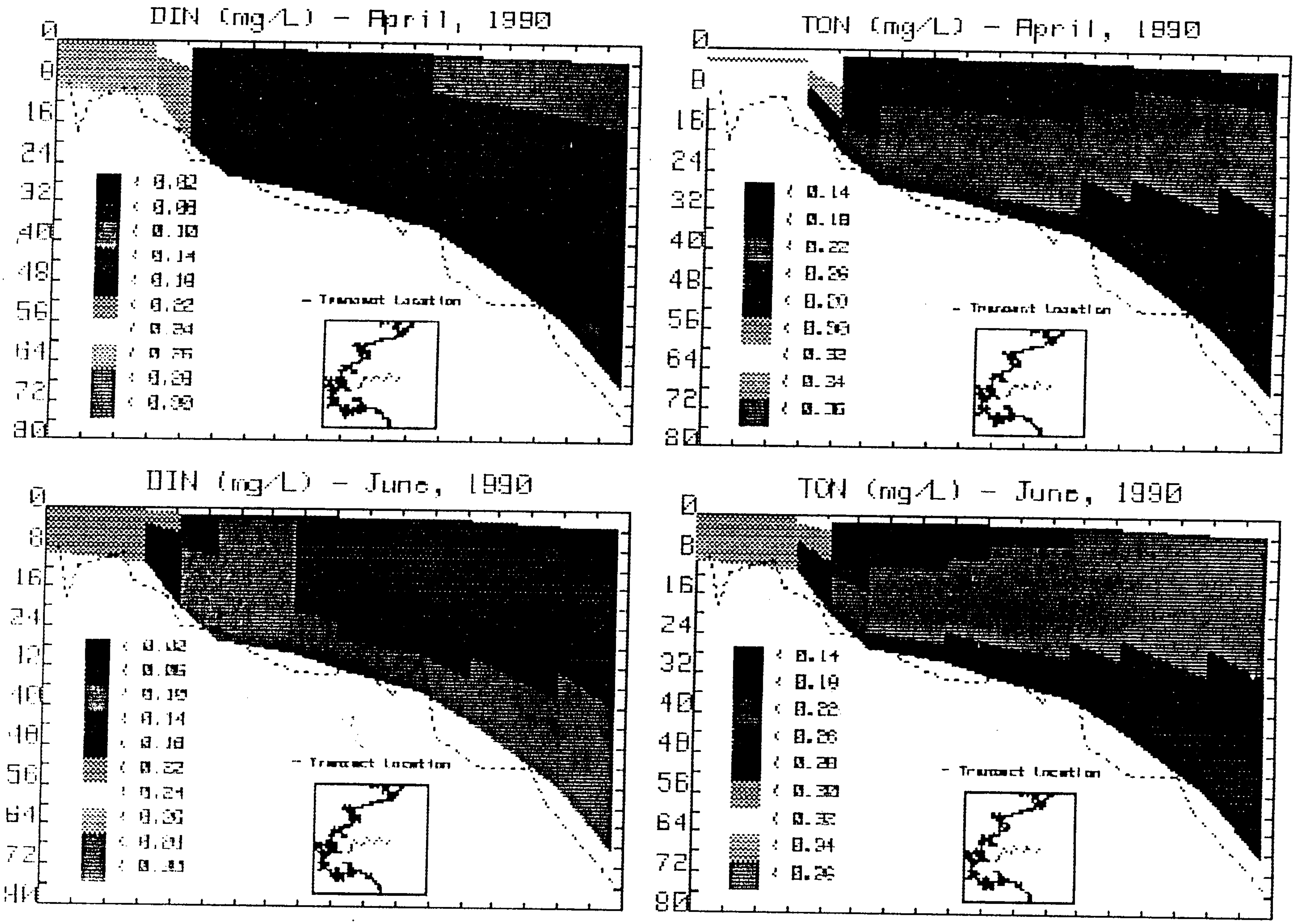


PROJECTION

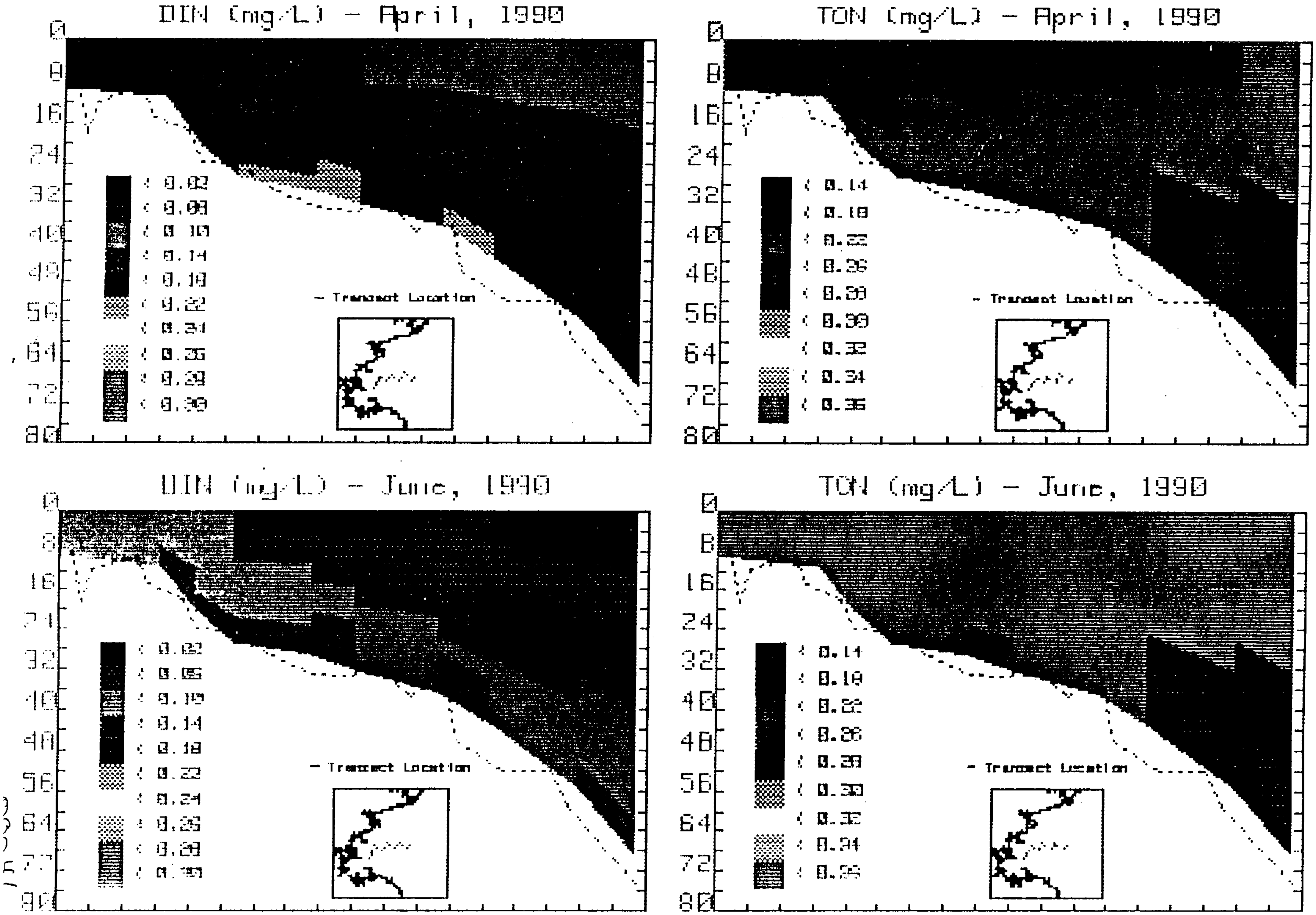


00044

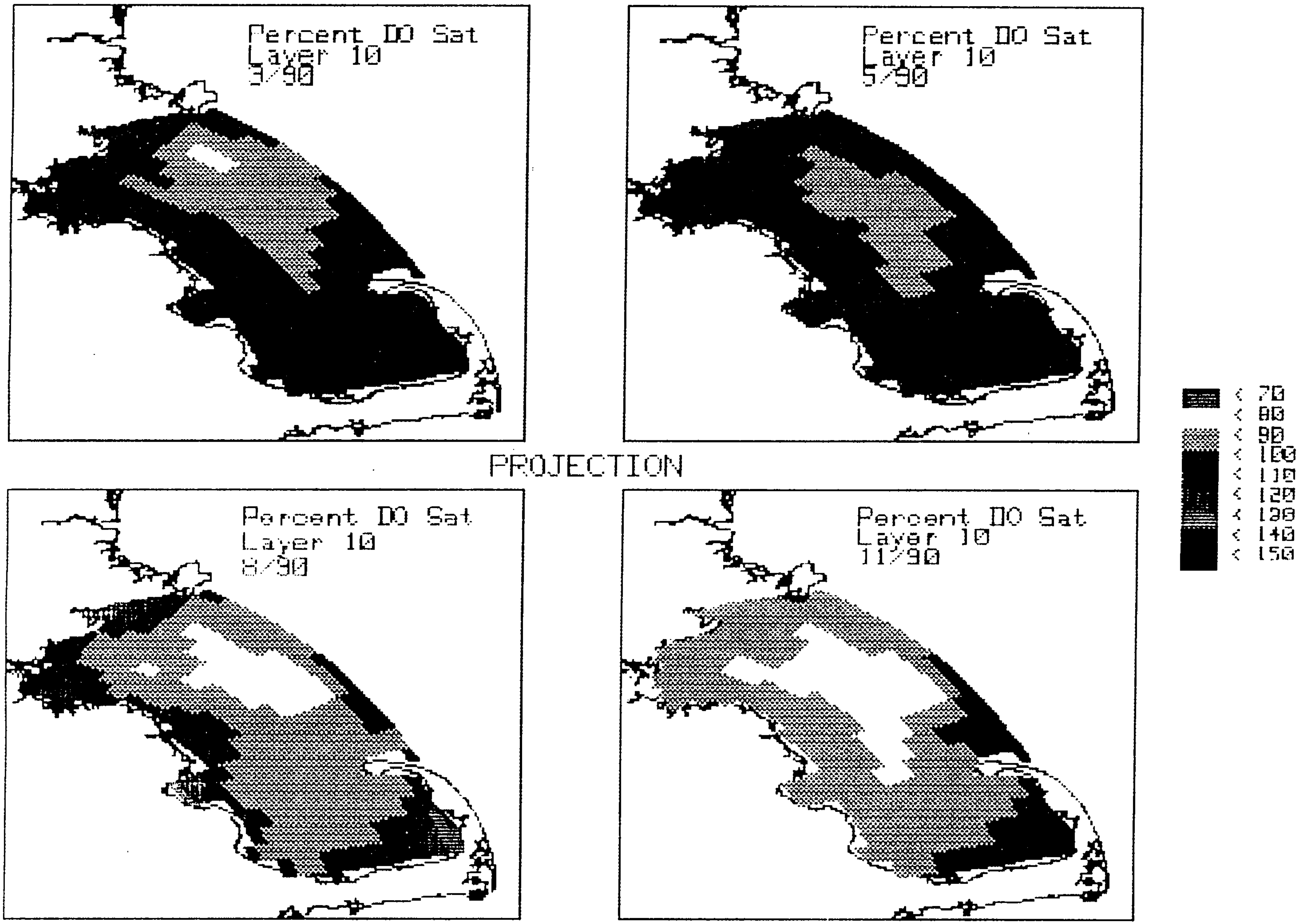
CALIBRATION



PROJECTION



DIN (mg/L) - April, 1990
TON (mg/L) - April, 1990
DIN (mg/L) - June, 1990
TON (mg/L) - June, 1990
0
8
16
24
32
40
48
56
64
72
80
< 0.02
< 0.08
< 0.10
< 0.14
< 0.18
< 0.22
< 0.24
< 0.26
< 0.28
< 0.30
< 0.32
< 0.34
< 0.36
- Transect Location


Percent DO Sat
Layer 10
3/90
Percent DO Sat
Layer 10
5/90
PROJECTION
Percent DO Sat
Layer 10
8/90
Percent DO Sat
Layer 10
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< 80
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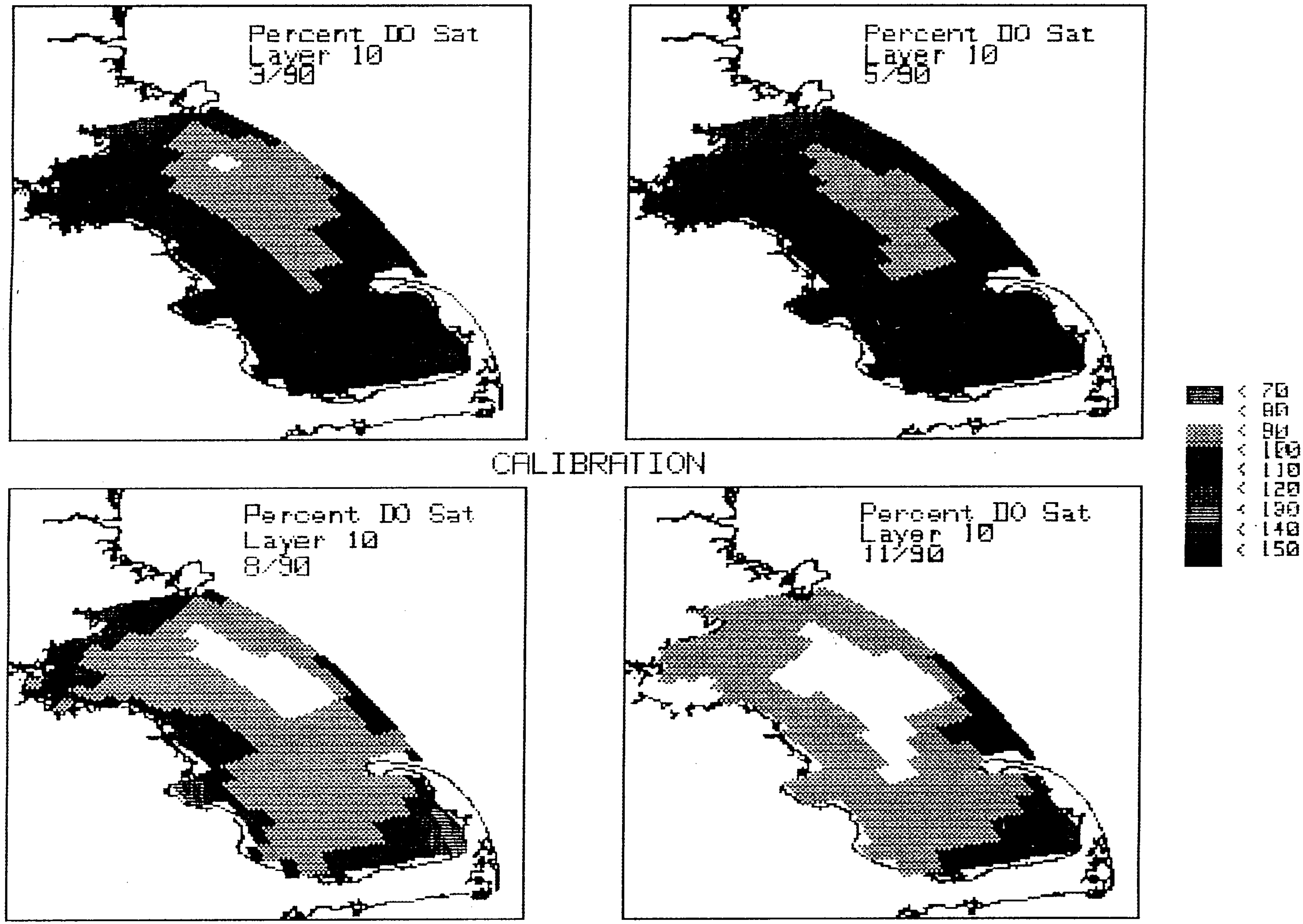
< 110
< 120
< 130
< 140
< 150


Percent DO Sat
Layer 10
3/90
Percent DO Sat
Layer 10
5/90
CALIBRATION
Percent DO Sat
Layer 10
8/90
Percent DO Sat
Layer 10
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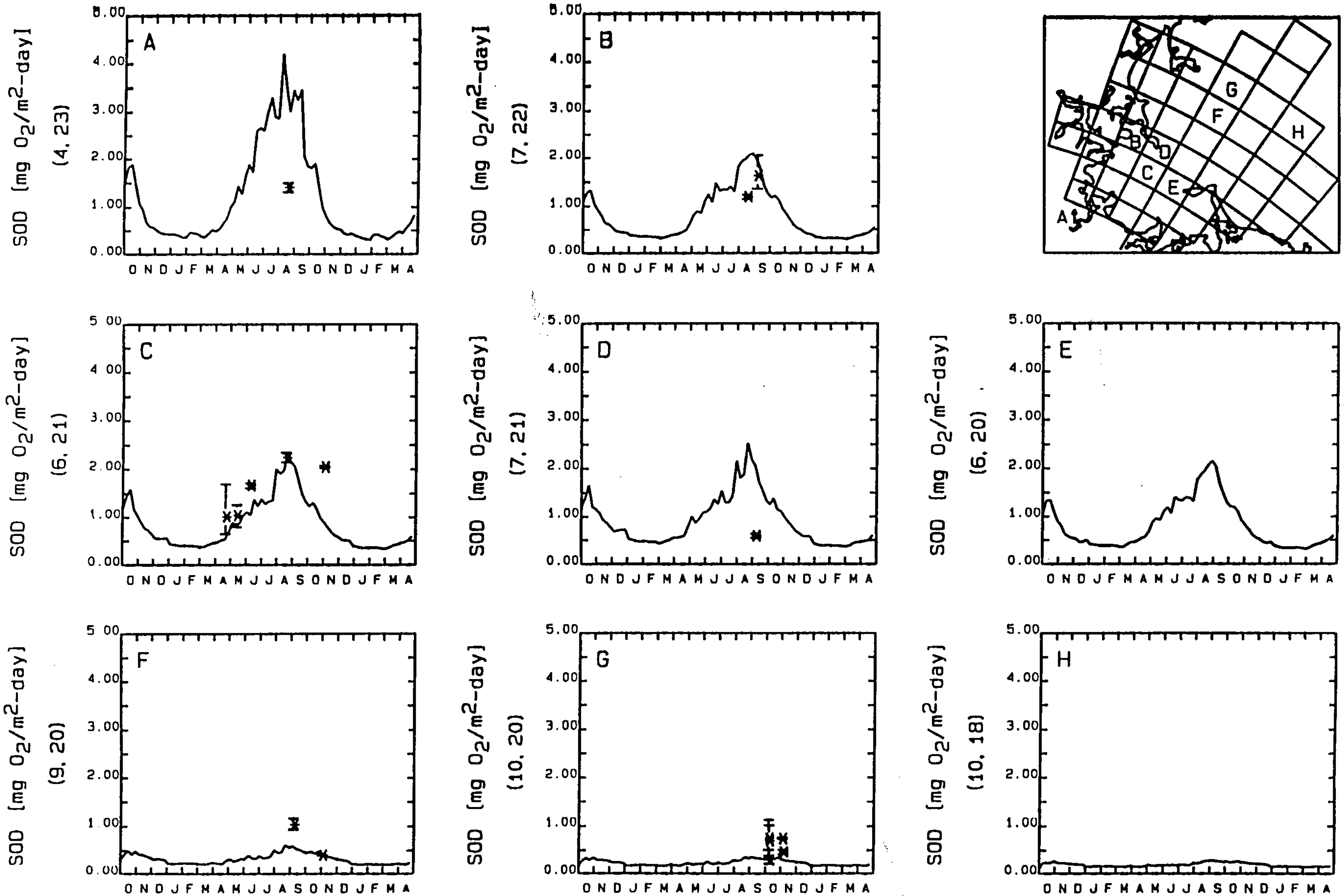
< 120
< 130
< 140
< 150



1989-1991 Calibration Results for Sediment Data

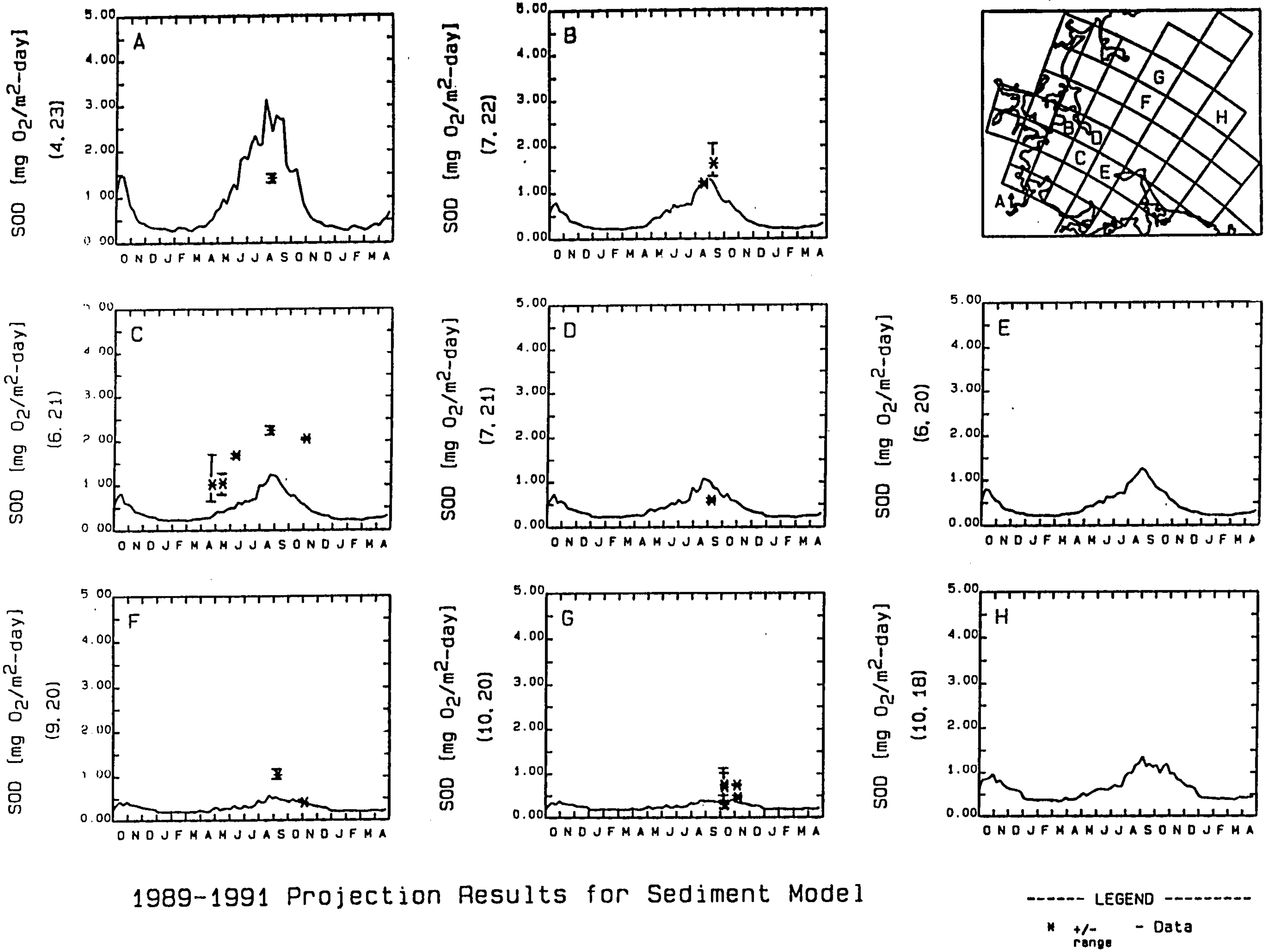
------ LEGEND ---------

* +/- range - Data

——— - Model

DATE: Sat Jan 15 TIME: 20:28:54

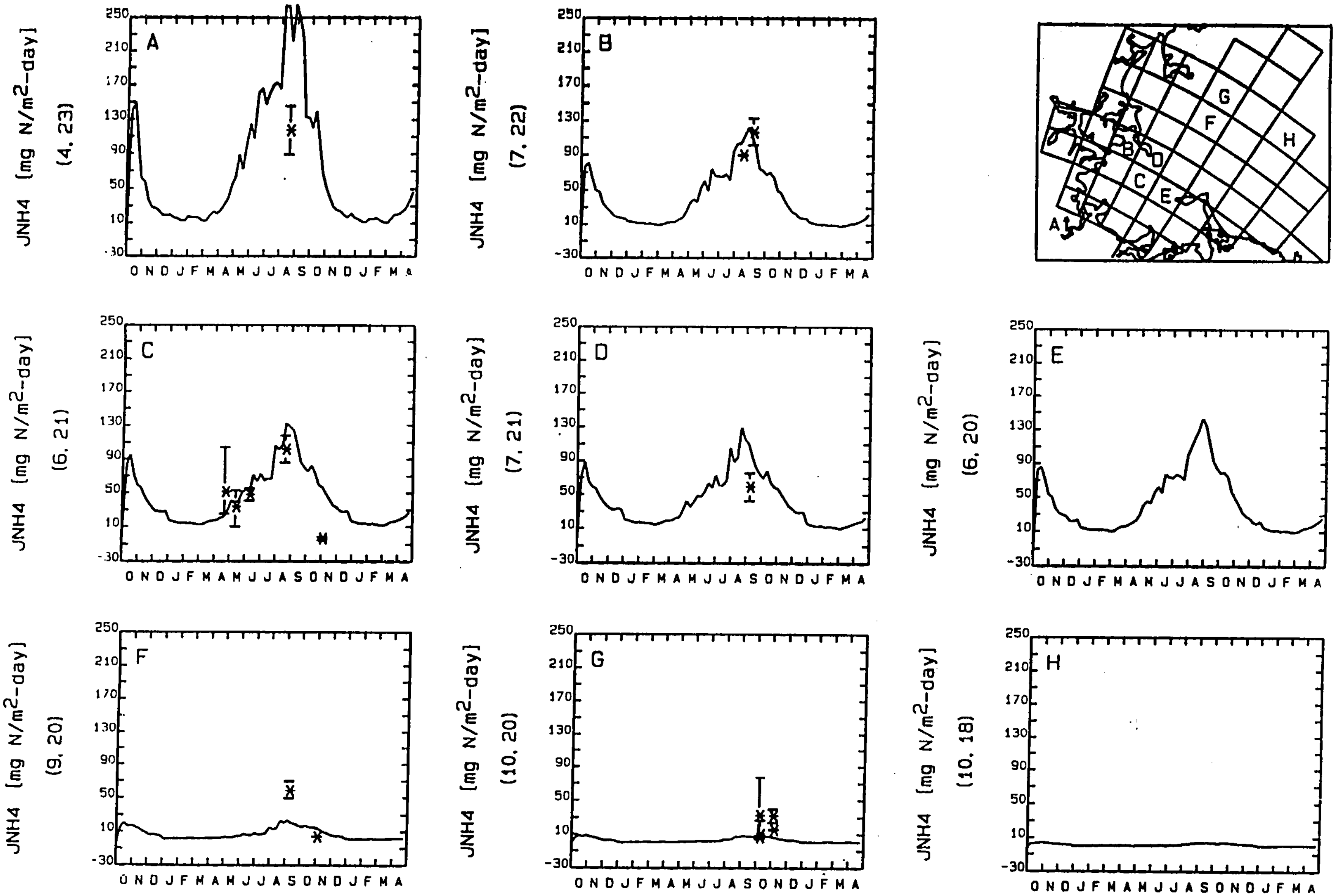
IroQual - Mass Bays Study



1989-1991 Projection Results for Sediment Model

DATE: Mon Jan 17 TIME: 13:07:33

HydroQual - Mass Bays Study



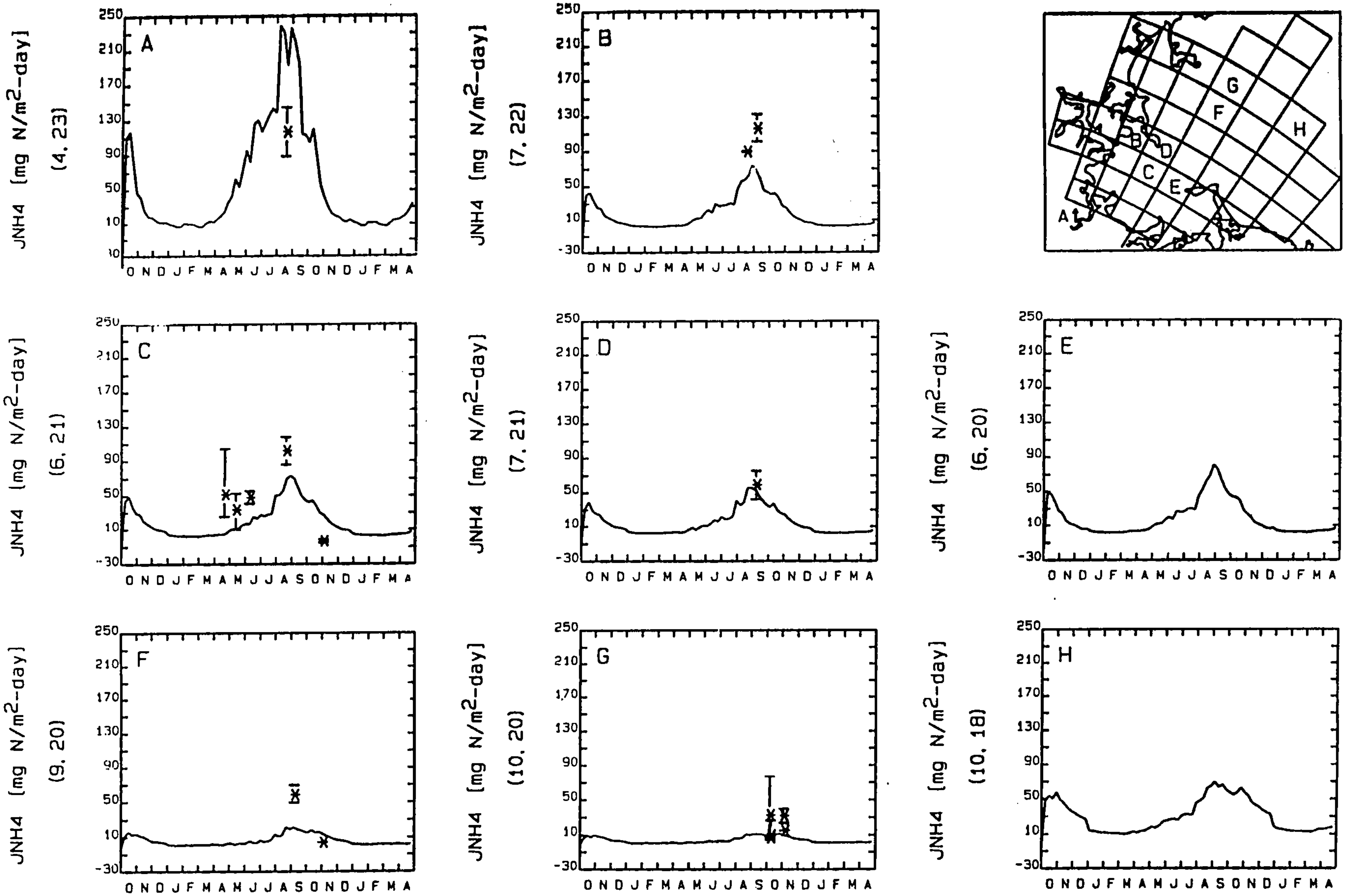
1989-1991 Calibration Results for Sediment Data

------ LEGEND ----------

* +/- range - Data

—— - Model

DATE: Sat Jan 15 TIME: 20:21:09



1989-1991 Projection Results for Sediment Model

------ LEGEND ---------

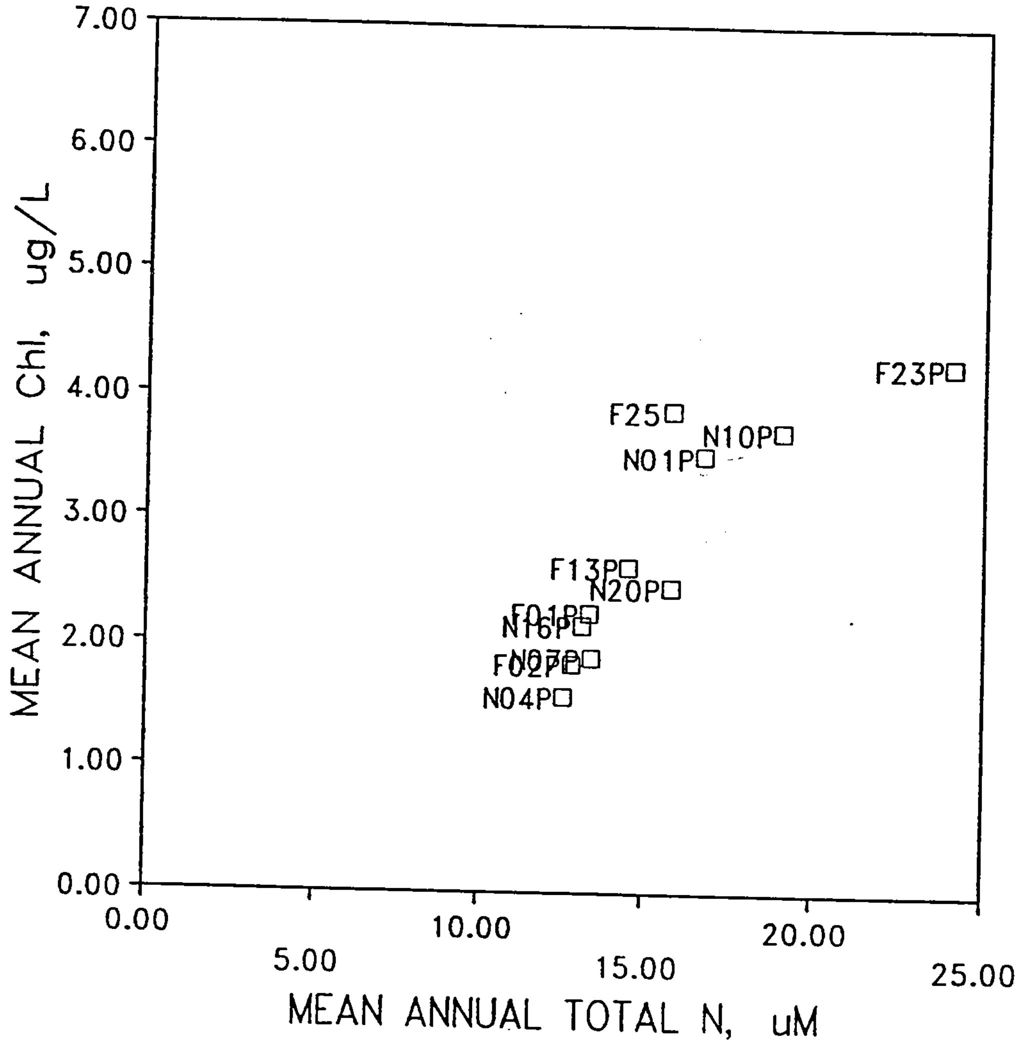
* +/- range - Data

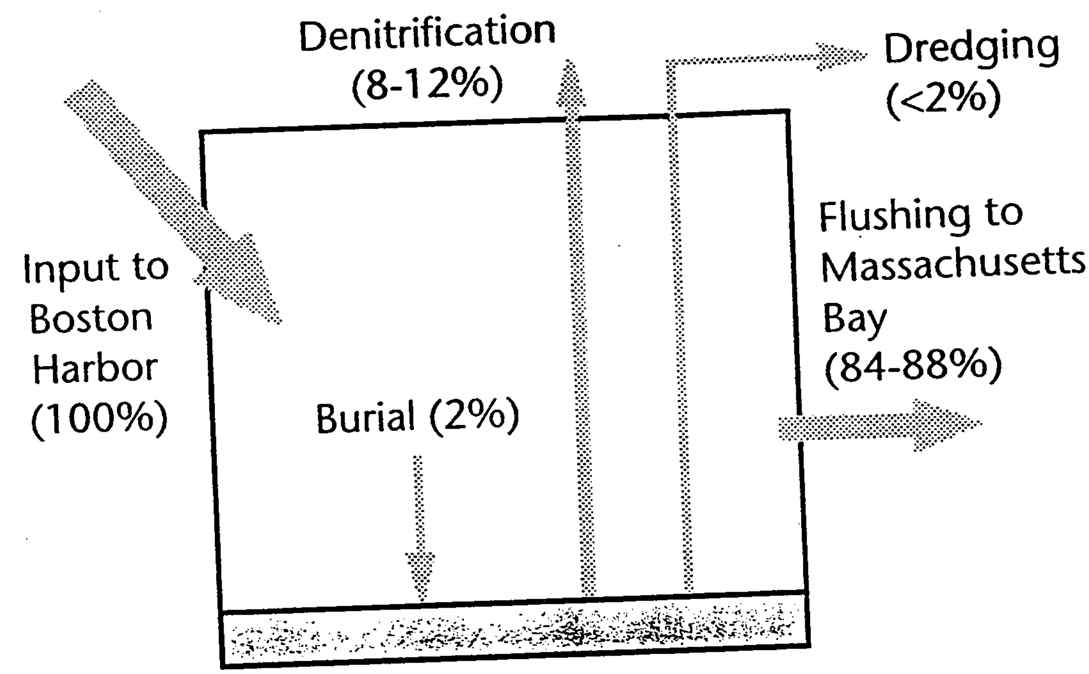
—— - Model

DATE: Mon Jan 17 TIME: 13:07:11

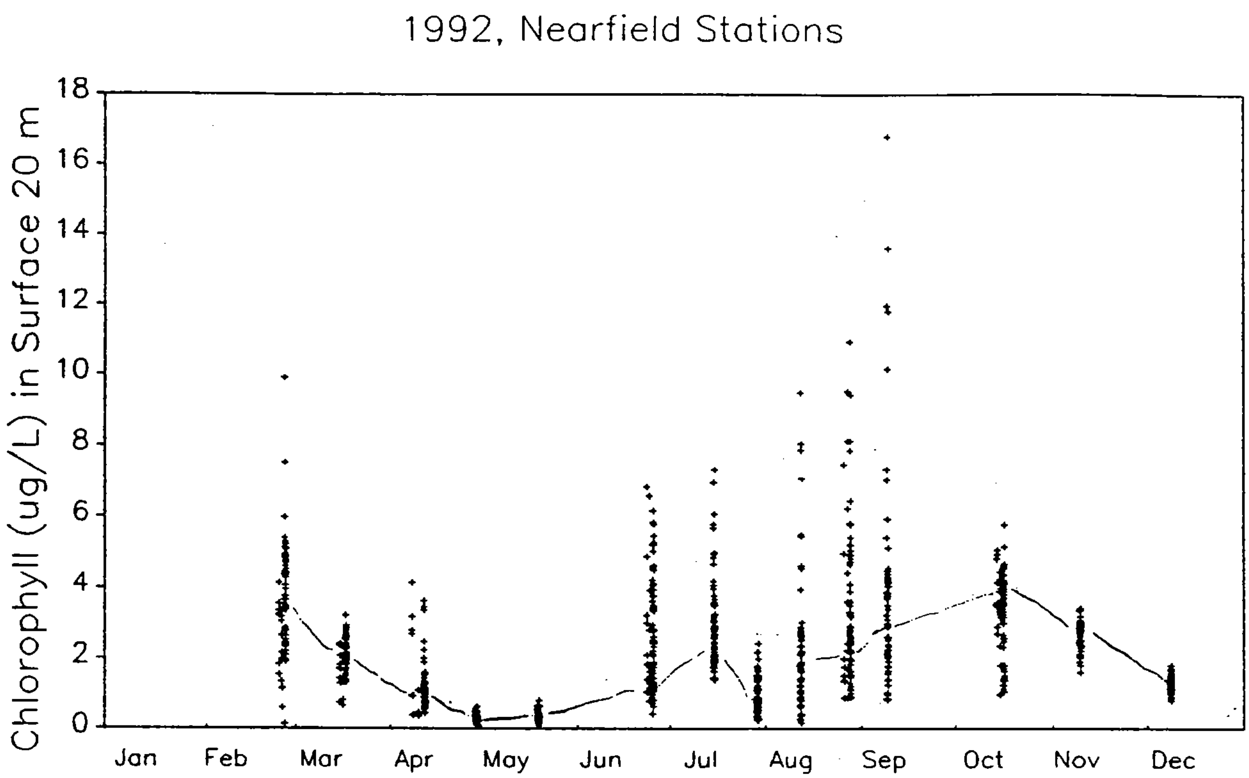
APPENDIX C-4

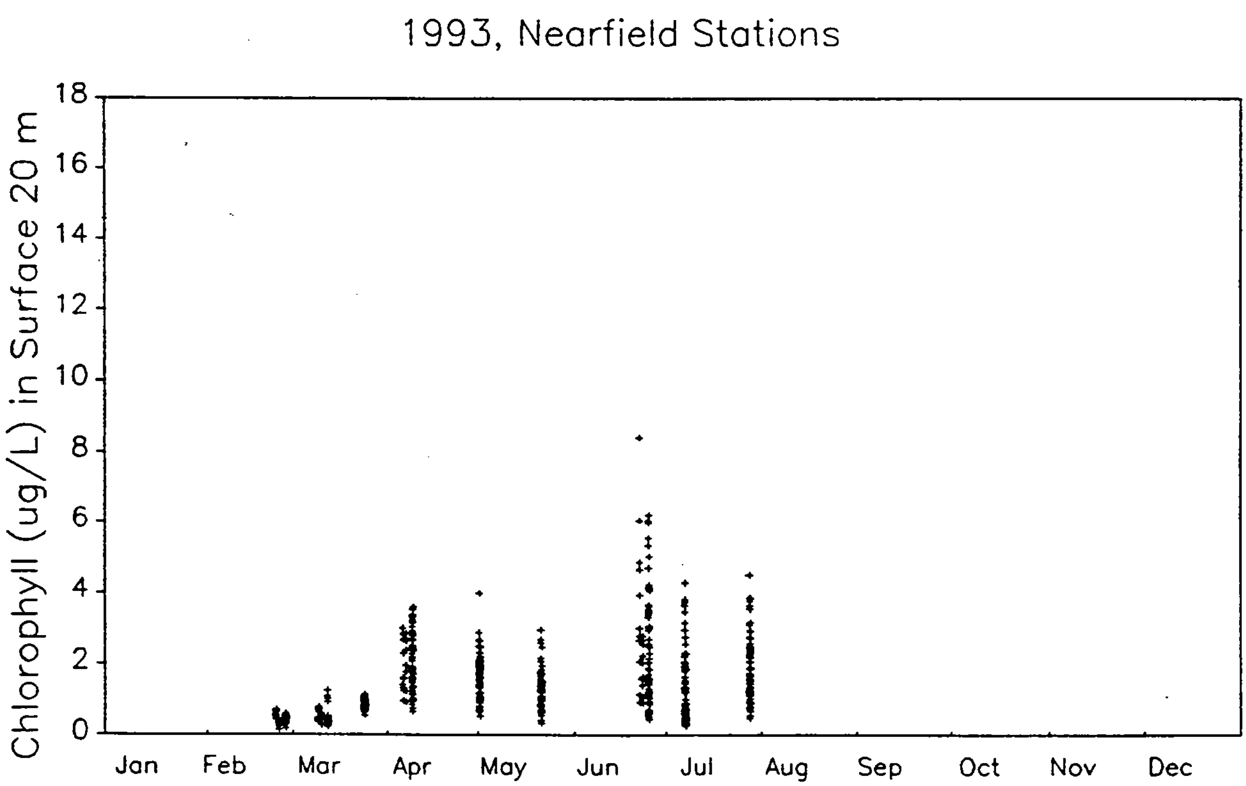
J. KELLY
BATTELLE


7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
MEAN ANNUAL Chl, ug/L
F23P
F25
N10P
N01P
F13P
N20P
F01P
N16P
N07P
F02P
N04P
0.00
5.00
10.00
15.00
20.00
25.00
MEAN ANNUAL TOTAL N, uM

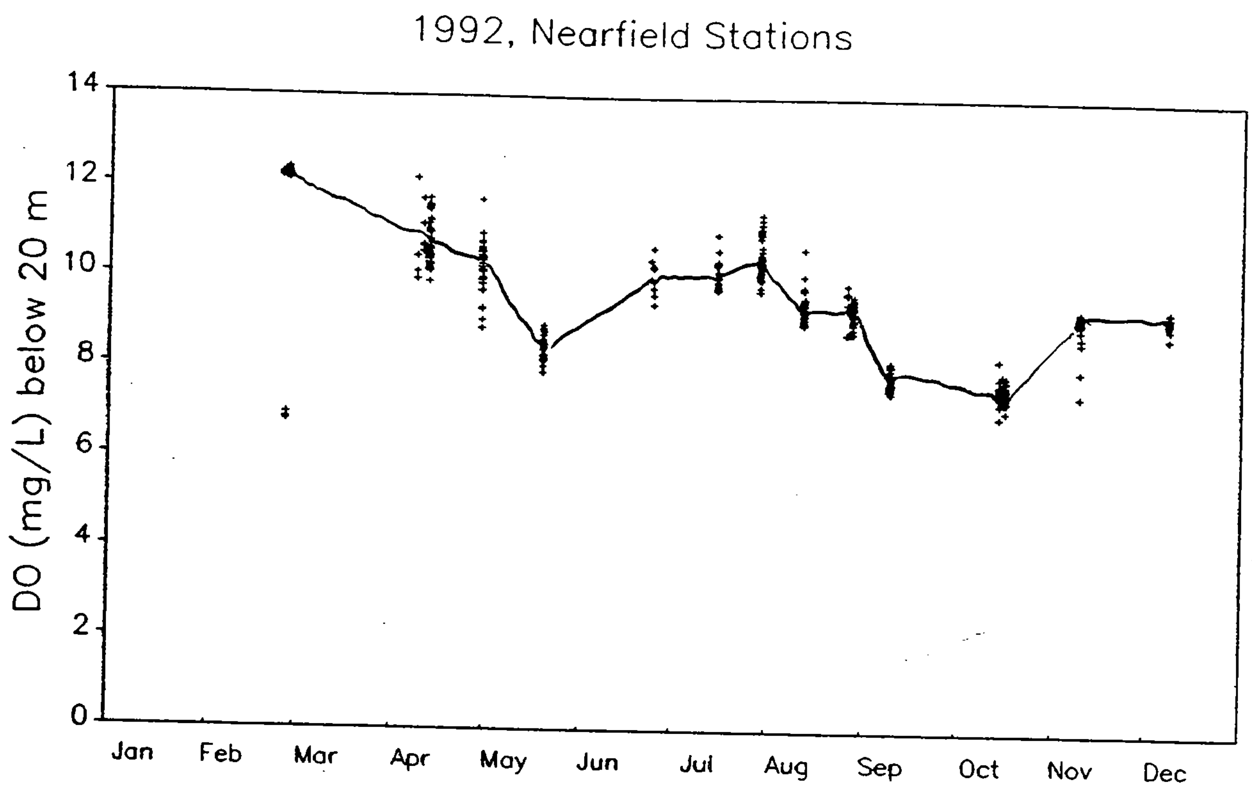


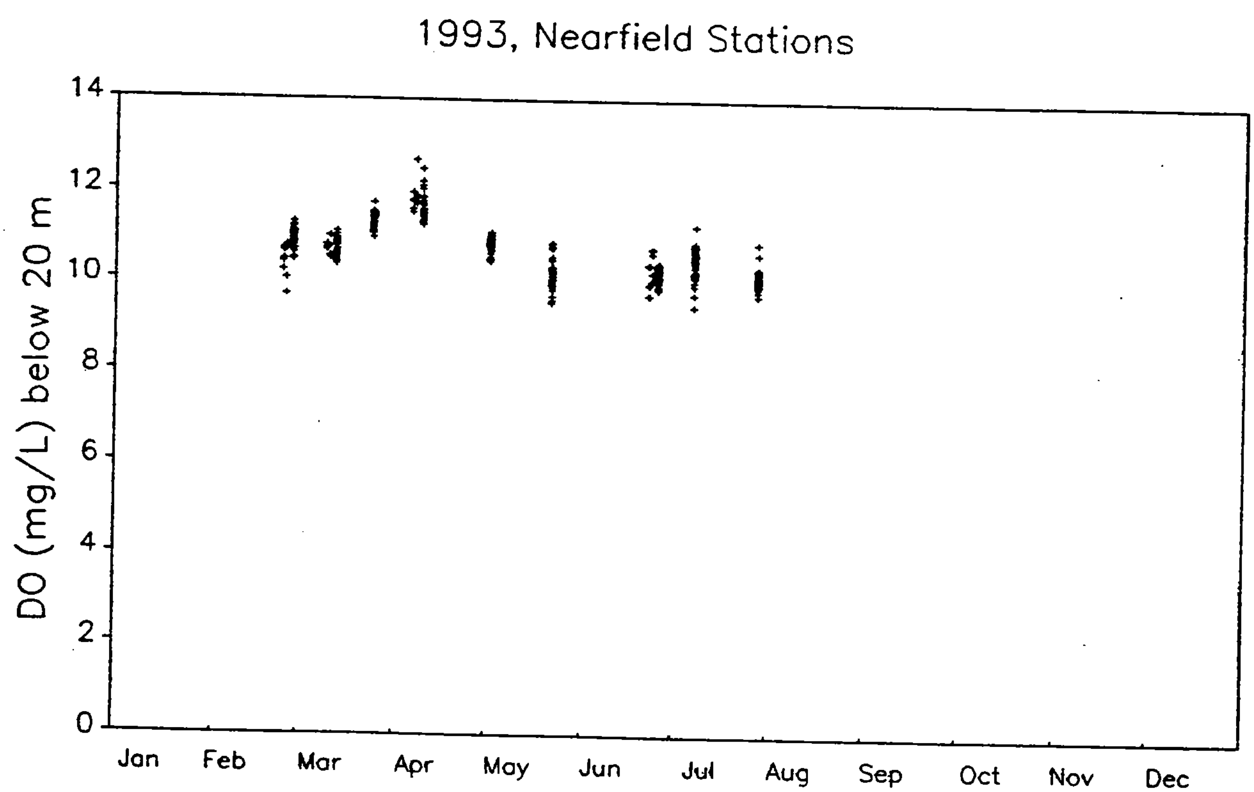
Source: Kelly and Nowicki, 1992

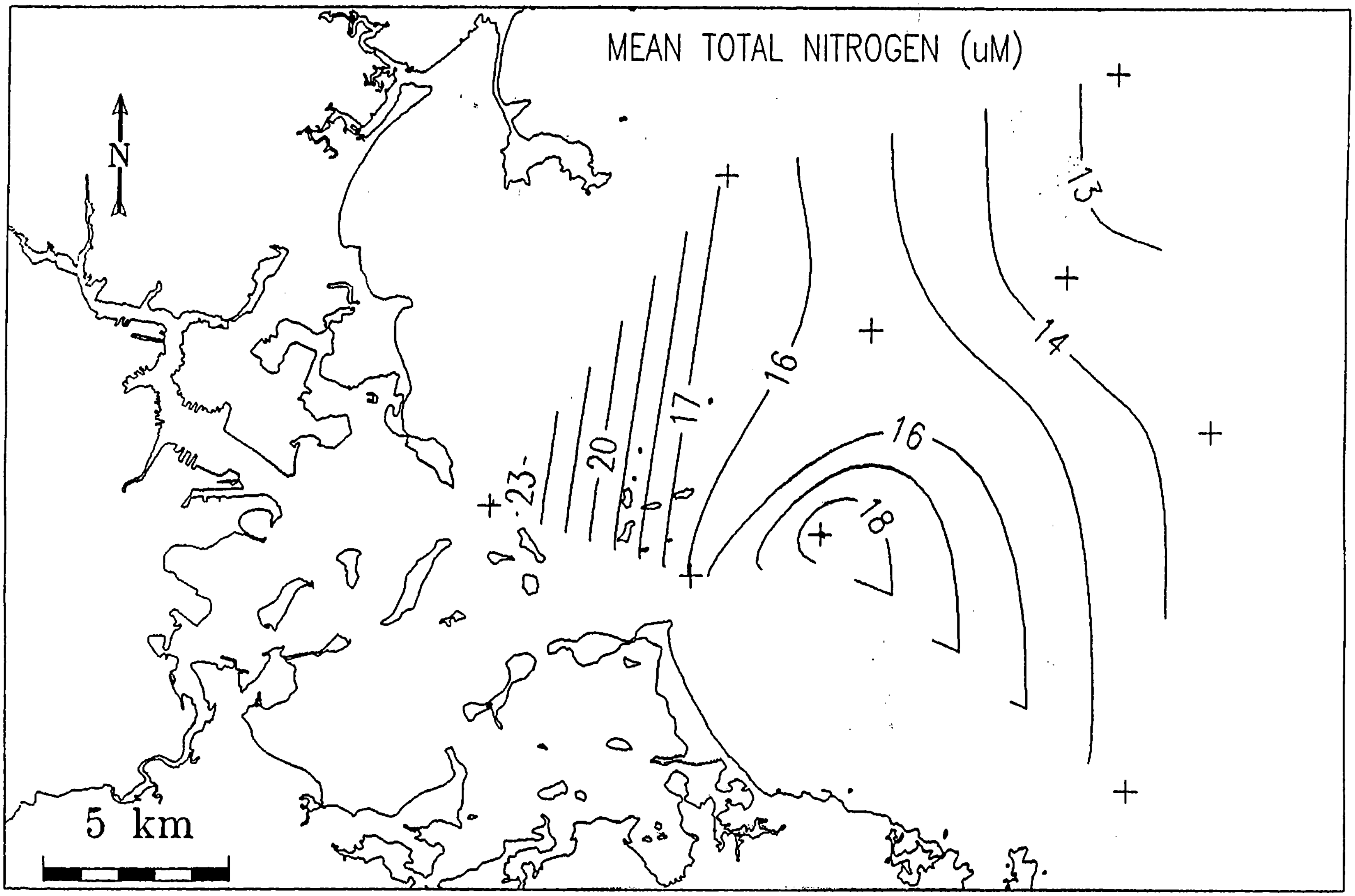

1992, Nearfield Stations
Chlorophyll (ug/L) in Surface 20 m
18
16
14
12
10
8
6
4
2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

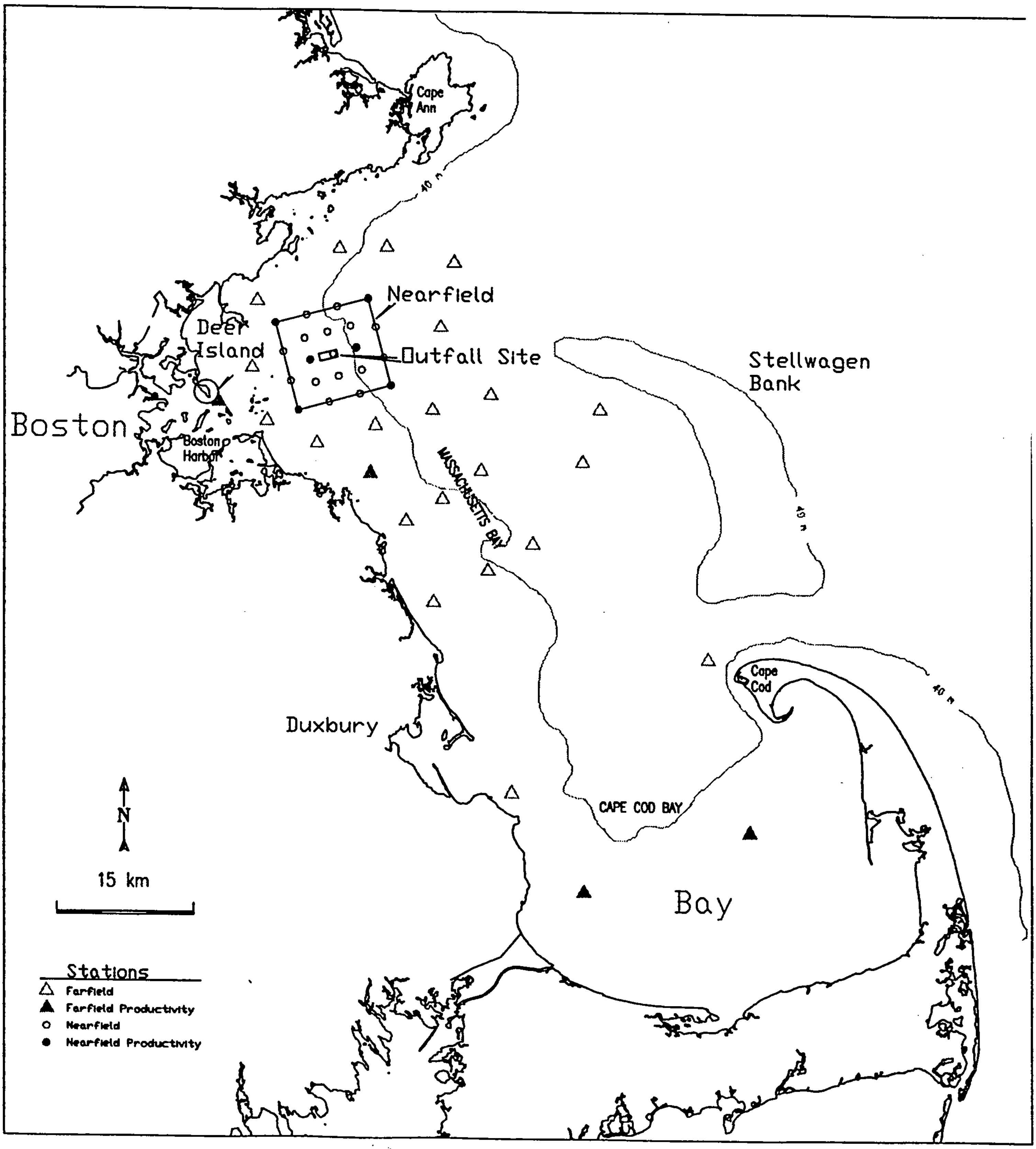

1993, Nearfield Stations
Chlorophyll (ug/L) in Surface 20 m
18
16
14
12
10
8
6
4
2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

(no page 56)


1992, Nearfield Stations
DO (mg/L) below 20 m
14
12
10
8
6
4
2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

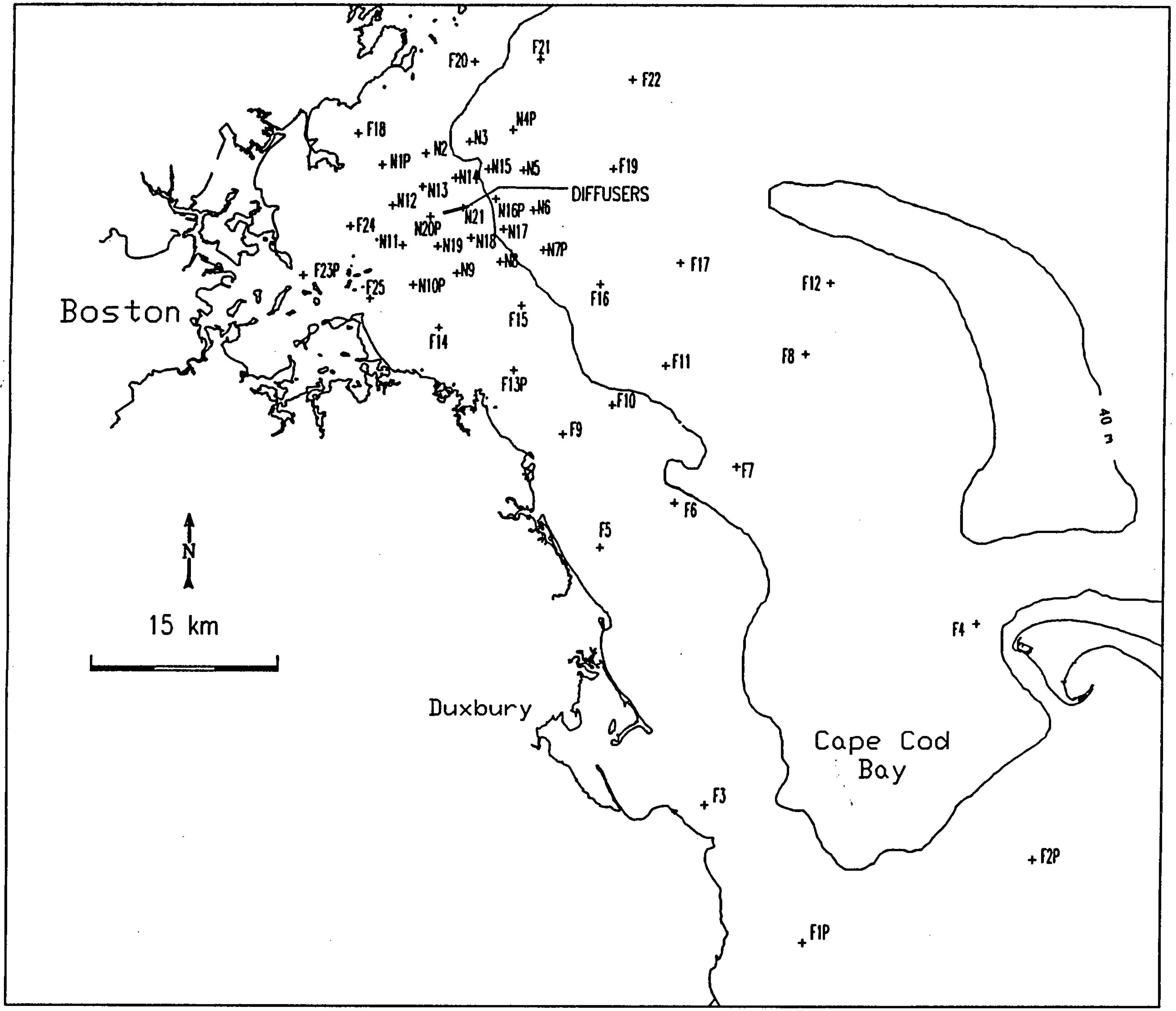

1993, Nearfield Stations
DO (mg/L) below 20 m
14
12
10
8
6
4
2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


MEAN TOTAL NITROGEN (uM)
13
14
16
16
18
17
20
23
N
5 km

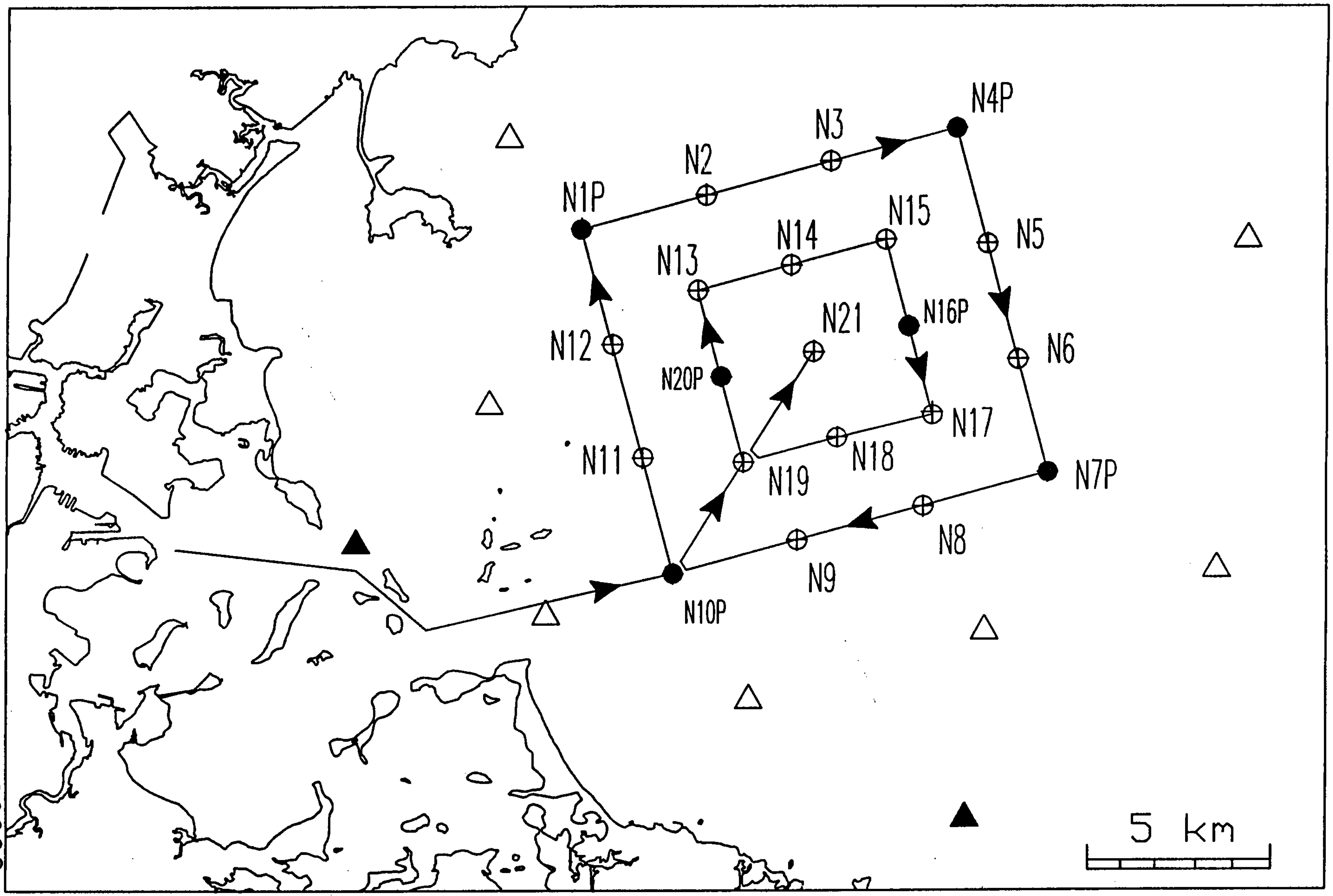


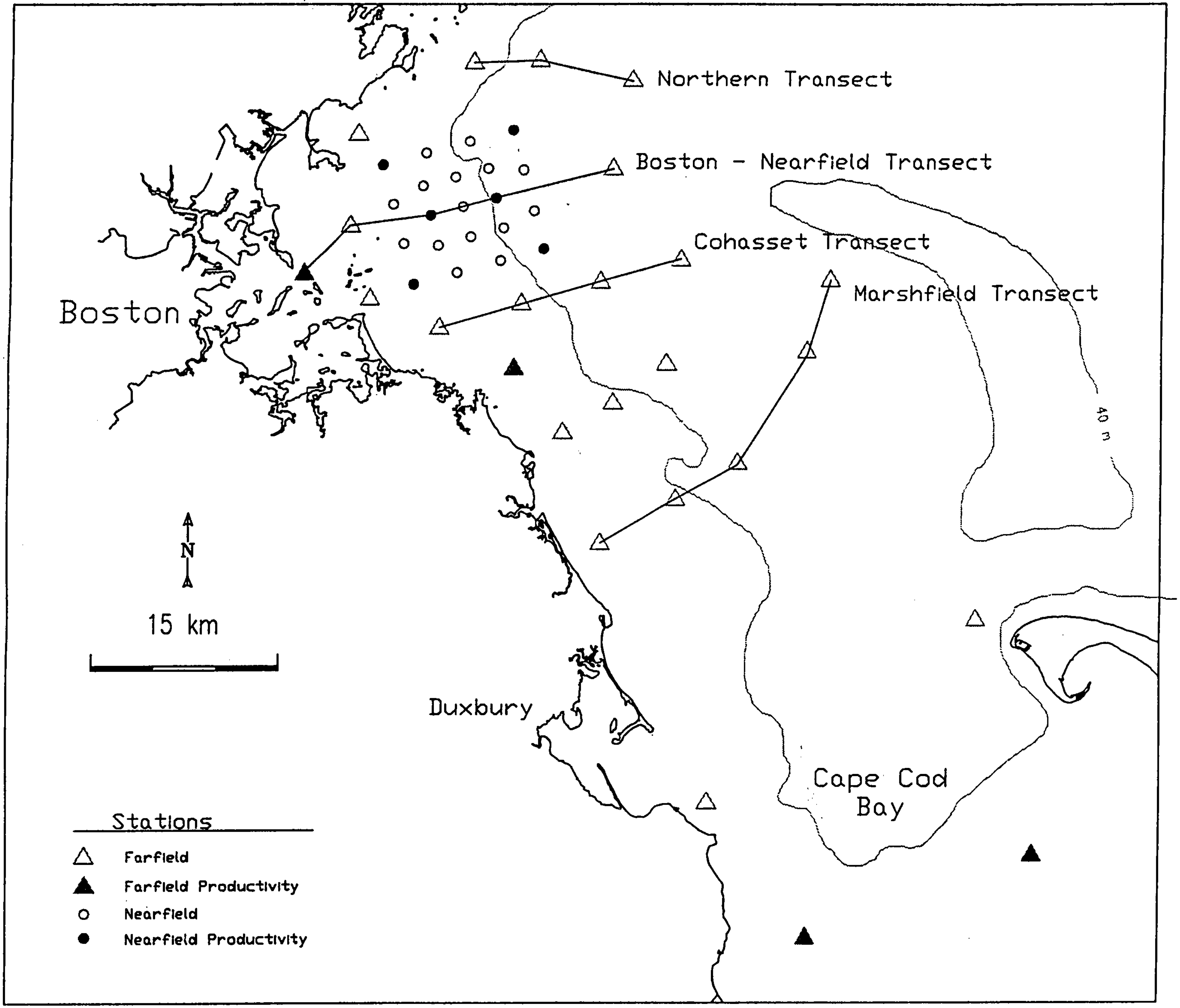
Cape Ann
40 m
Nearfield
Deer Island
Outfall Site
Stellwagen Bank
Boston
Boston Harbor
MASSACHUSETTS BAY
40 m
Cape Cod
40 m
Duxbury
N
15 km
CAPE COD BAY
Bay
Stations
Farfield
Farfield Productivity
Nearfield
Nearfield Productivity

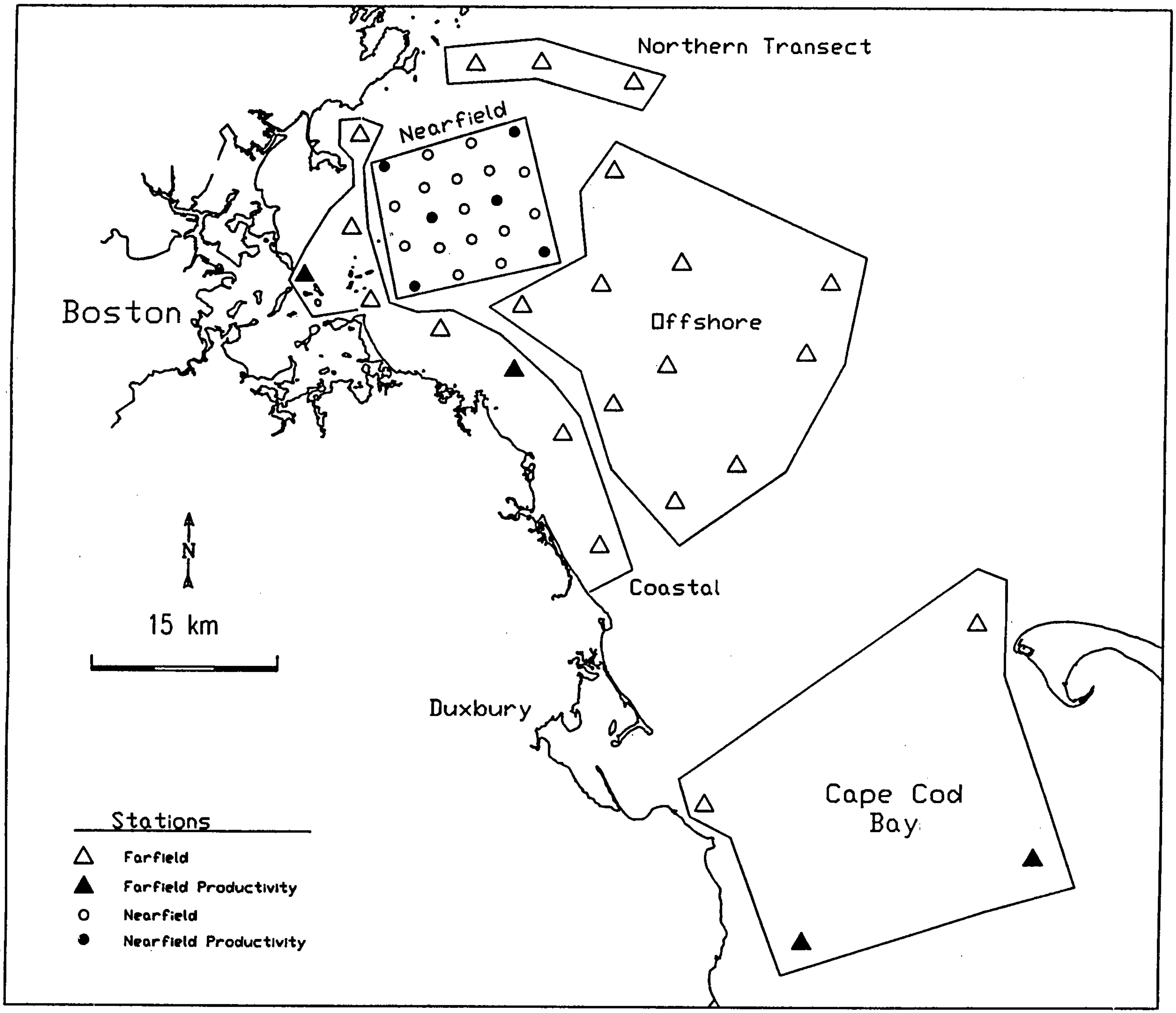
00060

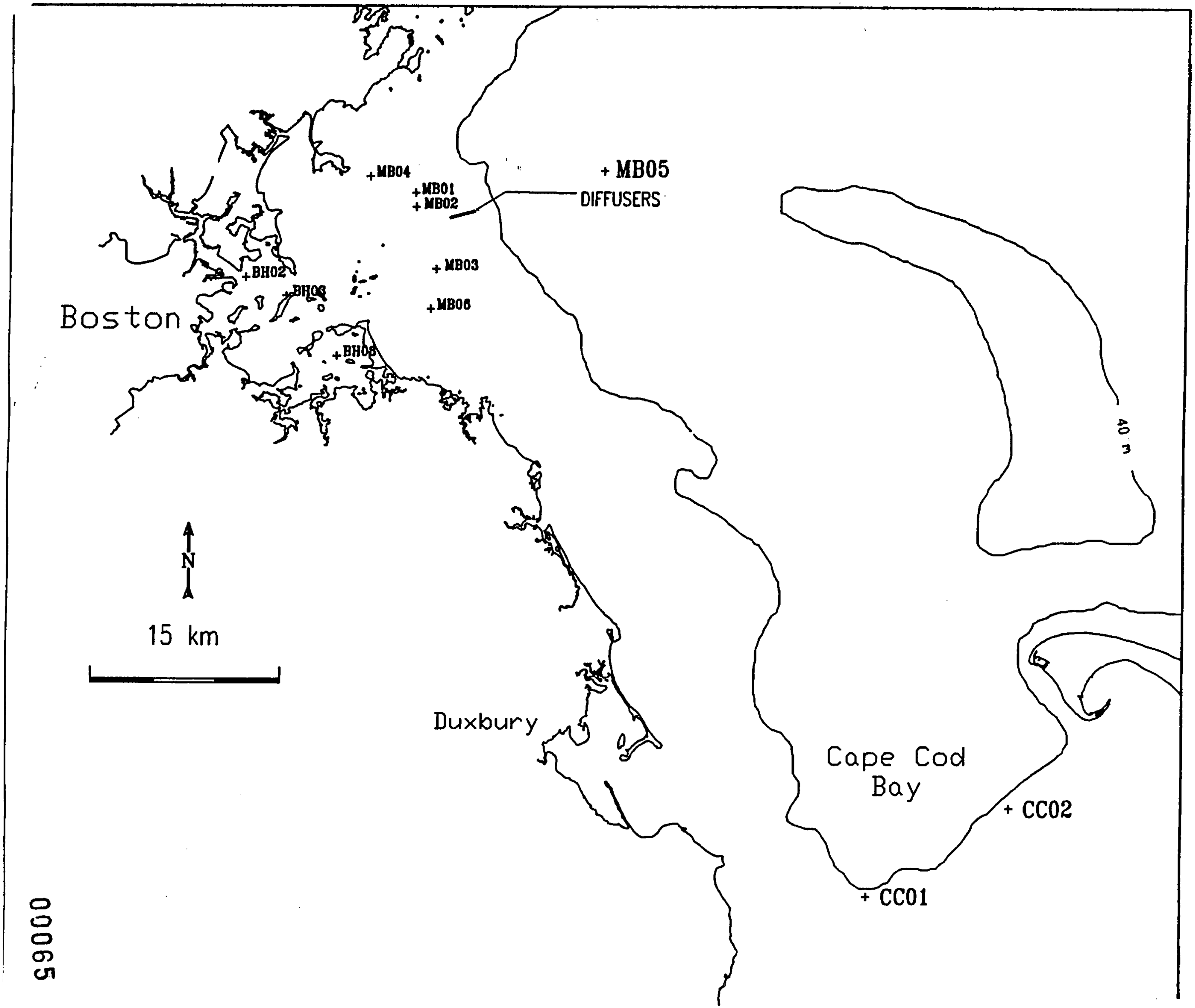


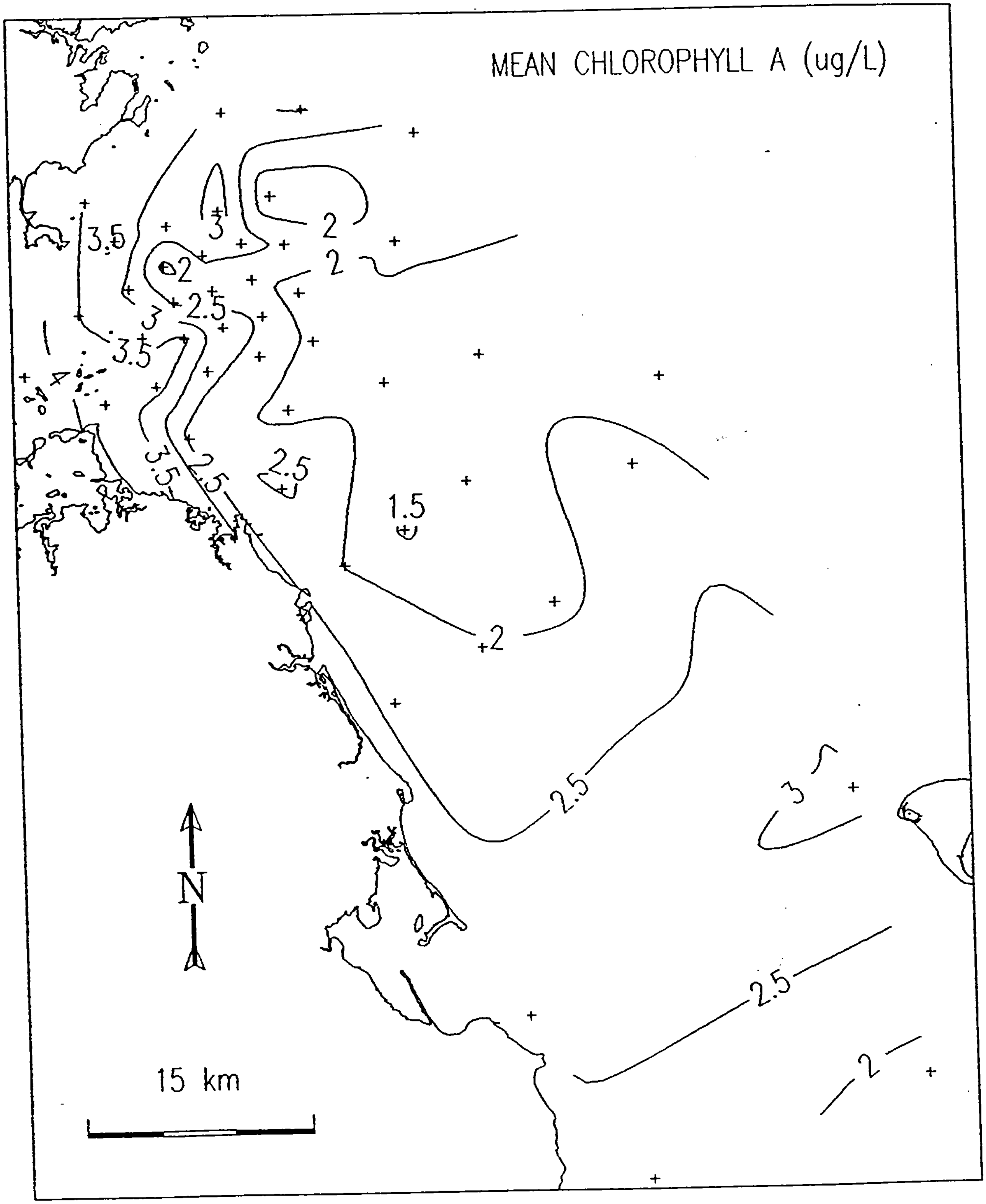
Boston
Duxbury
Cape Cod Bay
DIFFUSERS
40 m
N
15 km
F1P
F2P
F3
F4
F5
F6
F7
F8
F9
F10
F11
F12
F13P
F14
F15
F16
F17
F18
F19
F20
F21
F22
F23P
F24
F25
N1P
N2
N3
N4P
N5
N6
N7P
N8
N9
N10P
N11
N12
N13
N14
N15
N16P
N17
N18
N19
N20P
N21

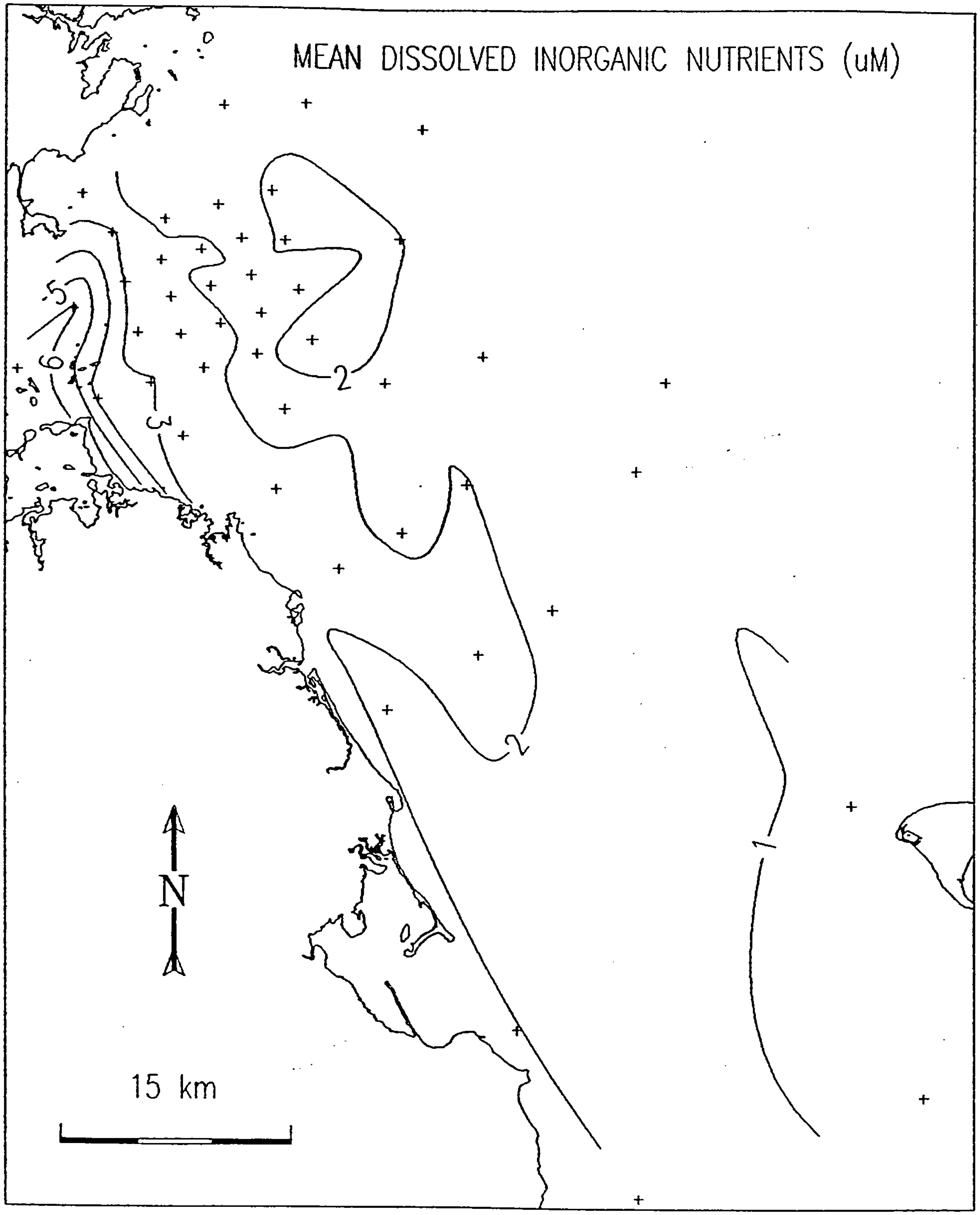

N1P
N2
N3
N4P
N5
N6
N7P
N8
N9
N10P
N11
N12
N13
N14
N15
N16P
N17
N18
N19
N20P
N21
5 km

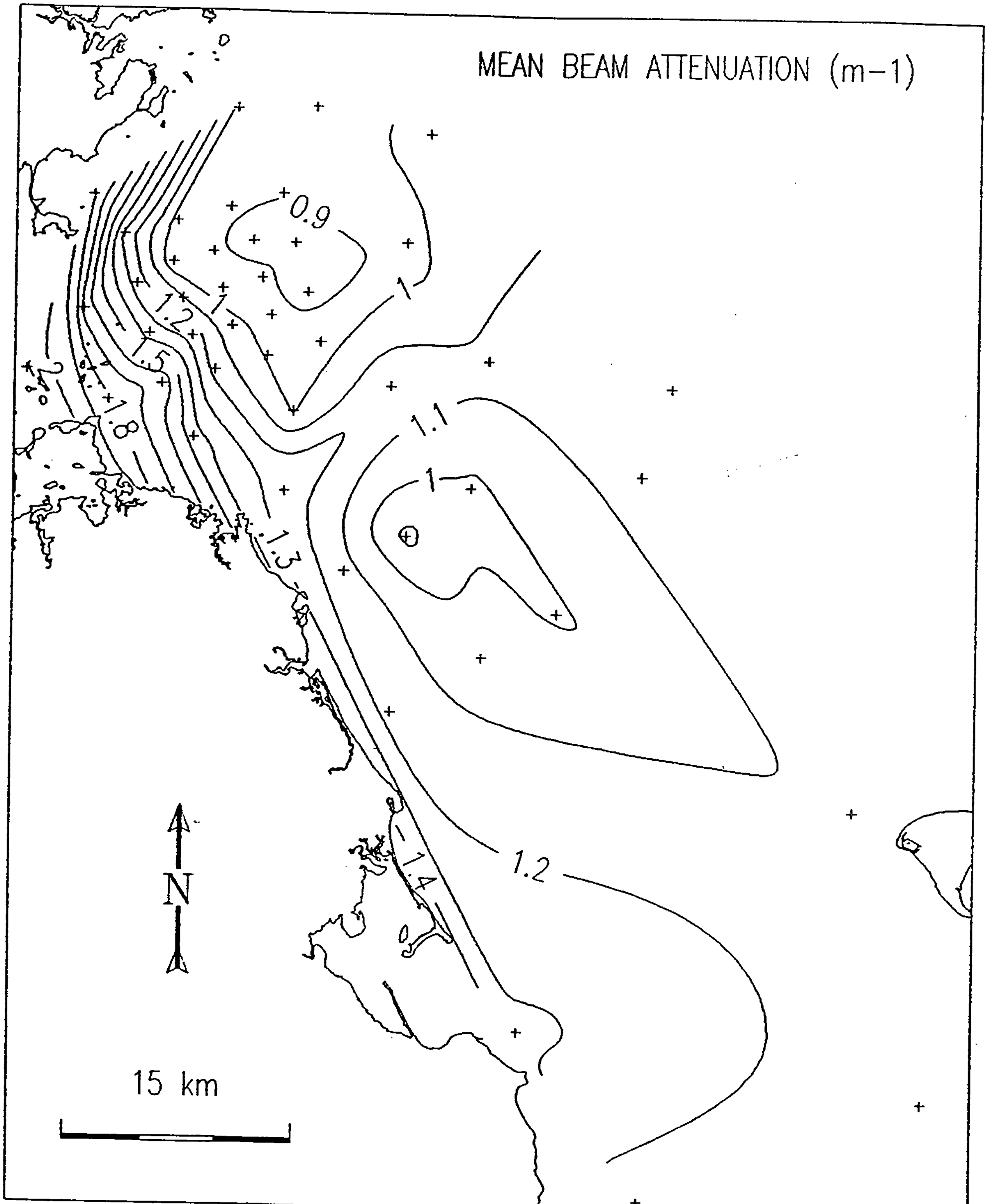

Northern Transect
Boston - Nearfield Transect
Cohasset Transect
Marshfield Transect
40 m
Boston
N
15 km
Duxbury
Cape Cod Bay
Stations
Farfield
Farfield Productivity
Nearfield
Nearfield Productivity

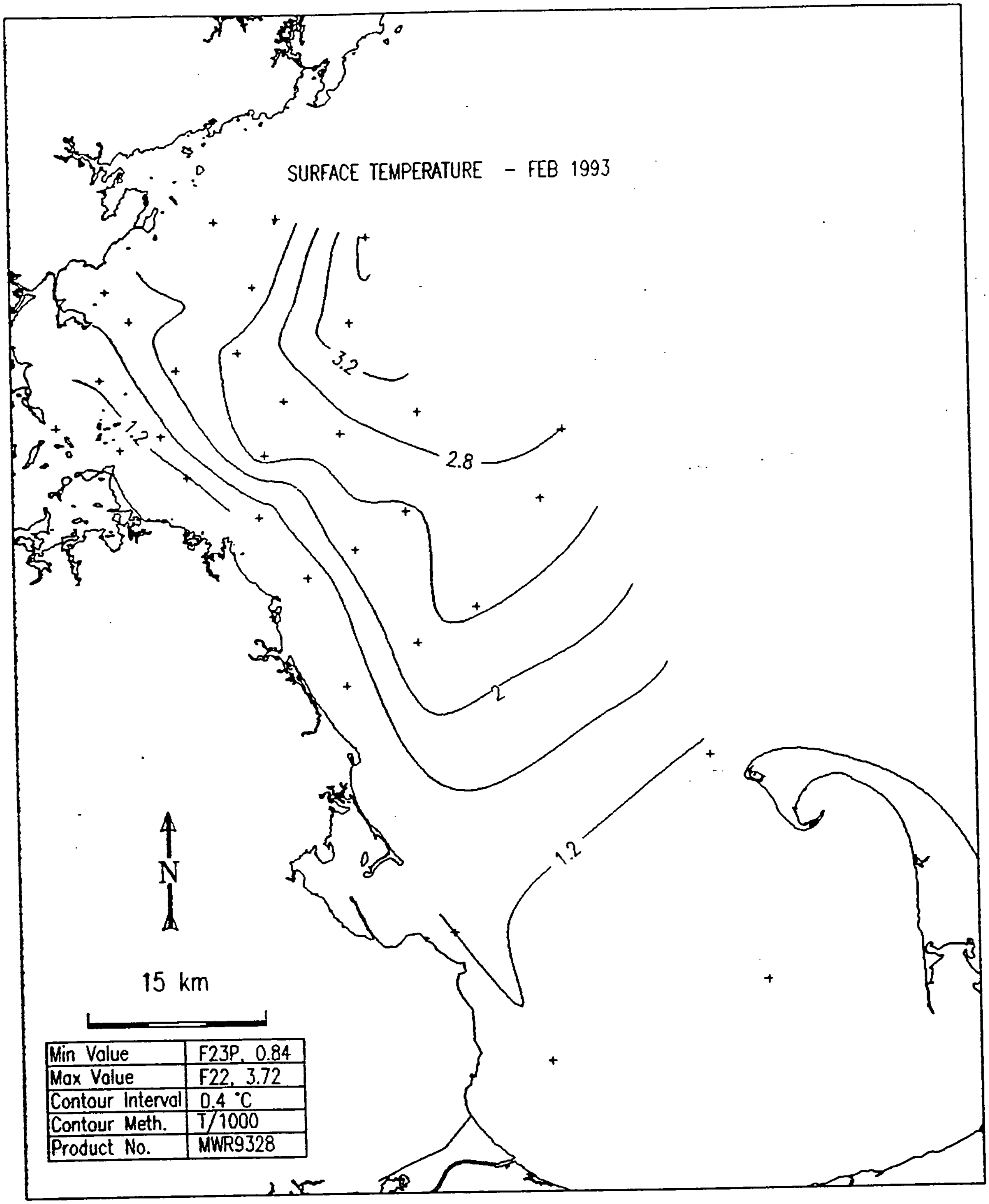

Northern Transect
Nearfield
Offshore
Coastal
Boston
Duxbury
Cape Cod Bay
N
15 km
Stations
Farfield
Farfield Productivity
Nearfield
Nearfield Productivity


+MB04
+MB01
+MB02
+MB05
DIFFUSERS
+MB03
+MB06
+BH02
+BH03
+BH08
Boston
40 m
15 km
N
Duxbury
Cape Cod
Bay
+ CC02
+ CC01

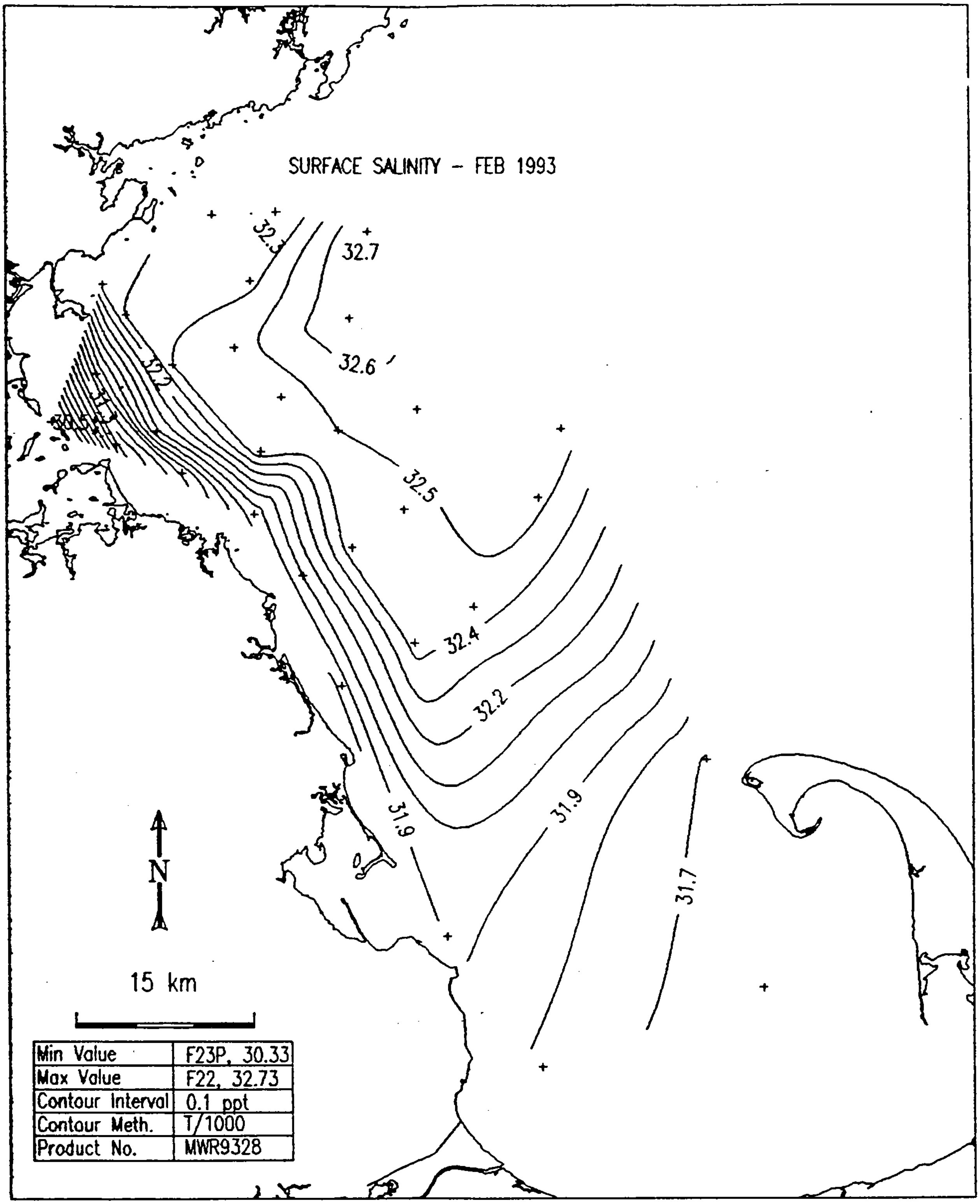

MEAN CHLOROPHYLL A (ug/L)
3.5
3
2
2
2
2.5
3
3.5
3.5
2.5
2.5
1.5
2
2.5
3
2.5
2
N
15 km

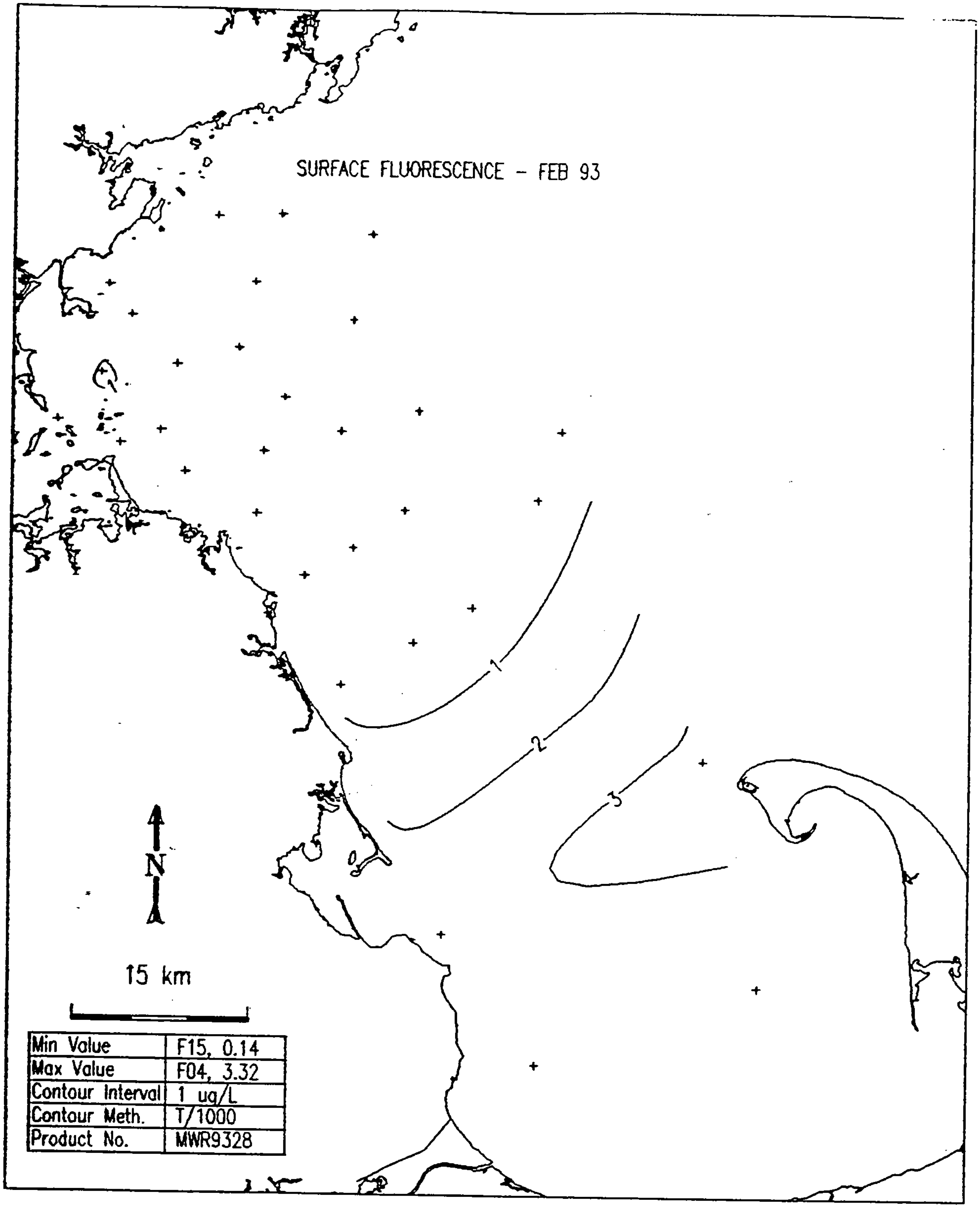

MEAN DISSOLVED INORGANIC NUTRIENTS (uM)
2
3
5
6
2
1
N
15 km

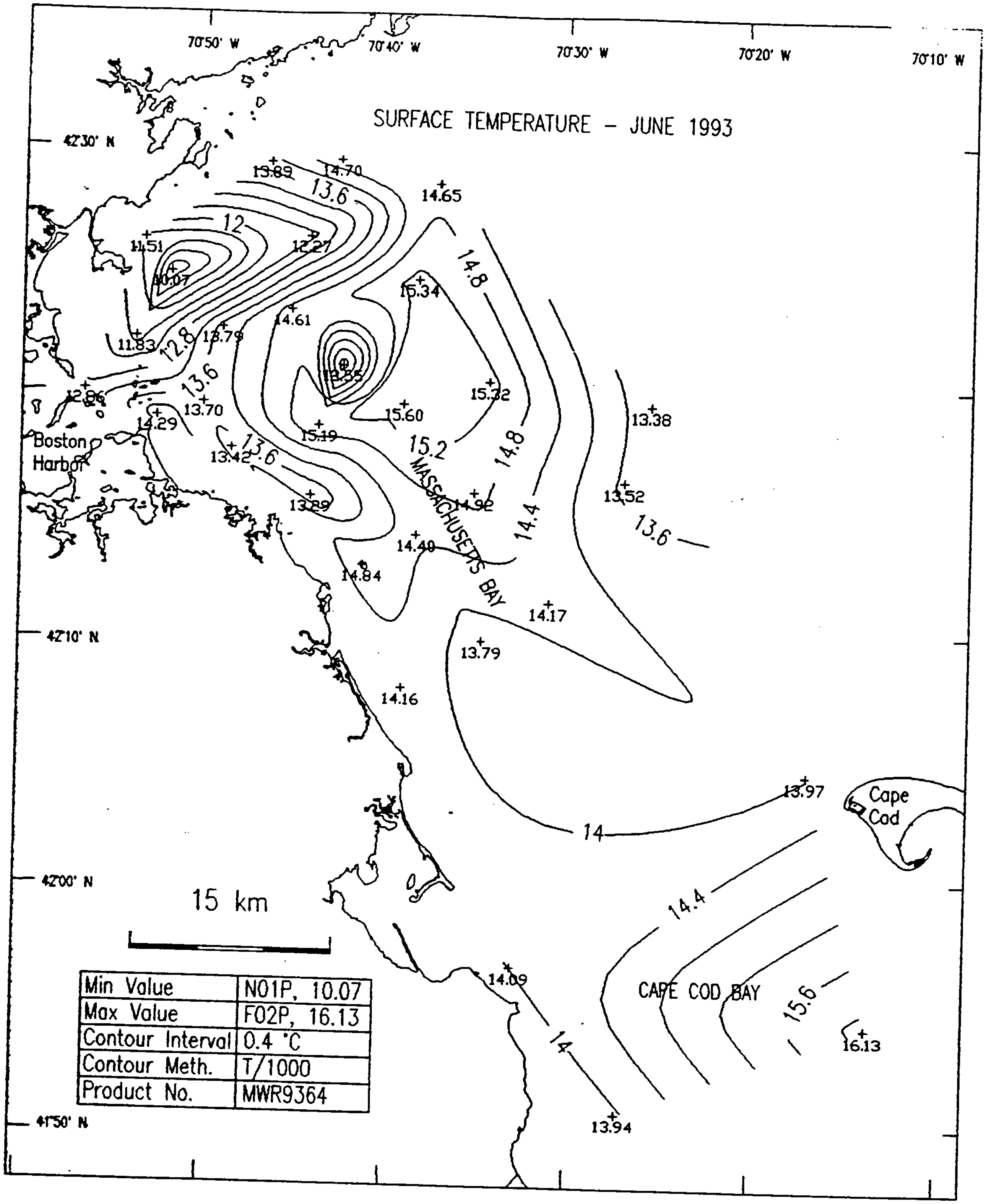

MEAN BEAM ATTENUATION (m-1)
0.9
1
1.1
1.2
1.3
1.4
1.5
1.8
2
N
15 km

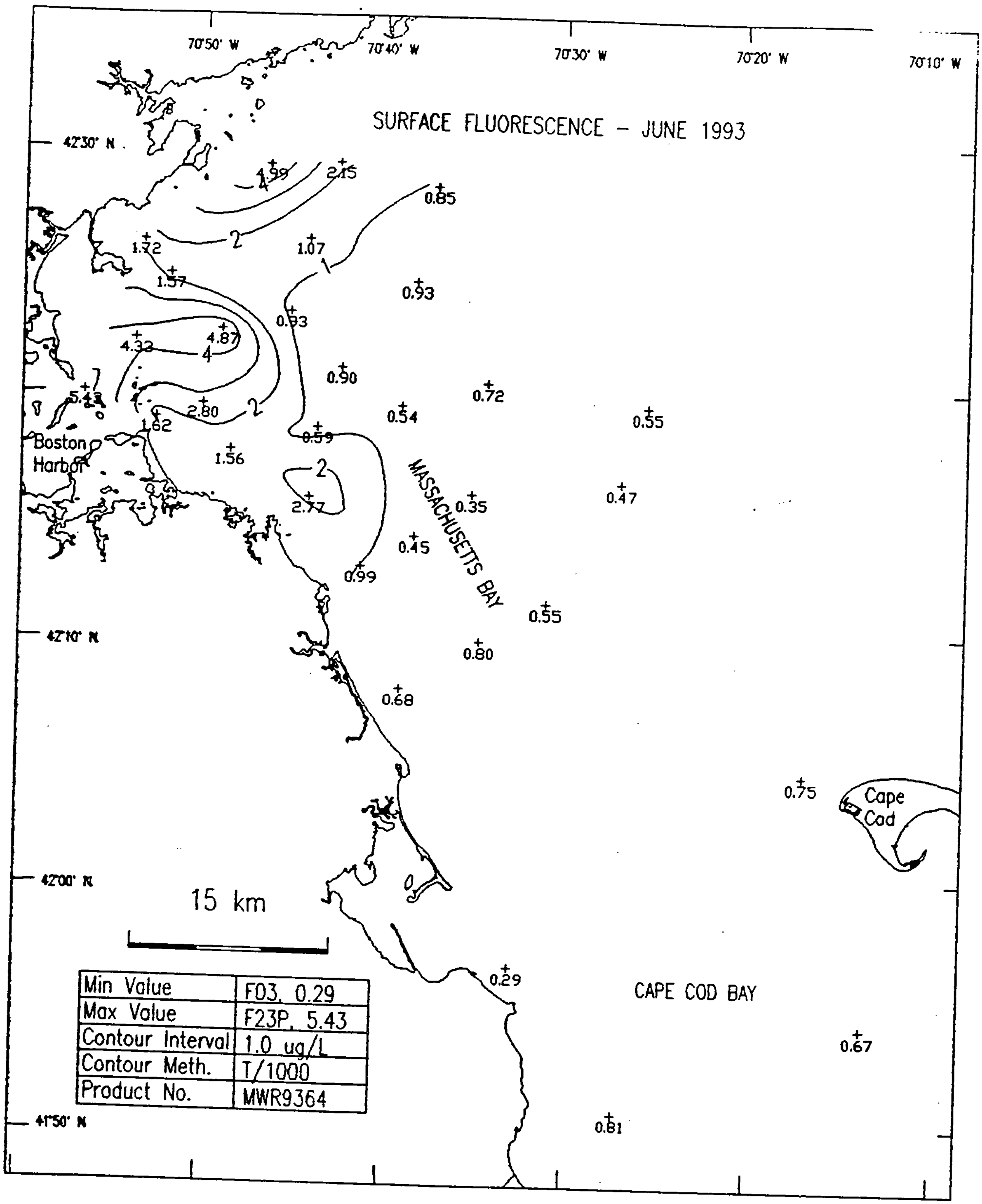


Min Value	F23P, 0.84
Max Value	F22, 3.72
Contour Interval	0.4 °C
Contour Meth.	T/1000
Product No.	MWR9328


SURFACE SALINITY - FEB 1993
32.7
32.6
32.5
32.4
32.2
31.9
31.9
31.7
N
15 km
Min Value | F23P, 30.33
Max Value | F22, 32.73
Contour Interval | 0.1 ppt
Contour Meth. | T/1000
Product No. | MWR9328

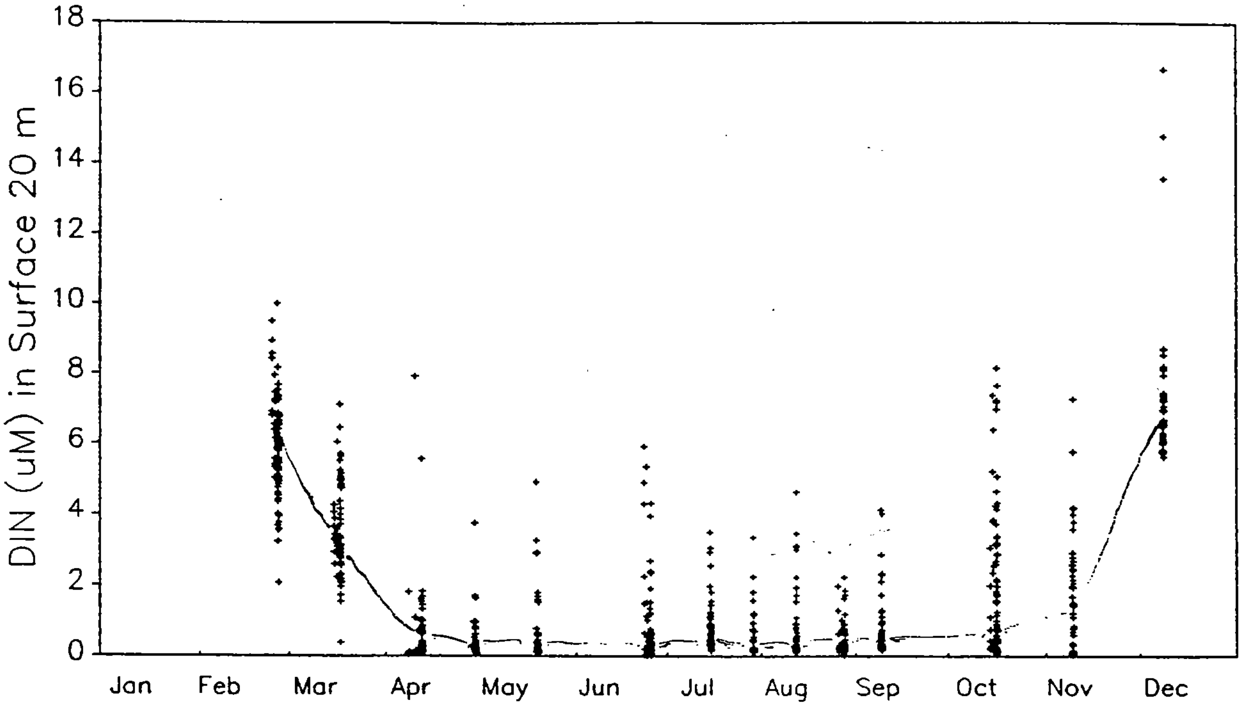

SURFACE FLUORESCENCE - FEB 93
1
2
3
N
15 km
Min Value | F15, 0.14
Max Value | F04, 3.32
Contour Interval | 1 ug/L
Contour Meth. | T/1000
Product No. | MWR9328


SURFACE TEMPERATURE – JUNE 1993
70°50' W
70°40' W
70°30' W
70°20' W
70°10' W
42°30' N
42°10' N
42°00' N
41°50' N
Boston Harbor
MASSACHUSETTS BAY
CAPE COD BAY
Cape Cod
15 km
Min Value | N01P, 10.07
Max Value | F02P, 16.13
Contour Interval | 0.4 °C
Contour Meth. | T/1000
Product No. | MWR9364

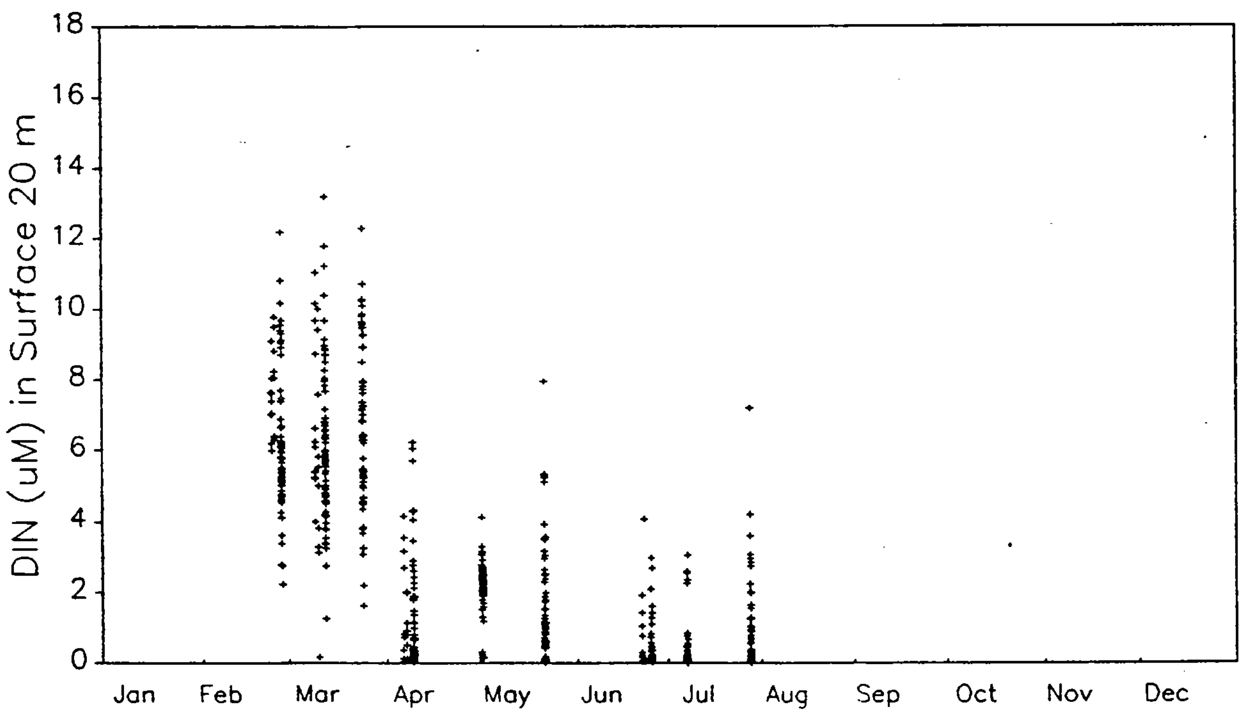


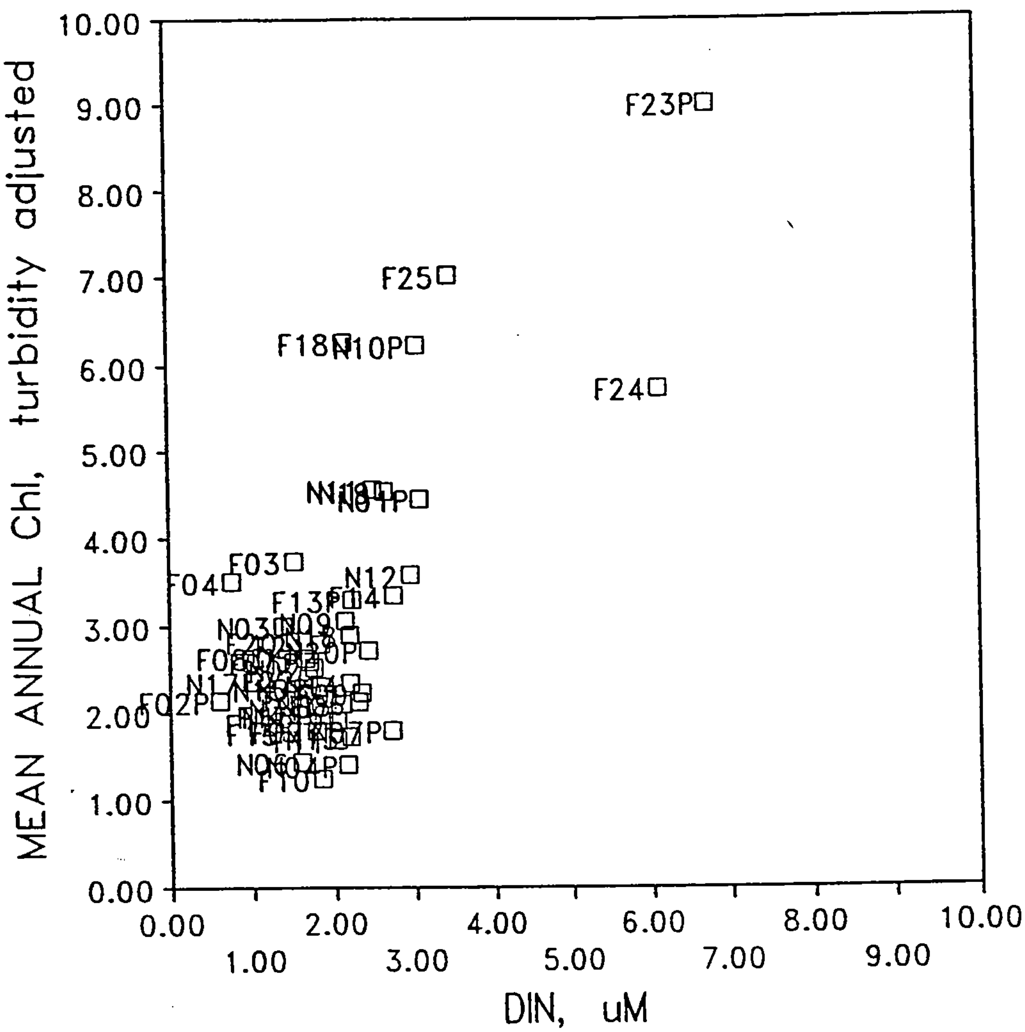
Min Value	F03, 0.29
Max Value	F23P, 5.43
Contour Interval	1.0 ug/L
Contour Meth.	T/1000
Product No.	MWR9364

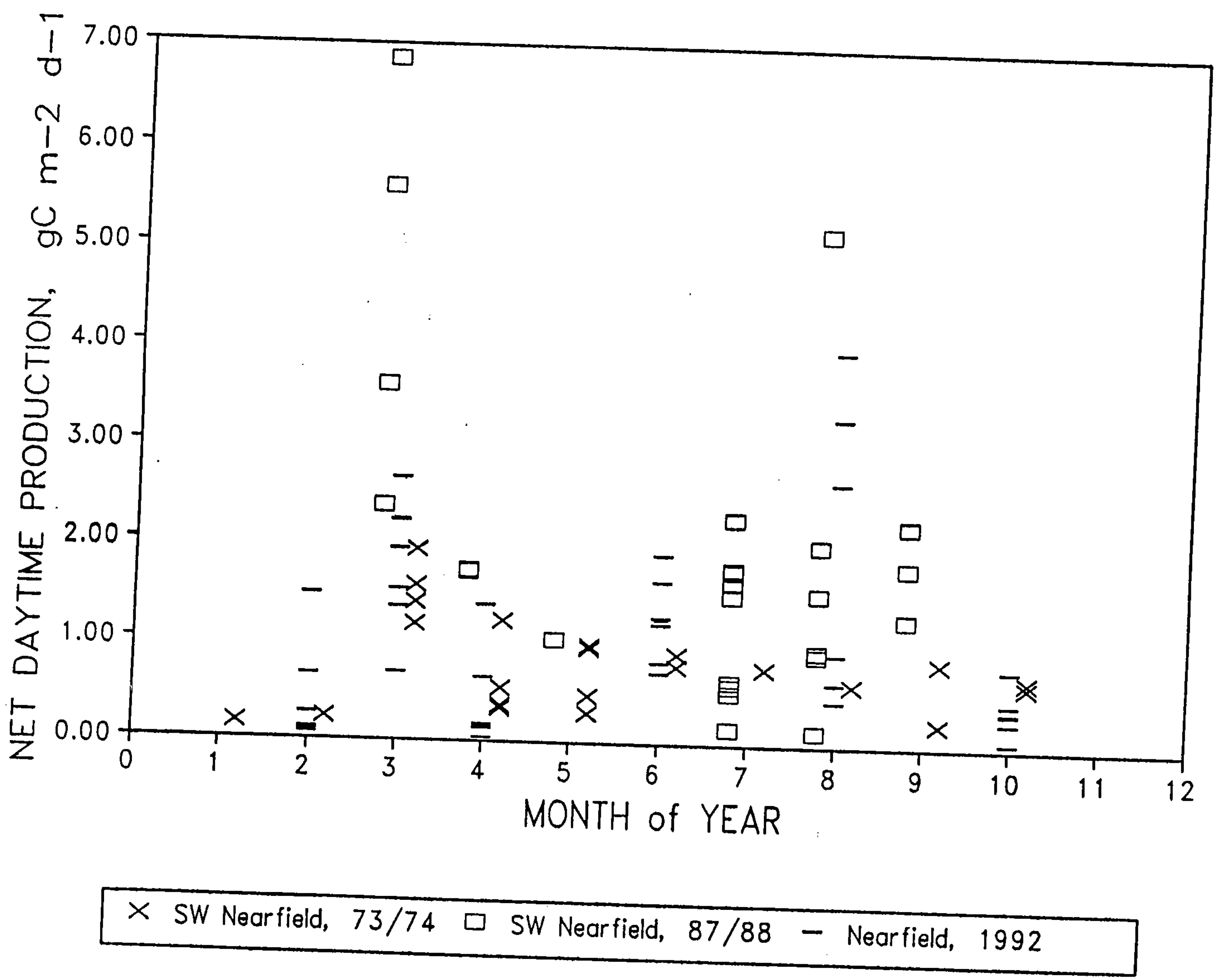
1992, Nearfield Stations



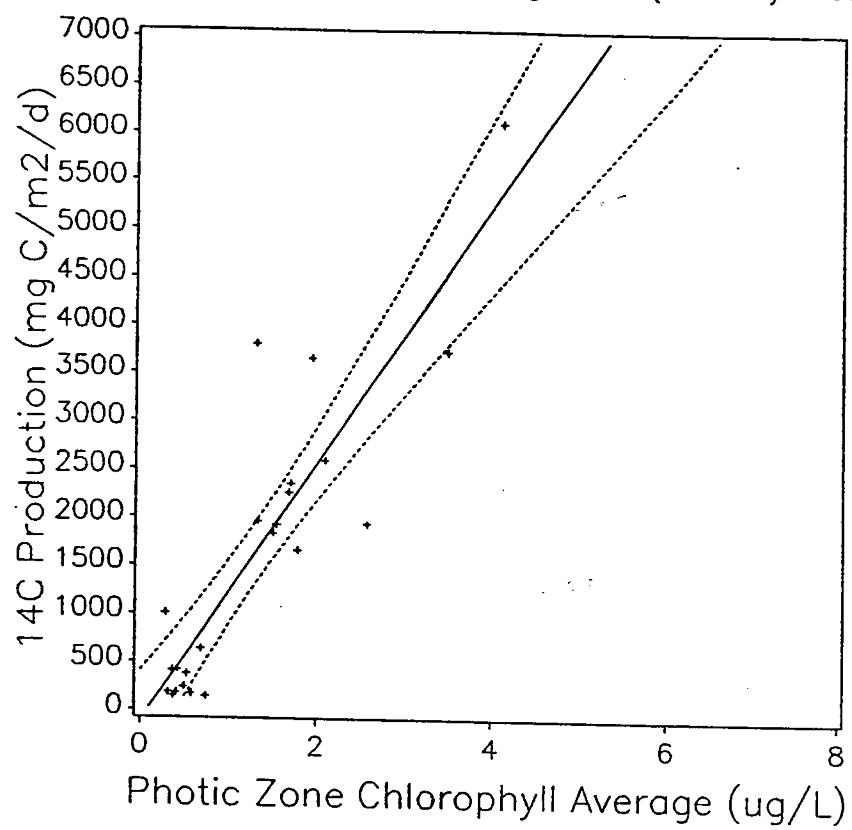
1993, Nearfield Stations




MEAN ANNUAL Chl, turbidity adjusted
DIN, uM
F23P
F25
F18
N10P
F24
F03
F04
N12
F13P
F02P
F10
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00


NET DAYTIME PRODUCTION, gC m−2 d−1
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
0
1
2
3
4
5
6
7
8
9
10
11
12
MONTH of YEAR
× SW Nearfield, 73/74
□ SW Nearfield, 87/88
— Nearfield, 1992

Nearfield Stations — February through June (surface) 1993



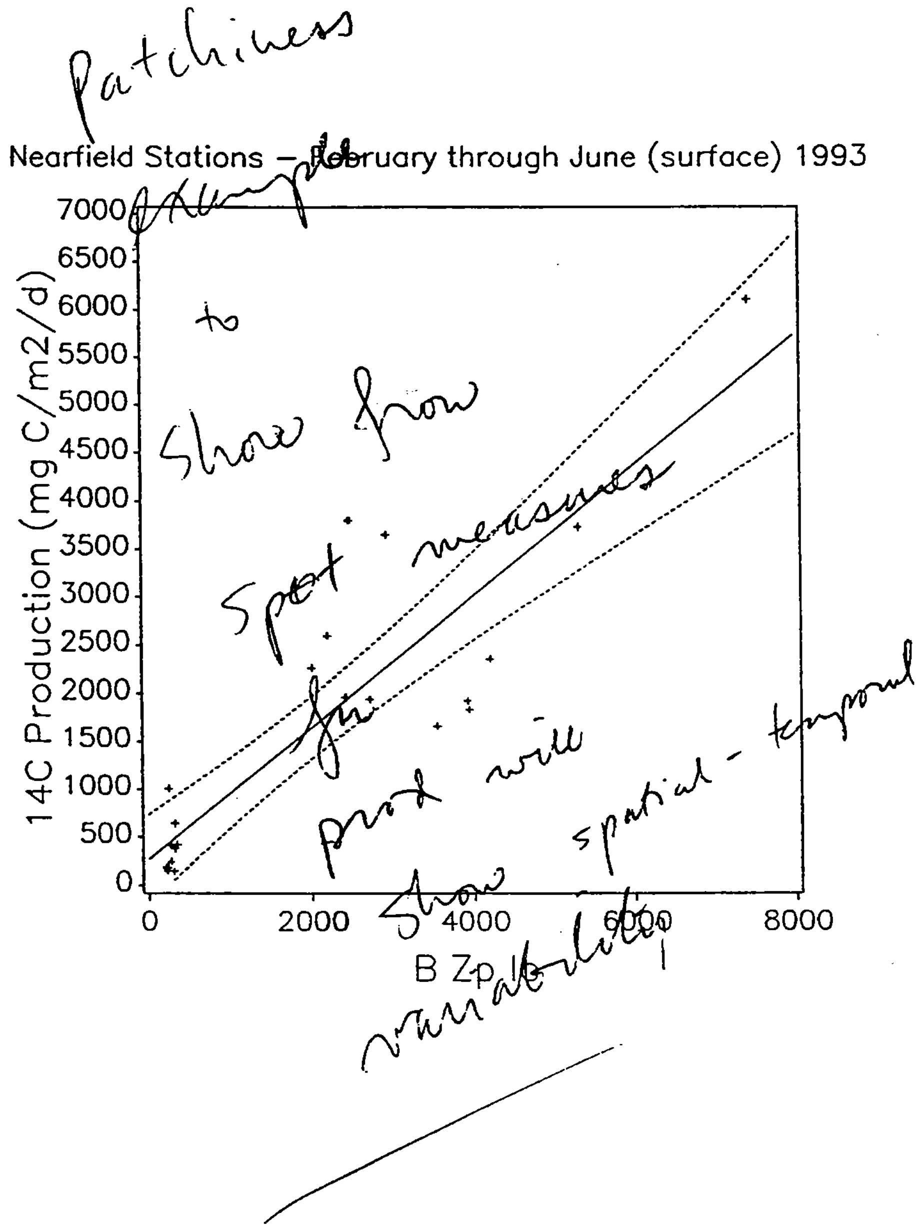
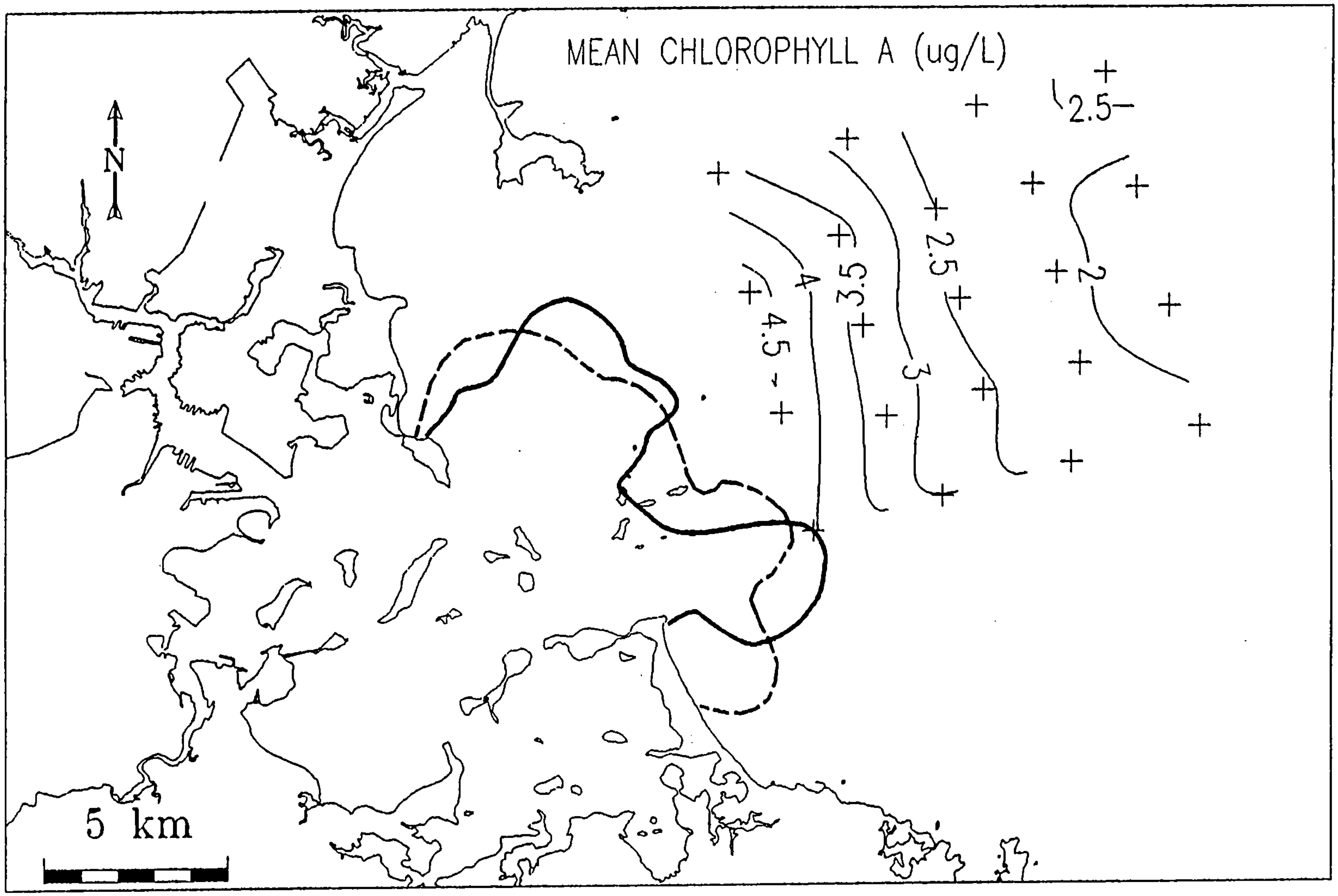
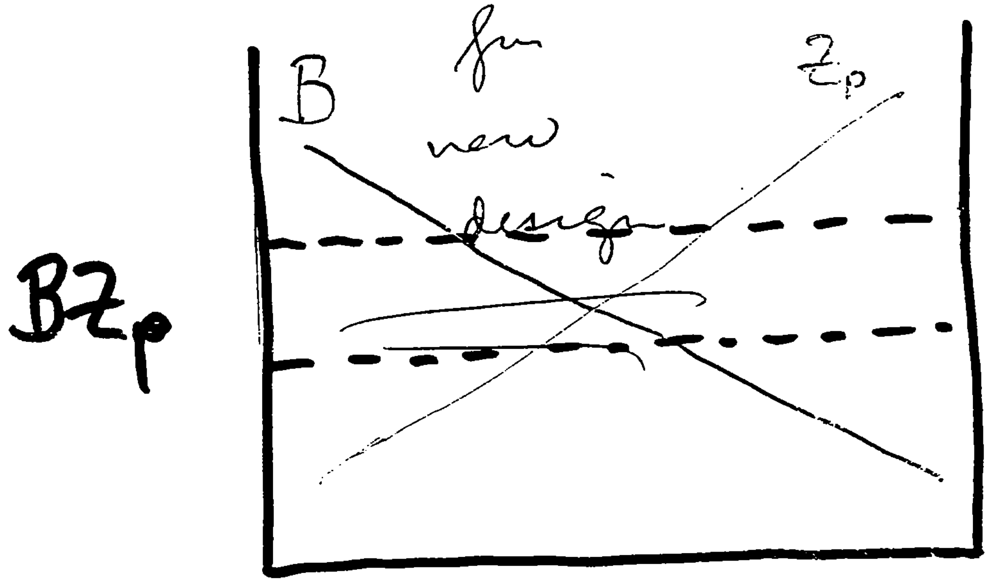


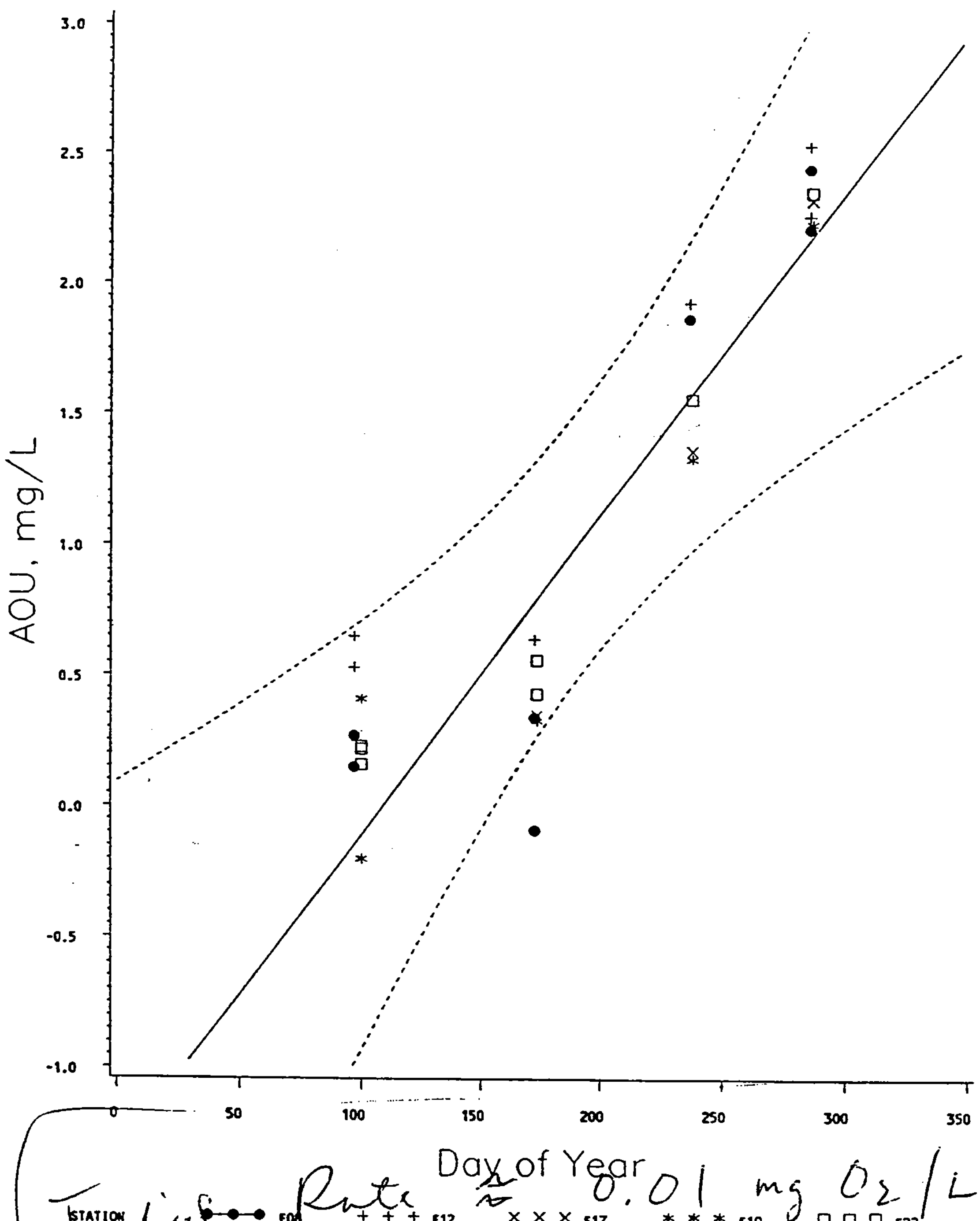
Figure 3. ^{14}C Production and BZ_pI_o for Nearfield Stations at all Surveys. Production for June survey (W9307) is based only on incubation of surface sample at a station. Graph shows linear regression model (solid line) with 95% confidence limits (dotted lines).


MEAN CHLOROPHYLL A (ug/L)
2.5
2
2.5
3
3.5
4
4.5
N
5 km

Recommendations



AOU vs JD≧50 m



Implied Rate ≈ 0.01 mg O_2/L/day

2.5 mg O_2/L ⇒ ≈ 27 g C/m² (30 m bottom

≈ 10% of production.
for year

00081

APPENDIX C-5

A. GIBLIN
MBL

The objectives of Task 19 are to measure rates of sediment oxygen demand, benthic nutrient (nitrogen and phosphate) release, and denitrification.

Questions from monitoring plan:

1) How do sediment oxygen demand, benthic flux, and denitrification influence the amount of oxygen and nutrients in the water near the outfall.

2) Have the rates of these processes changed?

Explanations:

1) Rates of sediment oxygen demand provide a good indication of the carbon inputs to the sediments and are used to predict water column hypoxia and anoxia.

2) Nutrient release rates are used in water quality models to predict the amount of nutrient recycling. The data will help validate the water quality model.

3) Denitrification rates measure how much nitrogen is being converted to forms which are not available to phytoplankton and lost from the ecosystem.

4) Benthic fluxes change with eutrophication. A good baseline data set will enable MWRA to more fully gauge the impact of the discharge on the benthos once the outfall becomes operational, as well as model future changes.

5) Porewater consitutents such as sulfide reflect benthic habitat quality and also give insights into processes controlling benthic fluxes.

6) By measuring these parameters in the Harbor as well as the Bay we can better calibrate the model. It also provides a "baseline" from which to monitor recovery.

Monitoring Design Questions

1) How does the variability of replicate measurements compare to the changes expected when the outfall moves? Is the level of minimum detectable change smaller than the level at which an important impacts or changes could occur?

2) How great is the spatial variability in the measured parameters in the nearfield and farfield area of the outfall? Are there factors such as temperature or depth which explain the variability?

3) What are the seasonal patterns of the fluxes? Are the patterns predictable and are they similar between the stations?

4) Do the porewater profiles reflect the fluxes? Are there differences in the porewater profiles between sites, between the Harbor and the Bay?

Sampling

Samples were taken in February, May, July, August, and October.

Two Harbor stations and three Massachusetts Bay statio were sampled every time. Three Mass Bay stations, one Harbor station and two stations in Cape Cod Bay were sampled 1-2 times over the course of the year.

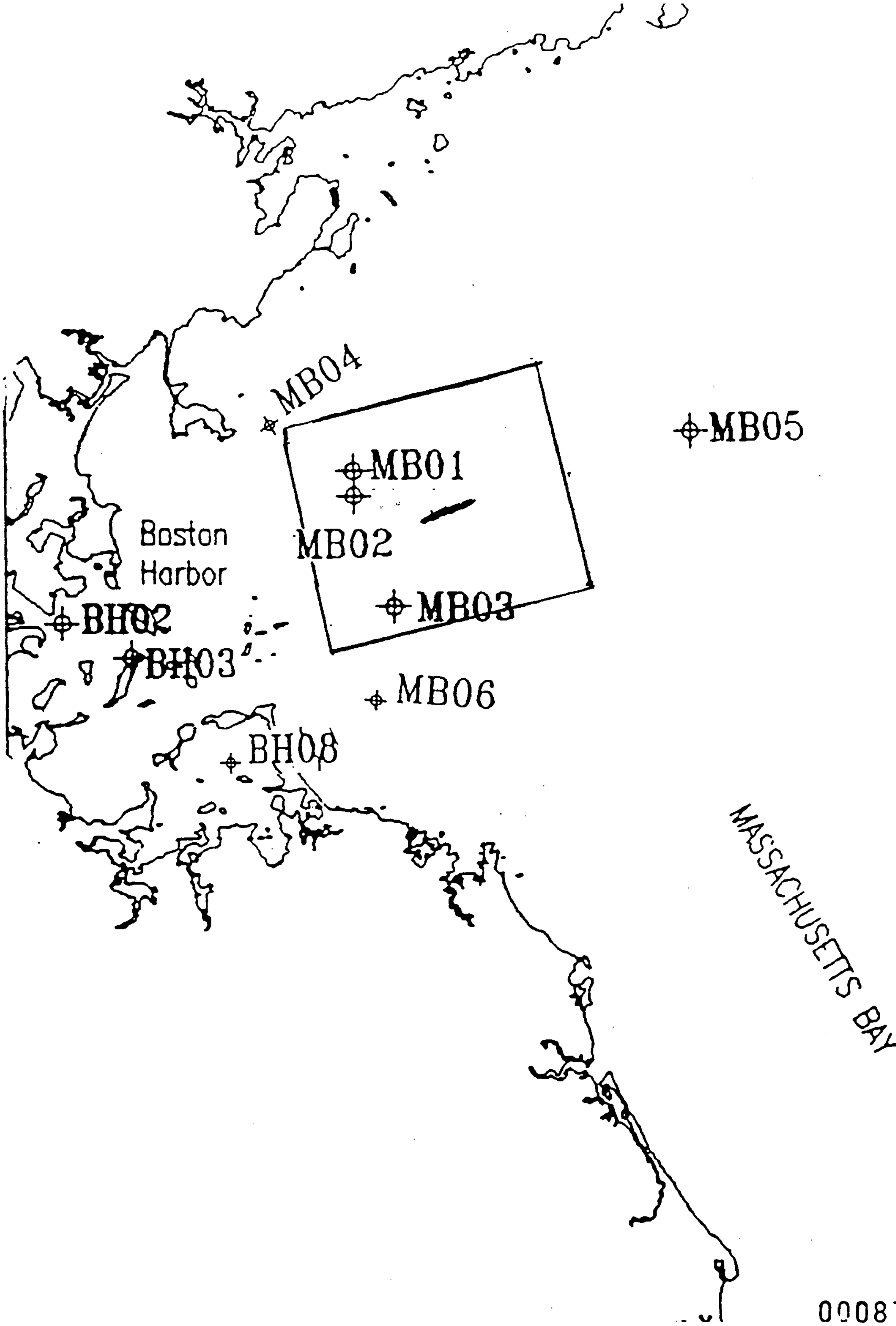
Methods

1) Intact sediment cores are taken by diver or by box coring Cores are brought back to the lab and placed in an incubat each night.

2) MBL measures benthic fluxes of oxygen, carbon dioxide, ammonium, nitrate, urea, phosphate and silicate.

3) MBL measures a complete set of porewater constituents (pH, alkalinity, the nutrients listed above, and sulfide) from one core. Eh is measured on a separate core.

4) URI makes denitrification measurements using a direct measurement of N2 flux .


MB04
MB05
MB01
MB02
Boston
Harbor
MB03
BH02
BH03
MB06
BH08
MASSACHUSETTS BAY

Variability

Oxygen - Mass Bay C.V. in Feb. were on the order of 30%. Most months they were even lower. We compared within to between box core variability and found that both were similar (30 vs. 28%). This implies that at a local scale the variability is being cause by feature on the scale of a few 10 cm such as large macrofauna burrows.

Harbor CV. for oxygen were similar or lower than in Mass Bay. All O2 data has very high r2's on regressions (typically .98 or above)

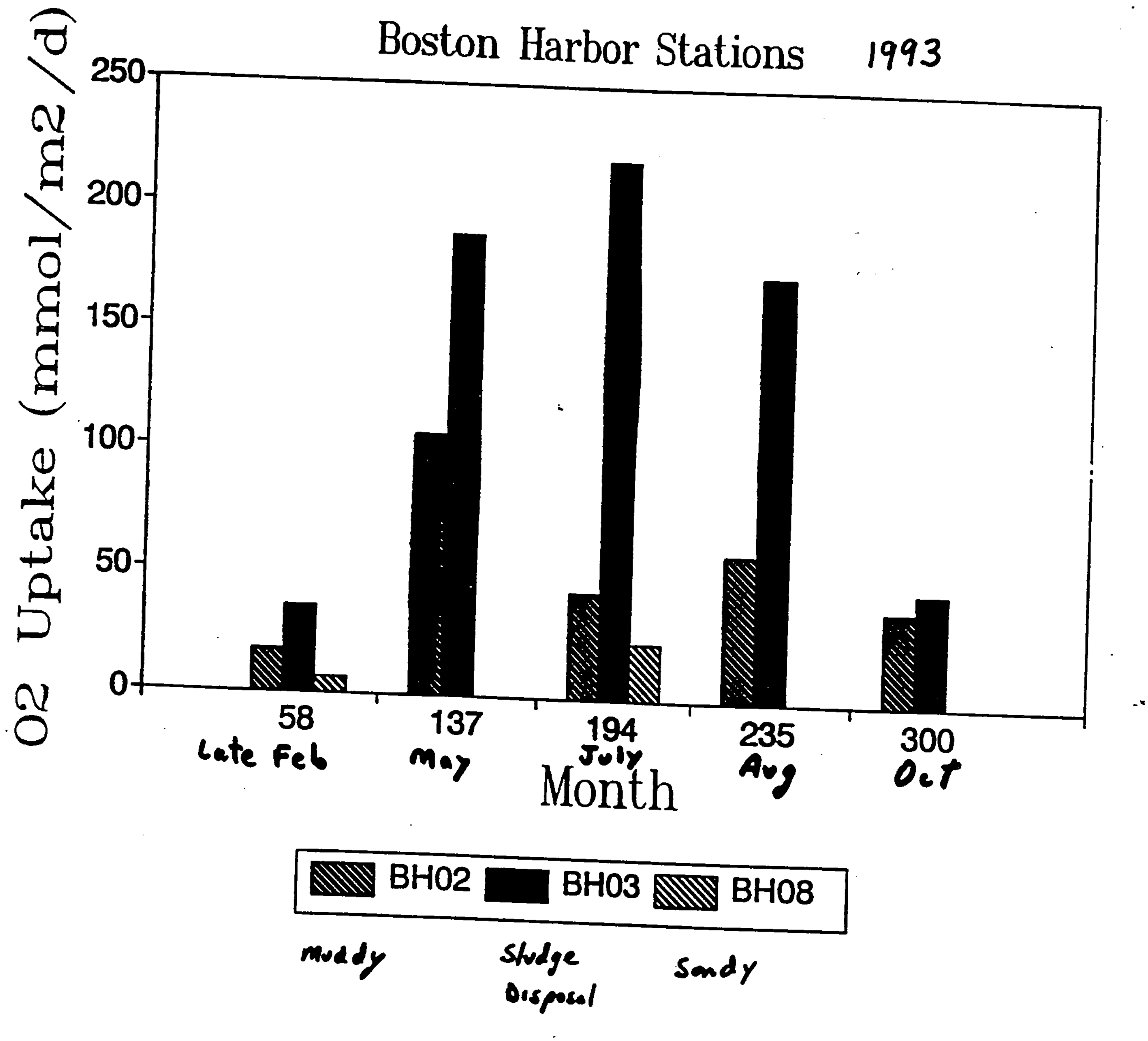
DIC - C.V. similar to O2.

Nitrogen - NH4 flux C.V. similar to or higher than O2 fluxes. r2's high. Nitrate fluxes tend to be lower than ammonium and can be more variable.

Phosphate - fluxes have the highest C.V. (can be > than 100%) within stations and the poorest regressions on individual cores.

Urea fluxes are low to non-detectable.

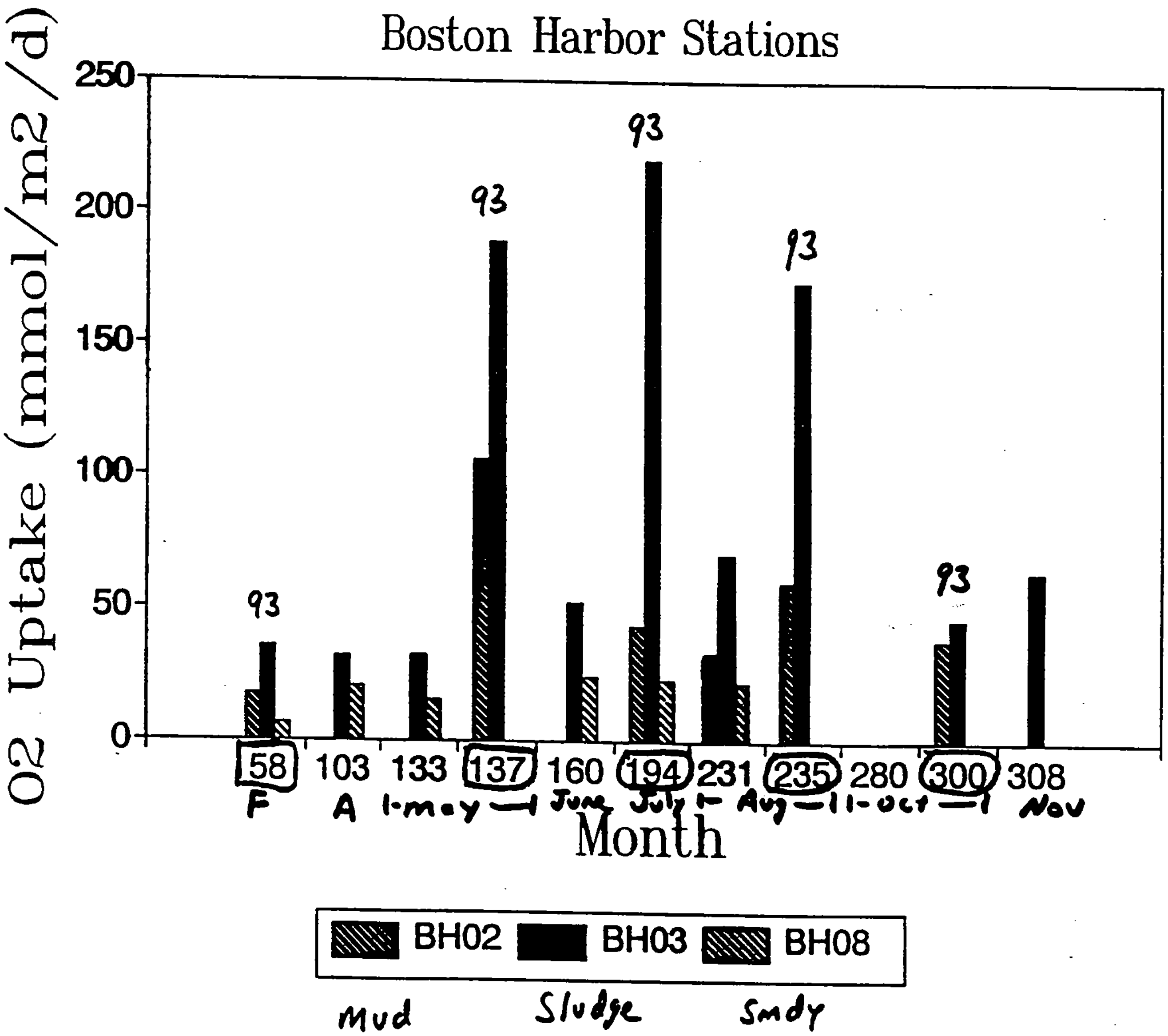
Si fluxes - high in Bay, low in Harbor. C.V.'s 20-30%.



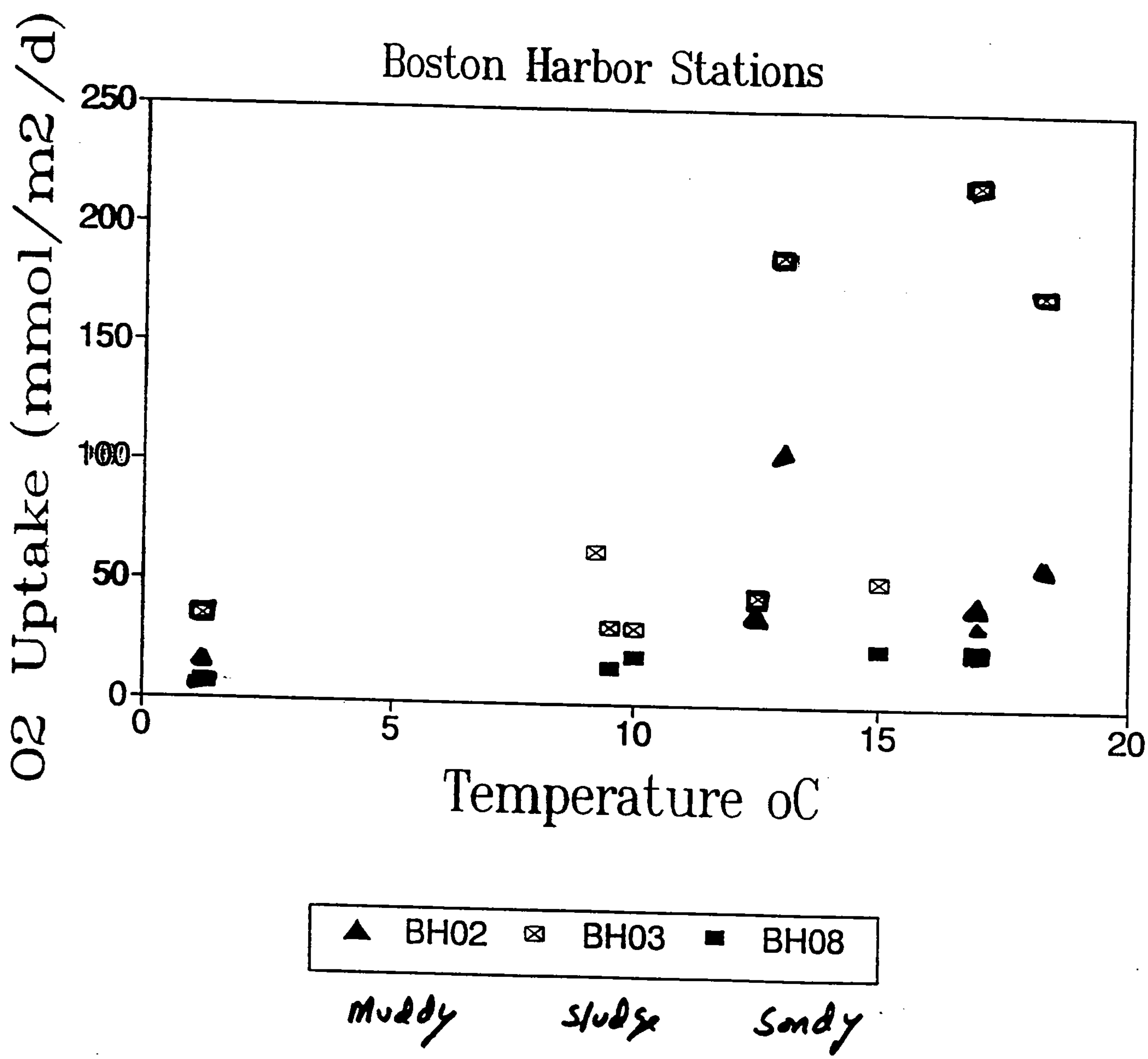
Boston Harbor Stations 1993
O2 Uptake (mmol/m2/d)
250
200
150
100
50
0
58
Late Feb
137
May
194
July
235
Aug
300
Oct
Month
BH02
BH03
BH08
Muddy
Sludge Disposal
Sandy

1992 + 1993 Different in Harbor

BH03 showed large changes



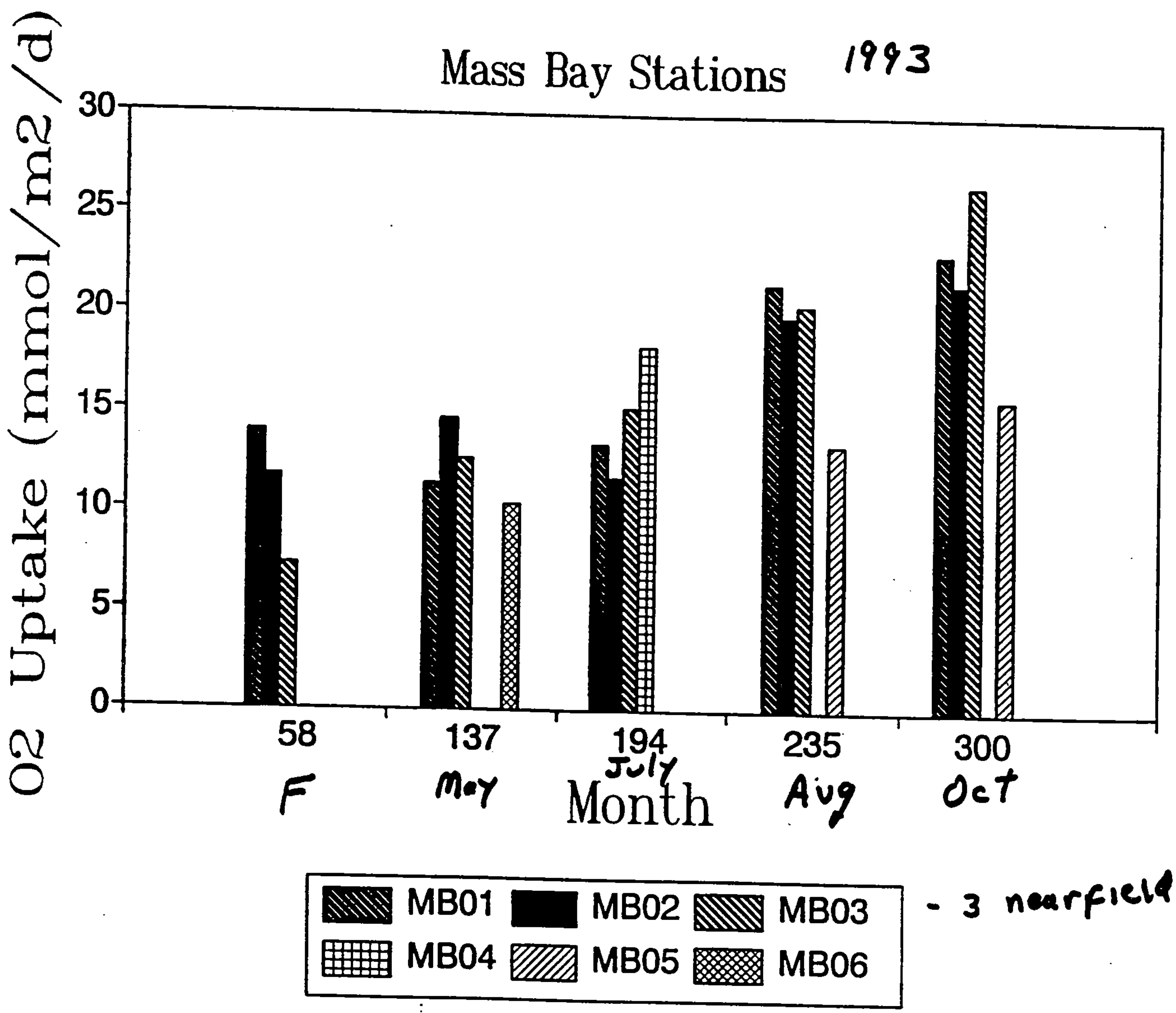
— 1993


Boston Harbor Stations
O2 Uptake (mmol/m2/d)
250
200
150
100
50
0
0
5
10
15
20
Temperature oC
BH02
BH03
BH08
Muddy
Sludge
Sandy

1993

Annual Average

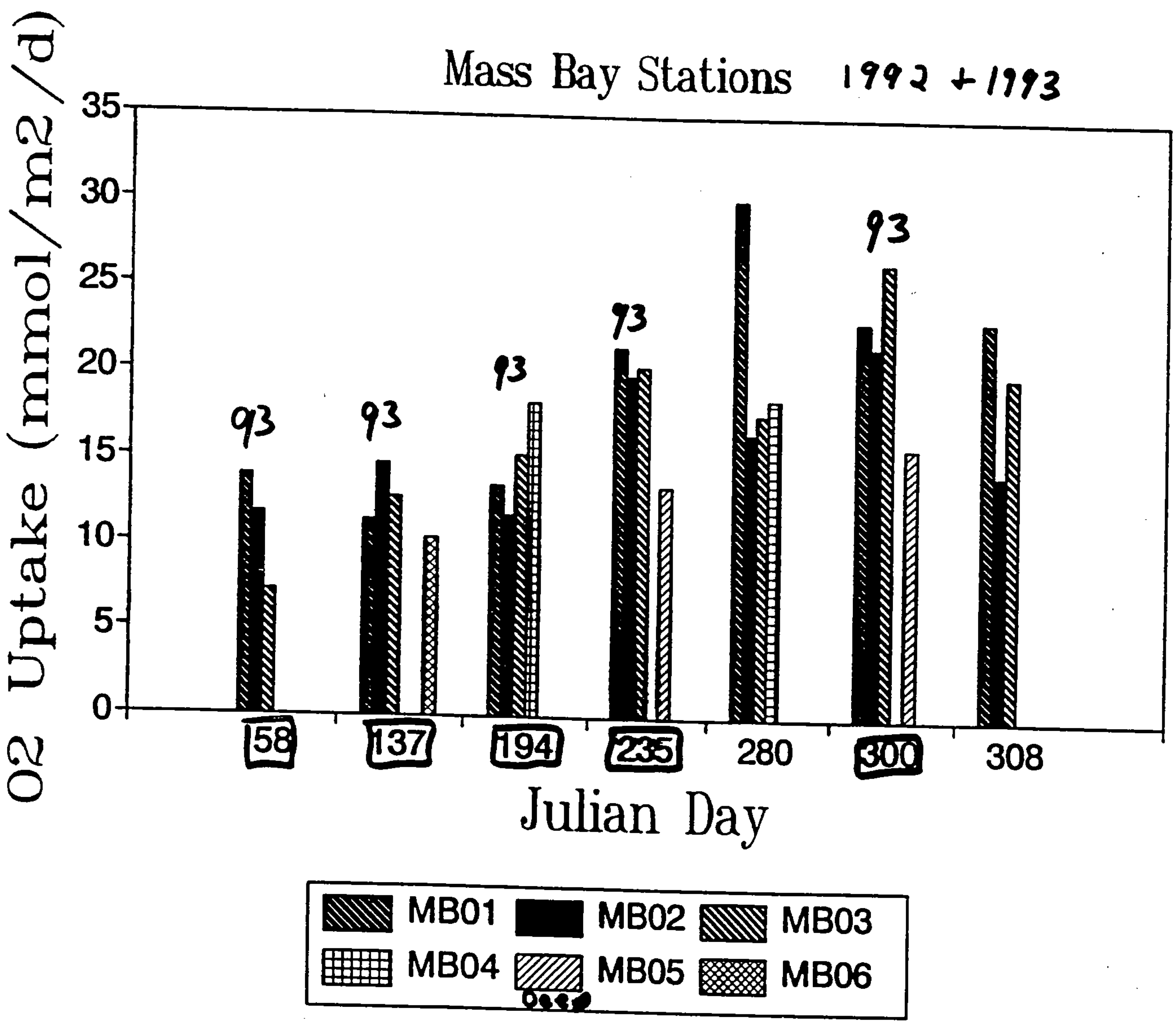
MB01	16.65	BH02	52.9
MB02	15.93	BH03	132.55
MB03	16.41		



MB stations quite similar

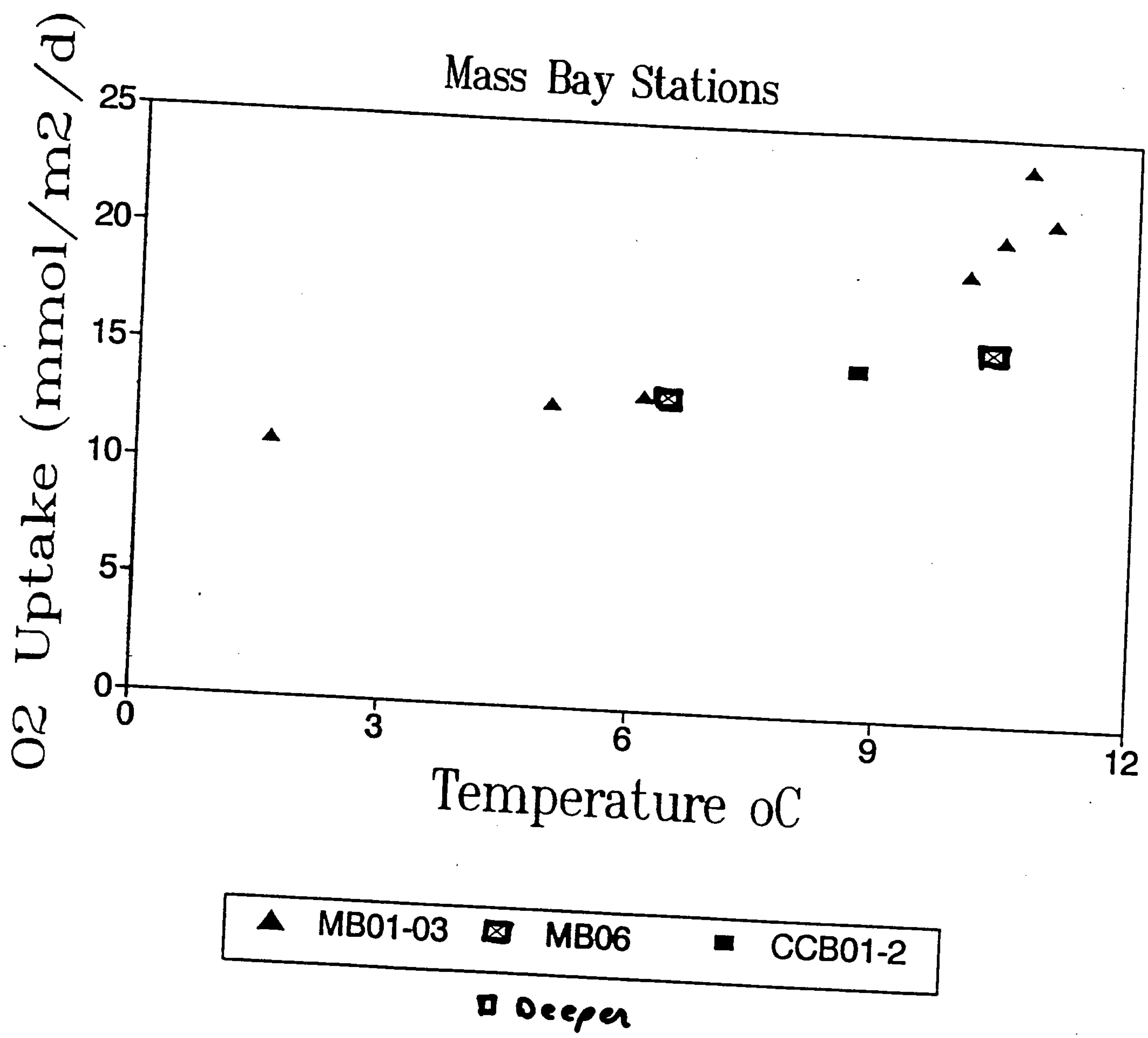
MBØ5 deeper + appears sig. lower

MB01 - MB03 Not diff over season

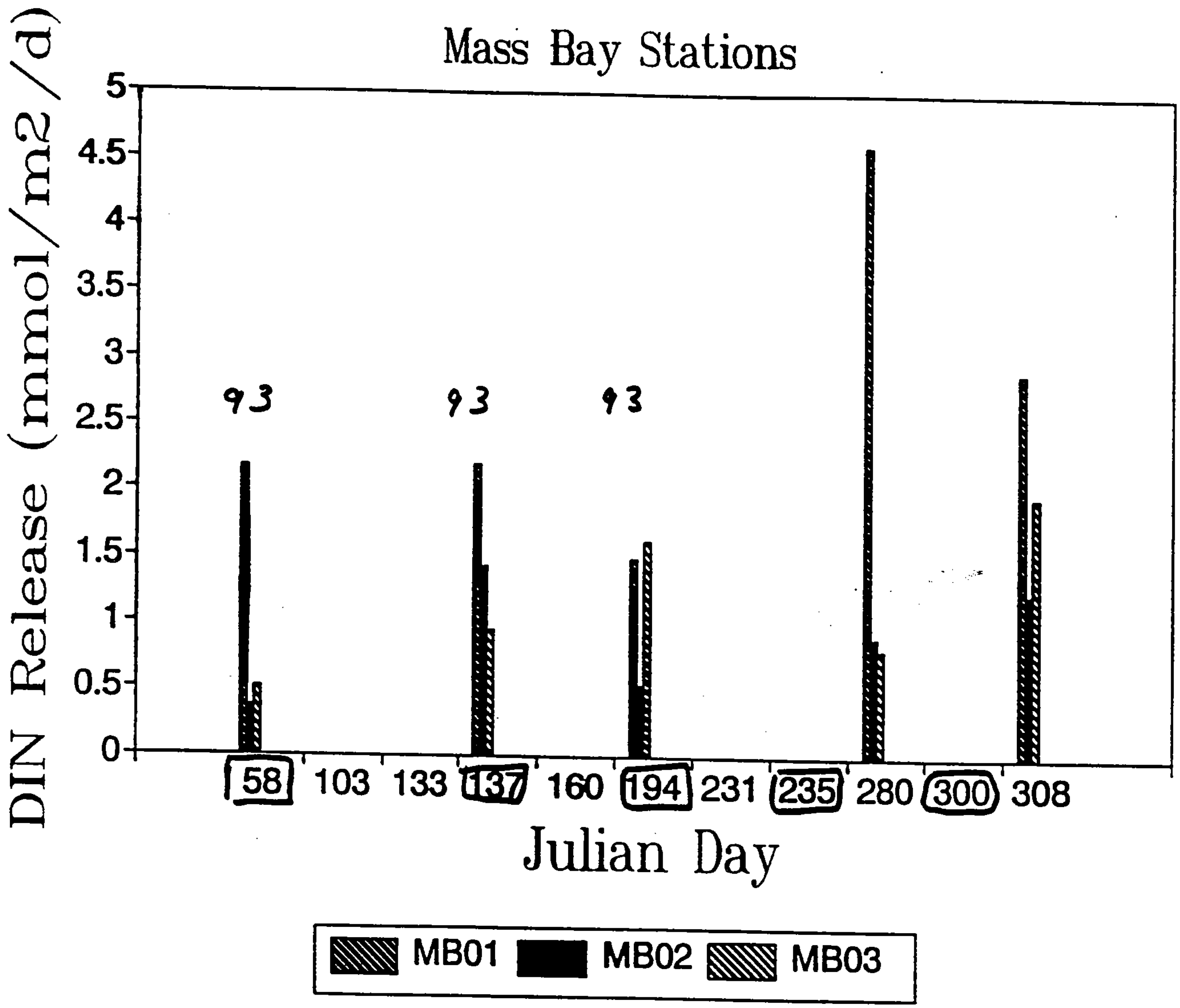


☐ 1993

So far looks like a consistent seasonal pattern



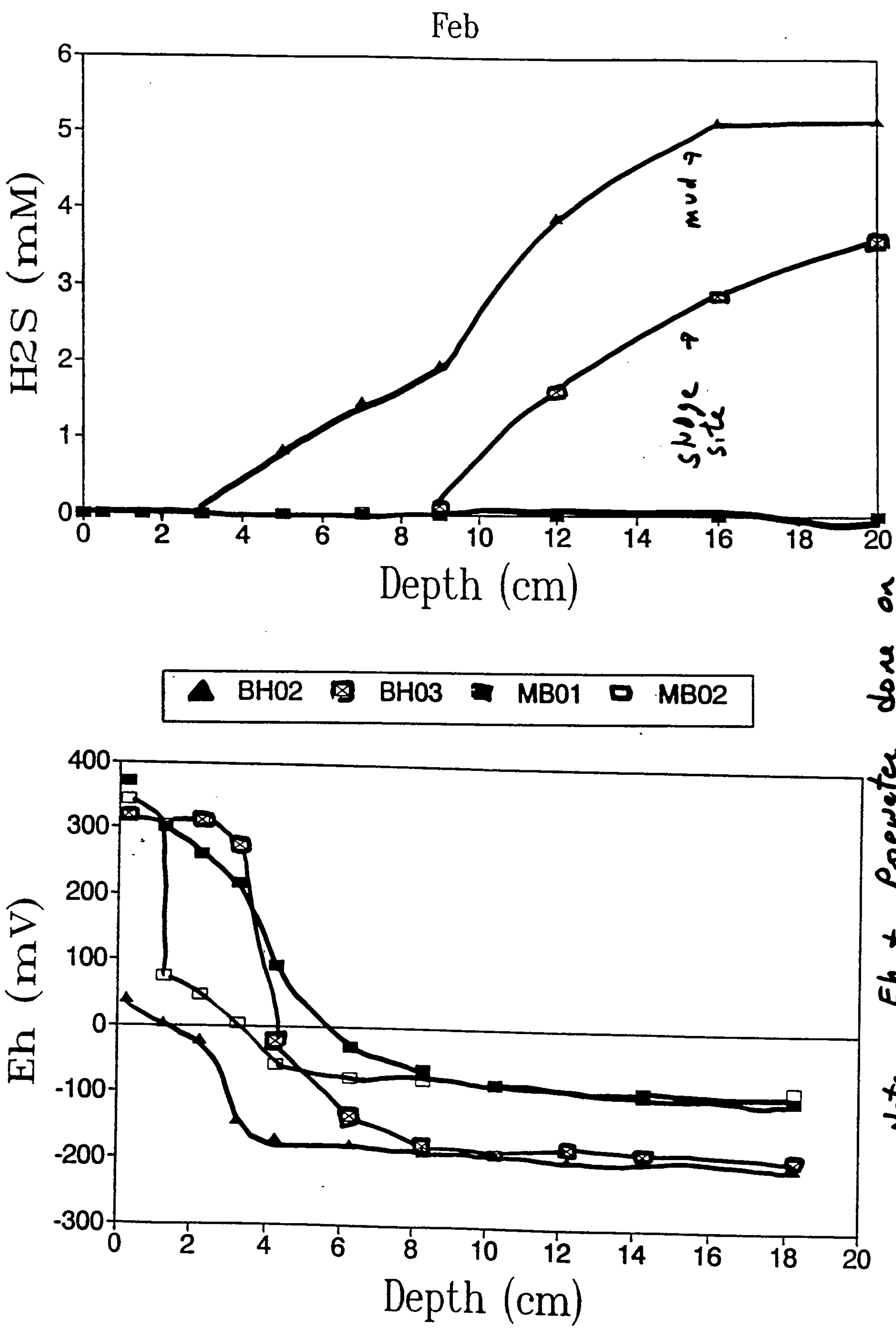
Temp + Depth both a factor?
Need to see if seasonal pattern only Temp driven



1993

DIN - more variable than O_2

No seasonal pattern



Note Eh + Porewater separate done on cores

APPENDIX C-6

B. NOWICKI
URI

SEDIMENT DENITRIFICATION

Boston Harbor

and

Massachusetts Bay

Barbara Nowicki

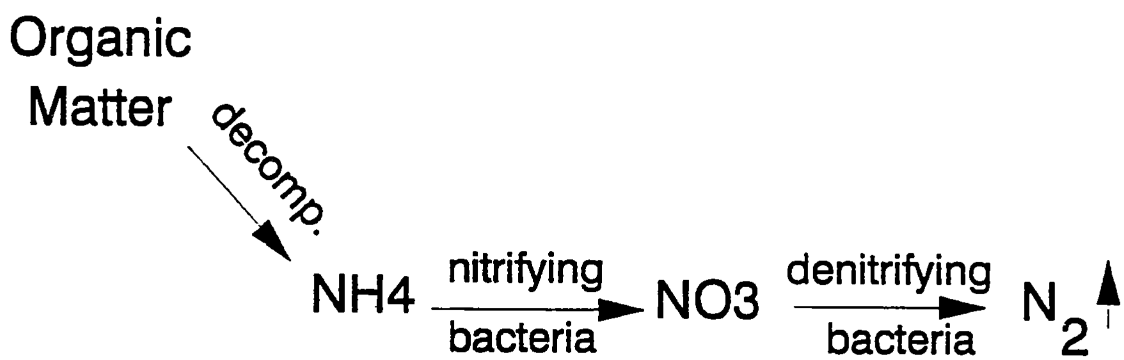
Edwin Requintina

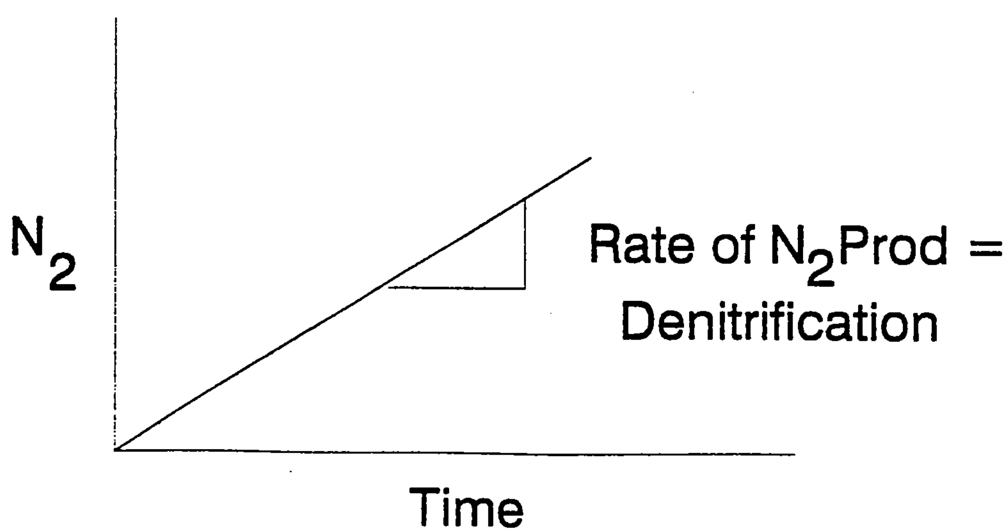
Donna Van Keuren

MTN13.DRW

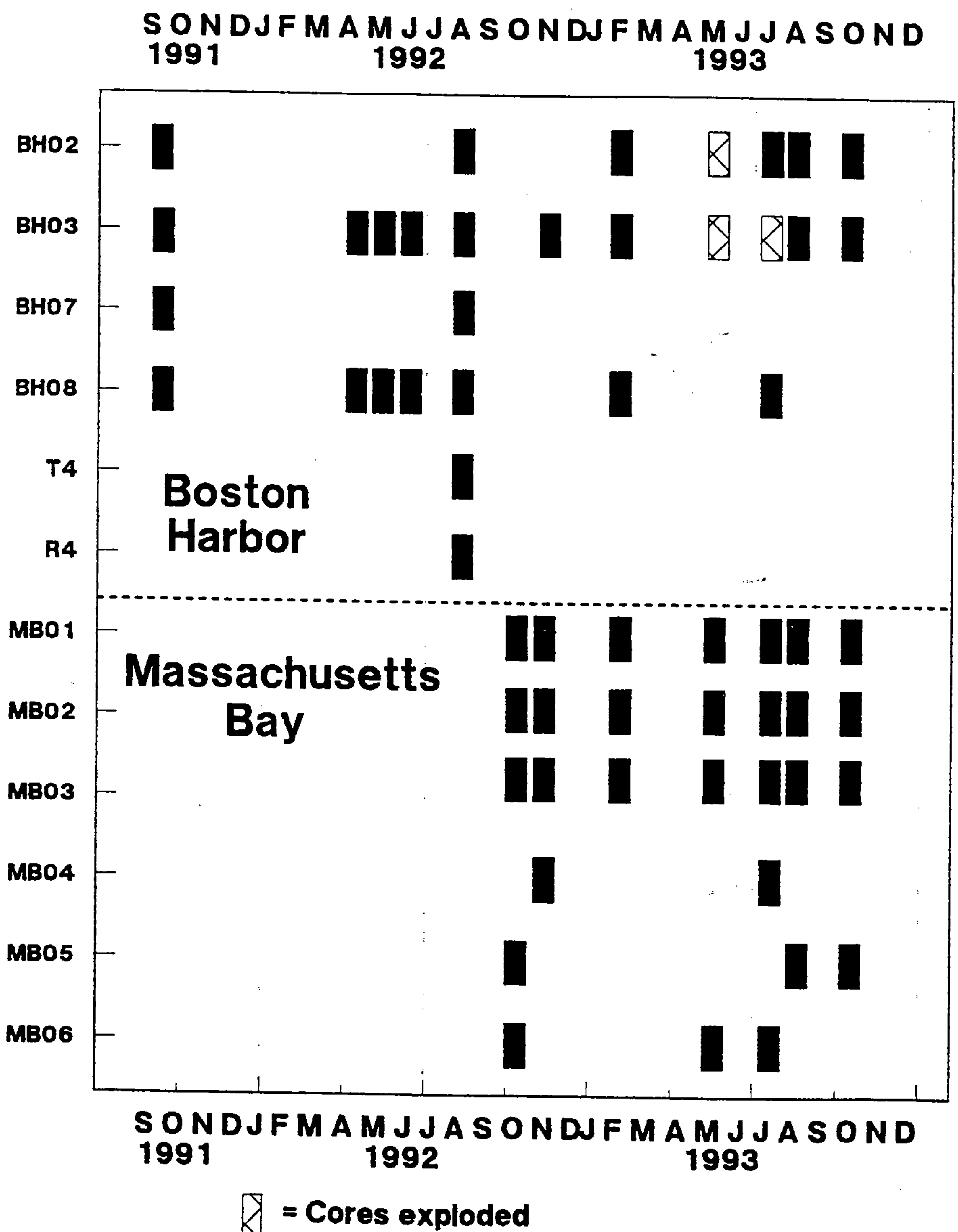
DENITRIFICATION IN BOSTON HARBOR

AND MASS BAY SEDIMENTS





Sampling Dates & Stations



MTN12.DRW

Summary of Results

- Mean rates were significantly lower in the Bay relative to the Harbor.
- No clear seasonal cycle.
- Correlation between denitrification rates and temperature in the Harbor. No temperature effect in the Bay.
- Considerable station-to-station and year-to-year variability.

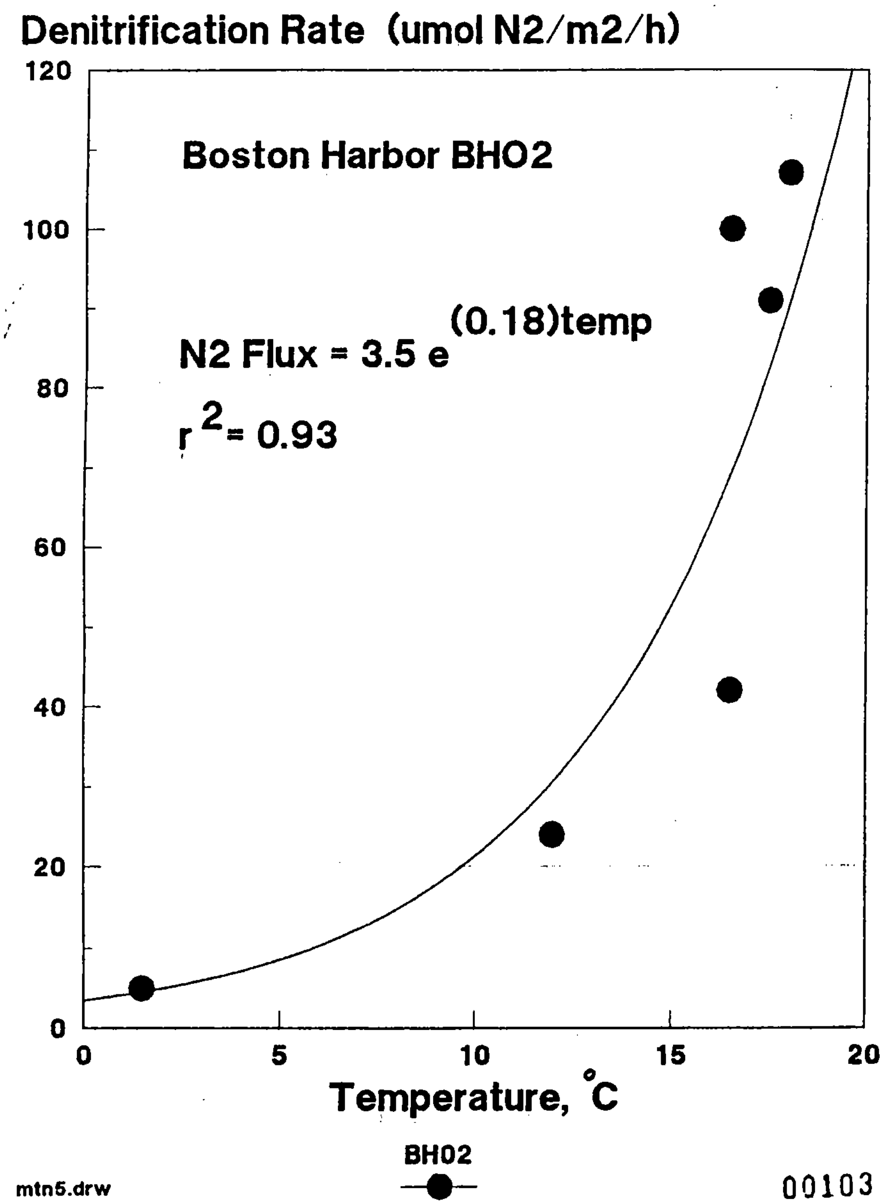
Sediment Denitrification

Summary of Observed Rates
(umol $N2\ m^{-2}h^{-1}$)

	Boston Harbor	Massachusetts Bay	Cape Cod Bay
Mean Rate	60	22	34
Range	ND - 206	ND - 54	33 - 35
n	26	29	2

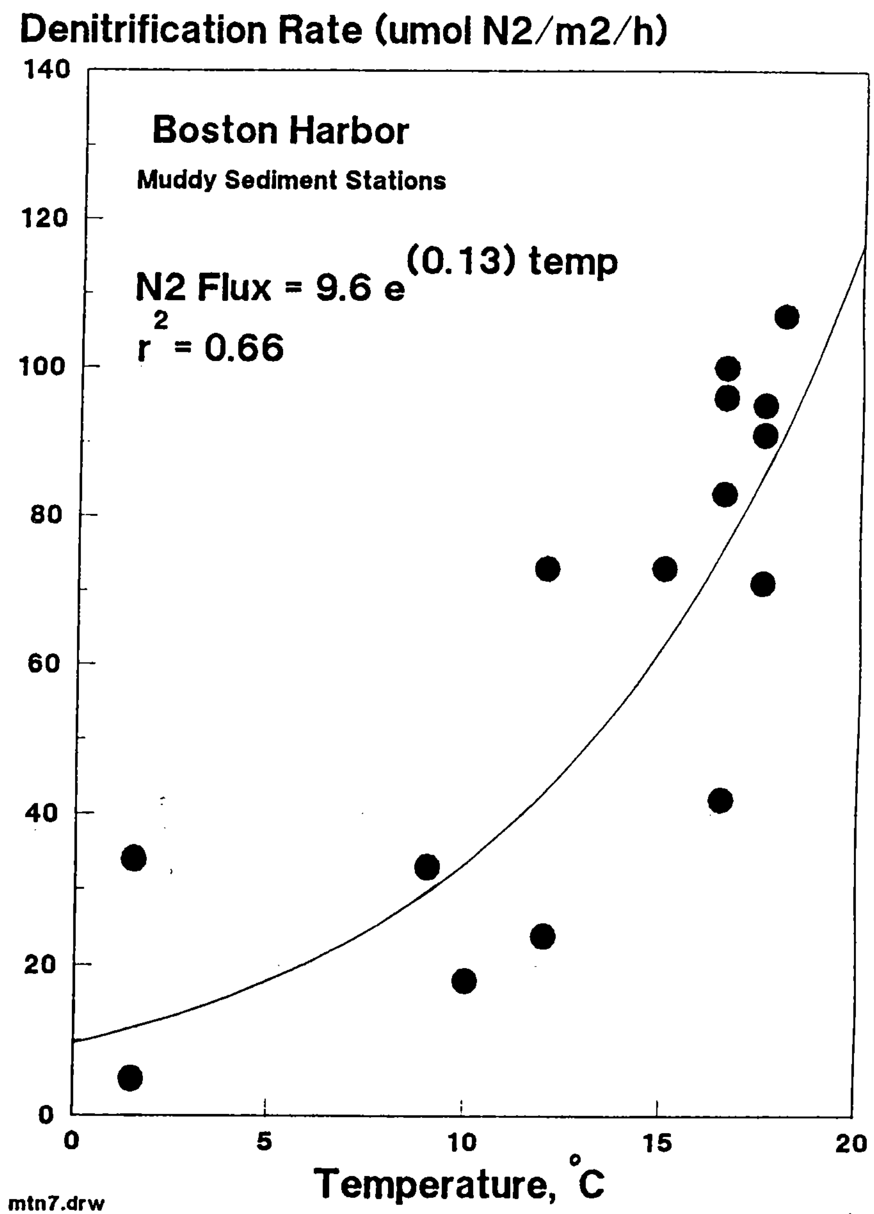
ND = < 5 umol $N2\ m^{-2}h^{-1}$

Jan. 1994 - B. Nowicki



mtn5.drw

00103

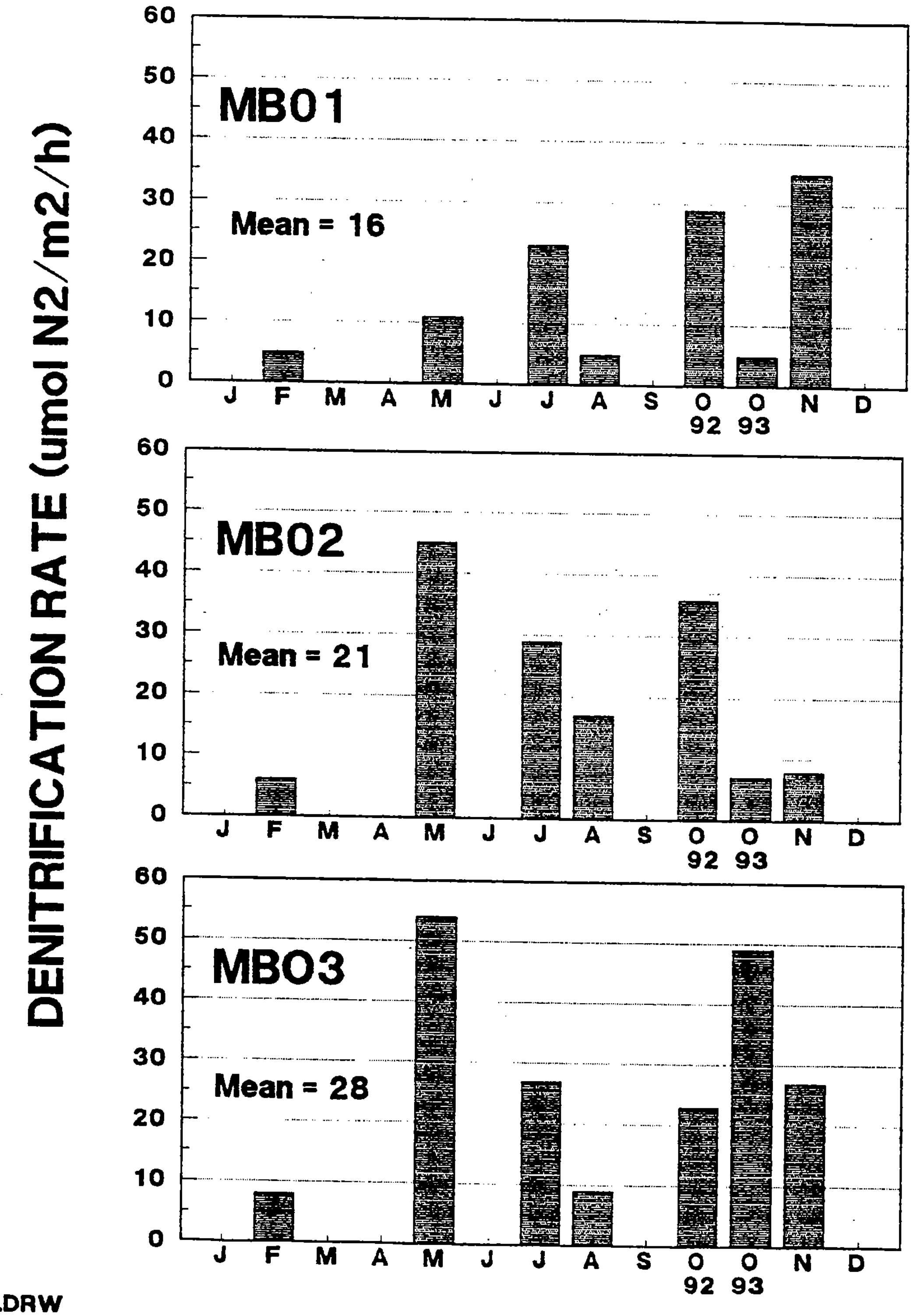


mtn7.drw

00104

SEASONAL CYCLE OF DENITRIFICATION

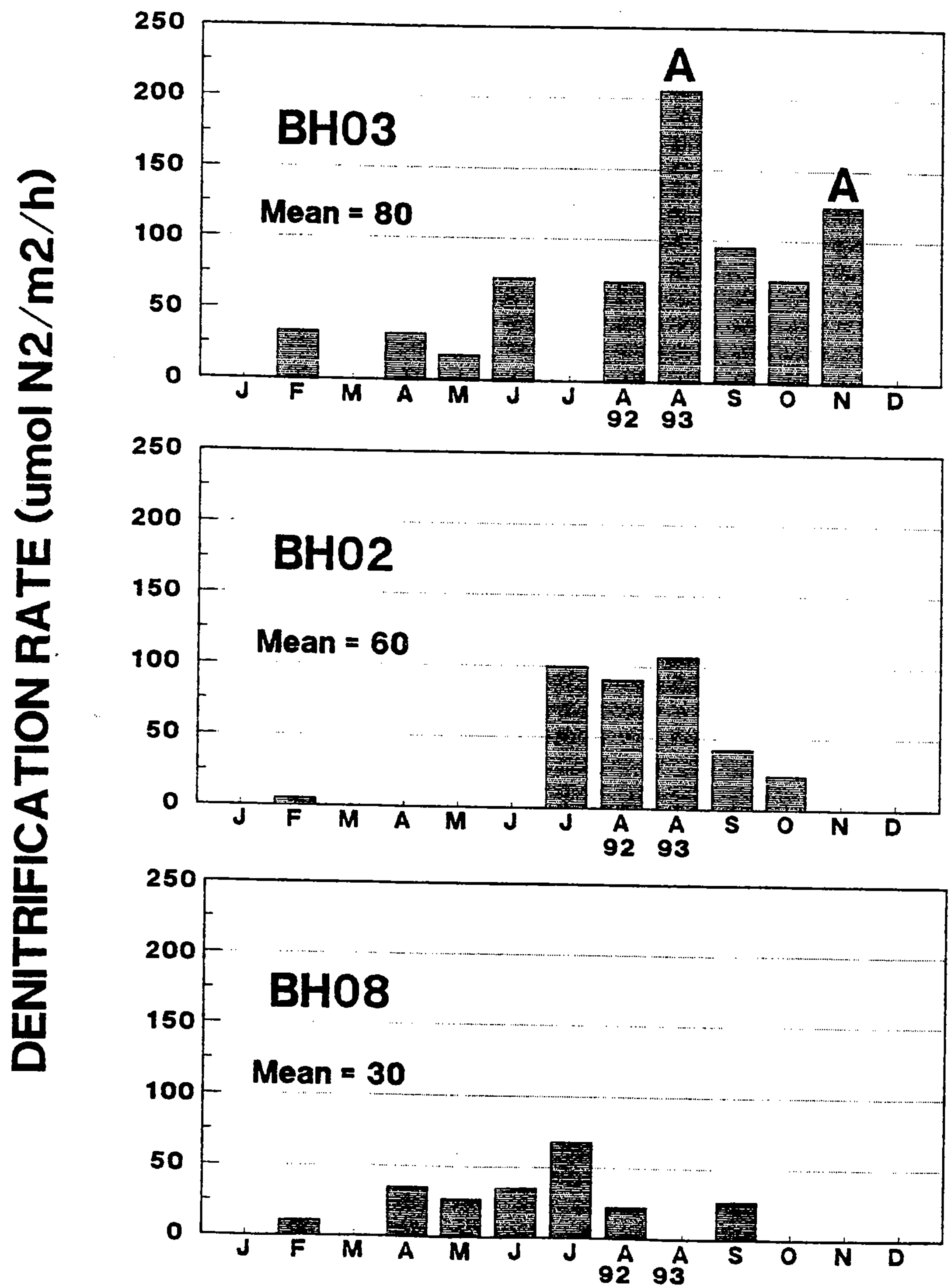
Massachusetts Bay



MTN2.DRW

Jan. 1994 - B. Nowicki

SEASONAL CYCLE OF DENITRIFICATION
Boston Harbor

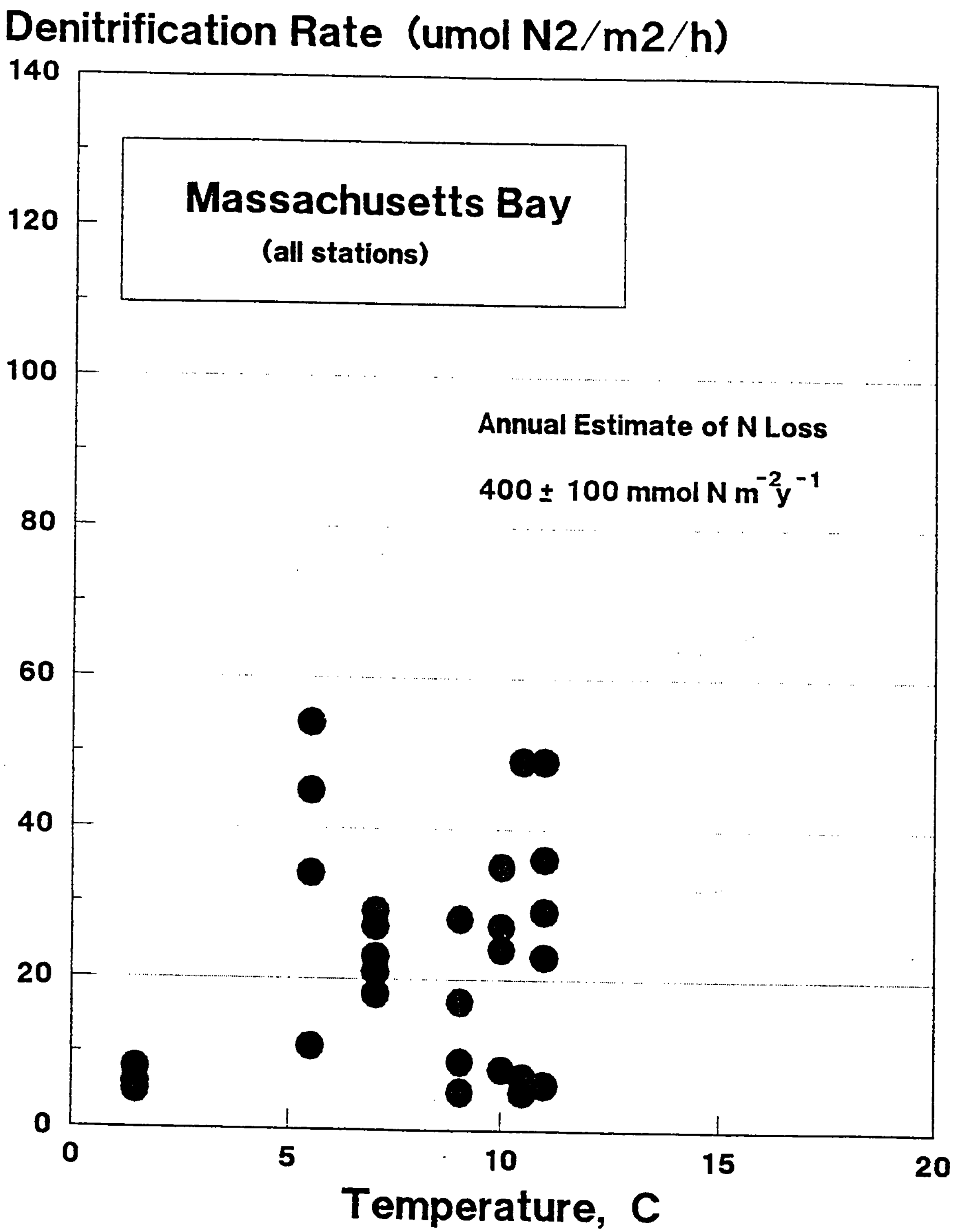


A = tremendous nos. of amphipods

MTN1.DRW

Jan.1994 - B. Nowicki

00106



mtn8.drw

Jan. 1994 - B. Nowicki

APPENDIX C-7

P. DOERING
URI

Primary Production Measurements For Monitoring Program

Monitor Productivity Because Nutrient Discharge From Outfall May Lead To Higher Production And Potential Eutrophication

Main Constraints

- A Number of Stations, geographically distant and sampled on different days
- Sampling only 6 times/year
- Desire standard protocol to allow comparisons across stations

Production vs Irradiance Response

- Provides standardized protocol comparable across stations sampled on different days.

- Parameters of the resulting P vs I curve correspond to physiological characteristics influenced by environmental factors.

- Factors include photoperiod, nutrient availability, temperature, phytoplankton community structure.

Production vs Irradiance Response Using Artificial Light

- Importance of these factors can be assessed through their relationship with P-I parameters.

- Model rate of water-column production.

I. Describe Productivity Measurements

II. Compare Data to Theoretical Limits

III. Relate P-I Curve Parameters to Environmental Factors - Relationship Between Increased Nutrients and Increased Productivity

Productivity Measurements

6 Cruises per Year

10 Stations: 6 Nearfield, 4 Farfield

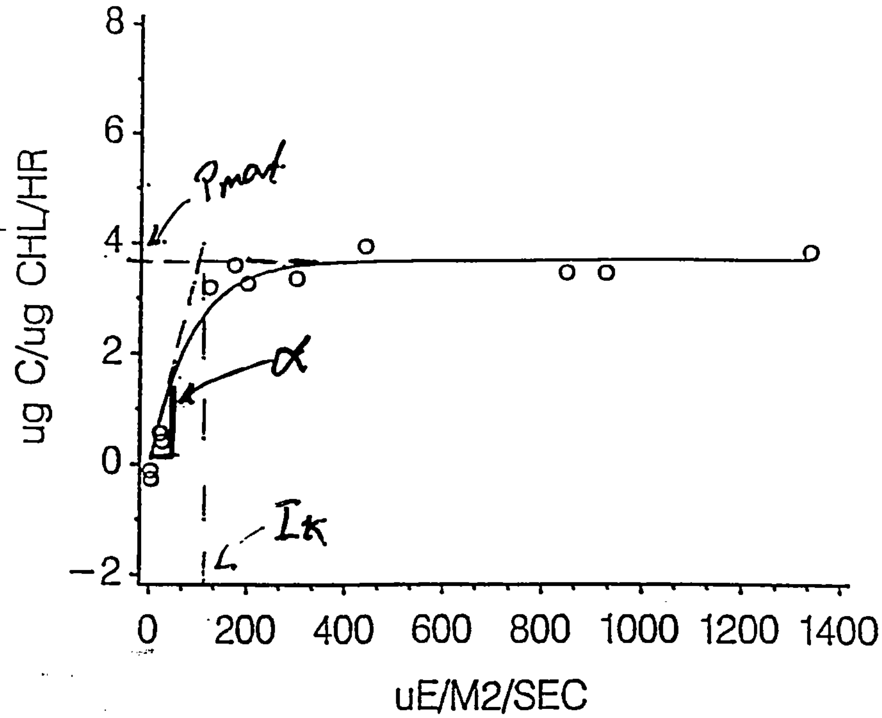
2 Depths: Surface and Chl Max

Incubate Samples at 12 Light Levels

On Deck, Temperature Controlled Incubator
Light Source: 250 Watt Metal Halide Lamps

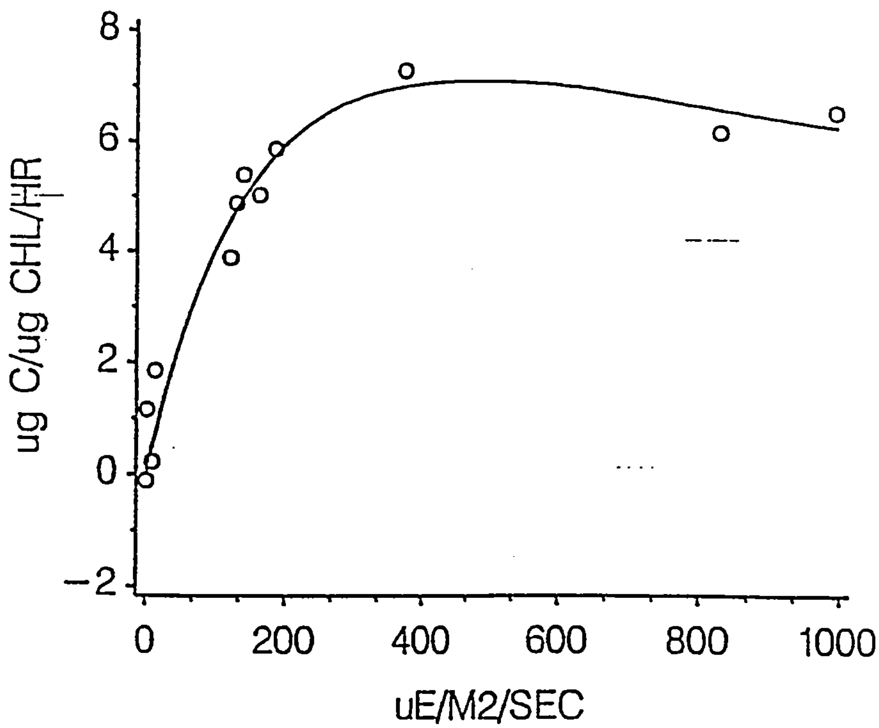
1992 Dissolved Oxygen
1993 C-14

STATION [illegible] CHLA MAXIMUM



NEGATIVE EXPONENTIAL MODEL, WEBB ET AL 1974
CRUISE NUMBER 9314 OCTOBER, 1993

STATION F13P CHLA MAXIMUM



NEGATIVE EXPONENTIAL MODEL WITH INHIBITION PLATT ET AL, 1980
CRUISE NUMBER 9314 OCTOBER, 1993

P vs I Models

•Hyperbolic Tangent Function (Jassby & Platt, 1976)

$$P=P_{max}\tanh(\alpha I/P_{max})$$

•Negative Exponential (Webb et al., 1974)

$$P=P_{max}(1-\exp(-\alpha I/P_{max}))$$

•Negative Exponential w/Photoinhibition (Platt et al., 1980)

$$P=P_s(1-\exp(-\alpha I/P_s)\ (\exp(-BI/P_s))$$

where

$$P_{max}=P_s\left(\frac{\alpha}{\alpha+\beta}\right)\left(\frac{\beta}{\alpha+\beta}\right)^{(B/\alpha)}$$

Theoretical Limits

Pmax ~25μg C(μg Chl)$^{-1}$ hr^{-1}
(Falkowski, 1981)
PQ=1.2
~78 μg O_2 (μg Chl)$^{-1}$ hr^{-1}

Alpha ~0.10 μg C(μg Chl)$^{-1}$ (μE/m^2/sec)$^{-1}$ hr^{-1}
(Bannister, 1974; Platt & Jassby, 1976)
PQ=1.2
~0.33 μg O_2 (μg Chl)$^{-2}$ (μE/m^2/sec)$^{-1}$ hr^{-1}

DISSOLVED OXYGEN PRODUCTIVITY 1992
ALL STATIONS

FREQUENCY OF PMAX

PMAX MIDPOINT		FREQ	CUM PERCENT
5	*	2	2.08
15	****************	32	35.42
25	**************	27	63.54
35	******	12	76.04
45	******	12	88.54
55	*	2	90.62
65	*	2	92.71
75	**	3	95.83
85		0	95.83
95		0	95.83
105	*	1	96.87
115	*	1	97.92
125		0	97.92
135		0	97.92
145		0	97.92
155	*	1	98.96
165		0	98.96
175		0	98.96
185	*	1	100.00
195		0	100.00

10 20 30 40 50

FREQUENCY

DISSOLVED OXYGEN PRODUCTIVITY 1992
ALL STATIONS

FREQUENCY OF ALPHA

```
 ALPHA                                                              CUM
MIDPOINT                                                   FREQ   PERCENT
          |
  0.0     |*********                                         23     23.96
          |
  0.2     |****************                                  39     64.58
          |
  0.4     |*****                                             13     78.12
          |
  0.6     |**                                                 5     83.33
          |
  0.8     |*                                                  3     86.46
          |
  1.0     |**                                                 4     90.62
          |
  1.2     |*                                                  2     92.71
          |
  1.6     |*                                                  2     94.79
          |
  2.2     |                                                   1     95.83
          |
  2.4     |                                                   1     96.87
          |
  2.8     |                                                   1     97.92
          |
  3.2     |                                                   1     98.96
          |
  9.8     |                                                   1    100.00
          ----+---+---+---+---+---+---+---+---+
             10  20  30  40  50  60  70  80  90

                    FREQUENCY
```

10

C-14 PRODUCTIVITY 1993

FREQUENCY OF PMAX

```
  PMAX                                                              CUM
MIDPOINT                                                   FREQ   PERCENT
          |
  2.5     |***********                                       22     18.33
          |
  7.5     |*****************************                     58     66.67
          |
  12.5    |*************                                     25     87.50
          |
  17.5    |*****                                              9     95.00
          |
  27.5    |**                                                 4     98.33
          |
  32.5    |*                                                  1     99.17
          |
  42.5    |*                                                  1    100.00
          -----+----+----+----+----+----+----+
              10   20   30   40   50   60   70

                    FREQUENCY
```

C-14 PRODUCTIVITY 1993

FREQUENCY OF ALPHA

```
 ALPHA                                                          CUM
MIDPOINT                                                FREQ  PERCENT
          |
  0.01    |***                                             3     2.50
          |
  0.03    |***********************                        23    21.67
          |
  0.05    |******************************                 30    46.67
          |
  0.07    |**************************                     26    68.33
          |
  0.09    |*****************                              17    82.50
          |
  0.11    |******                                          6    87.50
          |
  0.13    |**                                              2    89.17
          |
  0.15    |***                                             3    91.67
          |
  0.19    |***                                             3    94.17
          |
  0.23    |**                                              2    95.83
          |
  0.35    |*                                               1    96.67
          |
  0.43    |**                                              2    98.33
          |
  0.65    |*                                               1    99.17
          |
  2.61    |*                                               1   100.00
          -----+----+----+----+----+----+
               5   10   15   20   25   30

                     FREQUENCY
```

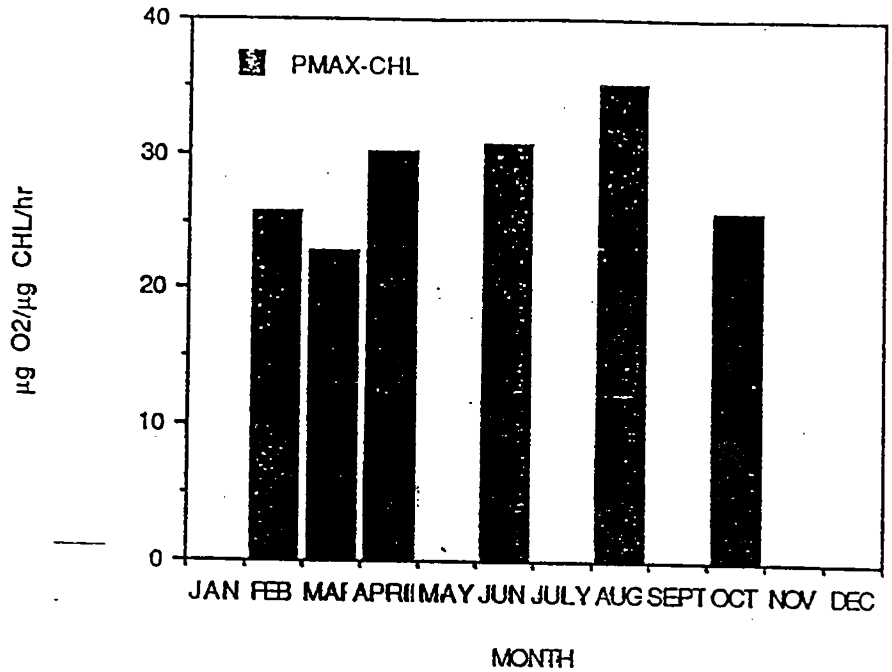
Dissolved Oxygen 1992

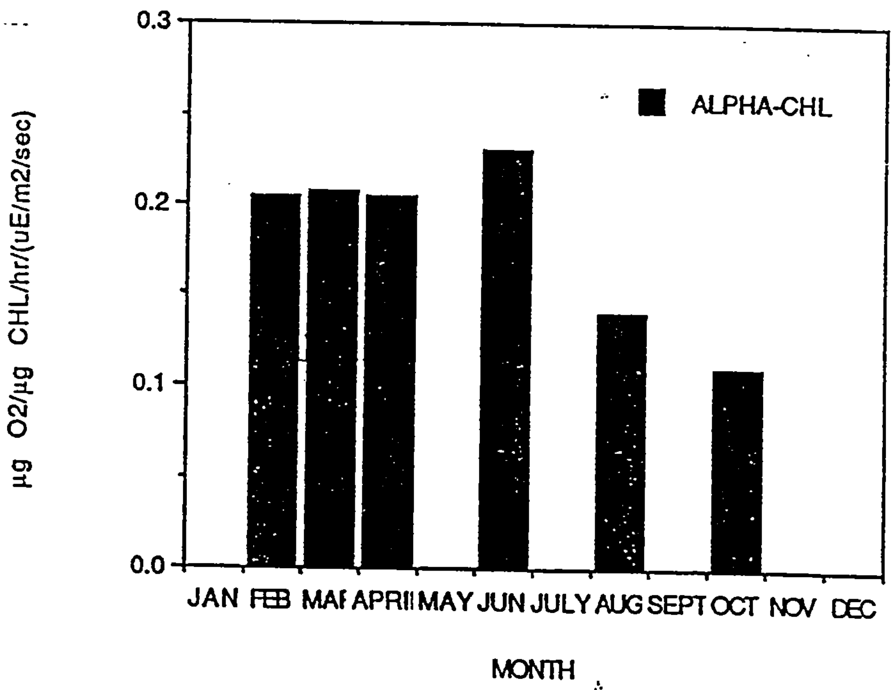
	CHL	SUR	$P>\lvert T\rvert$
I_k	202±192	261±232	0.24
Alpha-CHL	0.18±0.12	0.17±0.09	0.64
P_{max}-CHL	23.3±12.7	33.1±16.0	0.002

C-14 1993

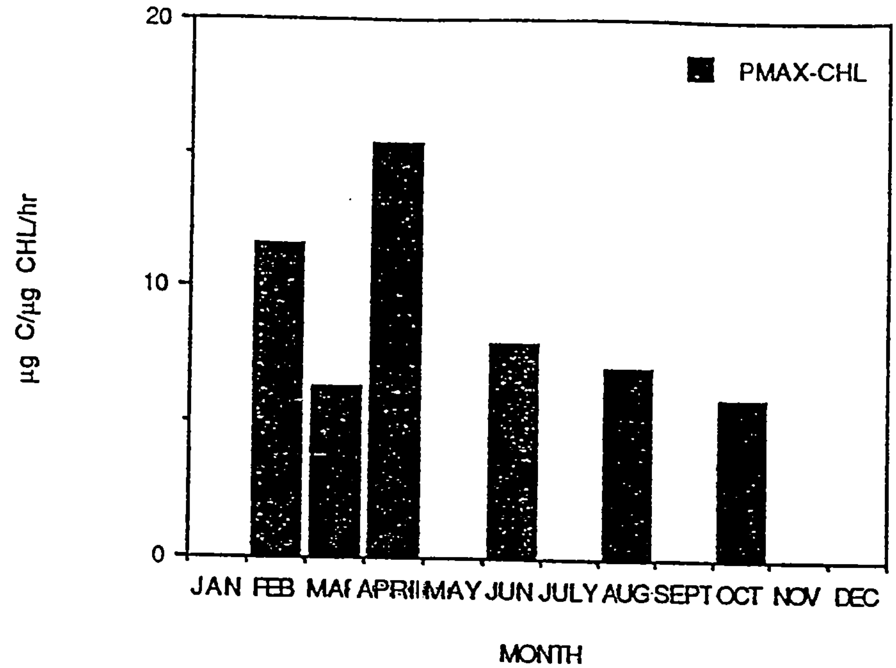
	CHL	SUR	$P>\lvert T\rvert$
I_k	124±51	172±137	0.02
Alpha-CHL	0.064±0.028	0.057±0.023	0.14
P_{max}-CHL	8.53±5.47	9.40±4.81	0.36

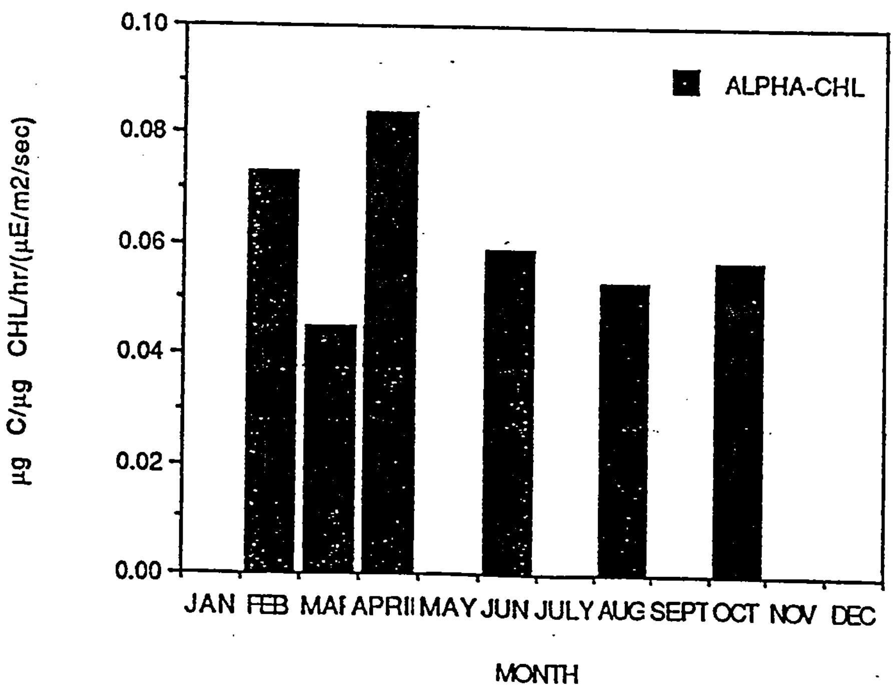
DISSOLVED OXYGEN PRODUCTIVITY 1992





C-14 PRODUCTIVITY 1993





Detectable Change in P_{max} Based on SNK Critical Range

Dissolved Oxygen 1992

Between Cruises	16	(60%)
Between Stations	23	(87%)
Between Depths	6	(21%)

C-14 1993

Between Cruises	3.7	(40%)
Between Stations	7.0	(78%)
Between Depths	1.9	(21%)

STEPWISE REGRESSION VARIABLES

Temperature
Chlorophyll *a*
Phytoplankton Cells
DIN
NO_2+NO_3
NO_3
NO_2
NH_4
PO_4
SiO_4
TDN
TDP

STEPWISE REGRESSION SUMMARY
DISSOLVED OXYGEN 1992

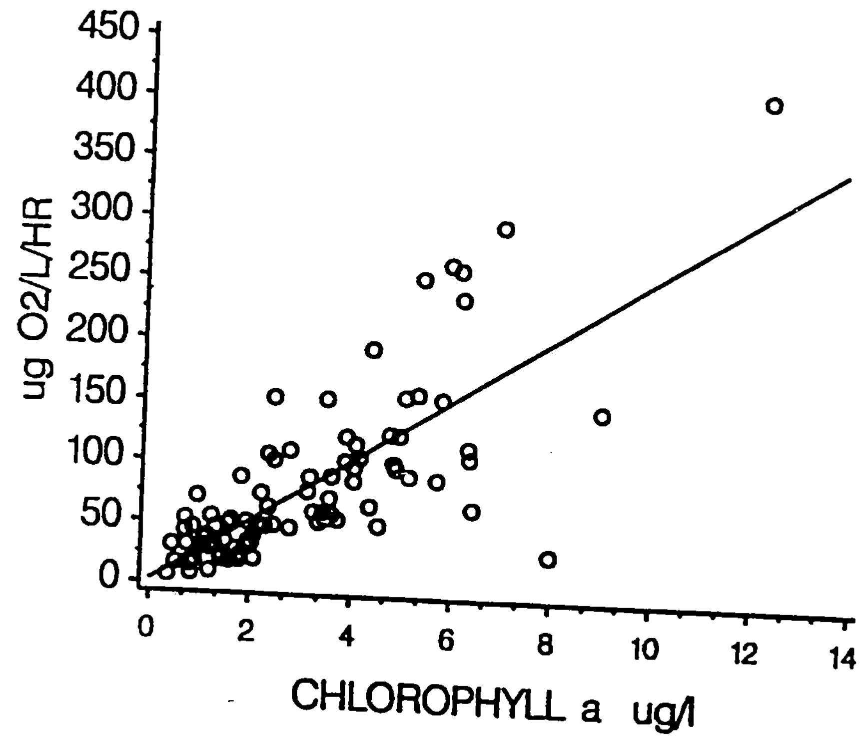
	Variable*	Coef. Sign	Partial R_2
P_{max}-CHL	Temp	+	0.15
	CHL	-	0.10
	TDN	+	0.04
	PO_4	-	0.05
			0.34
P_{max}-V	CHL	+	0.58
	Temp	+	0.07
	TDN	+	0.06
	PO_4	-	0.04
	SiO_4	-	0.01
	Phycel	+	0.01
			0.79
P_{max}-C	Temp	+	0.32
	Chl	+	0.17
	NOX	+	0.03
			0.52

*$p<0.05$ for all variables

STEPWISE REGRESSION SUMMARY
C-14 1993

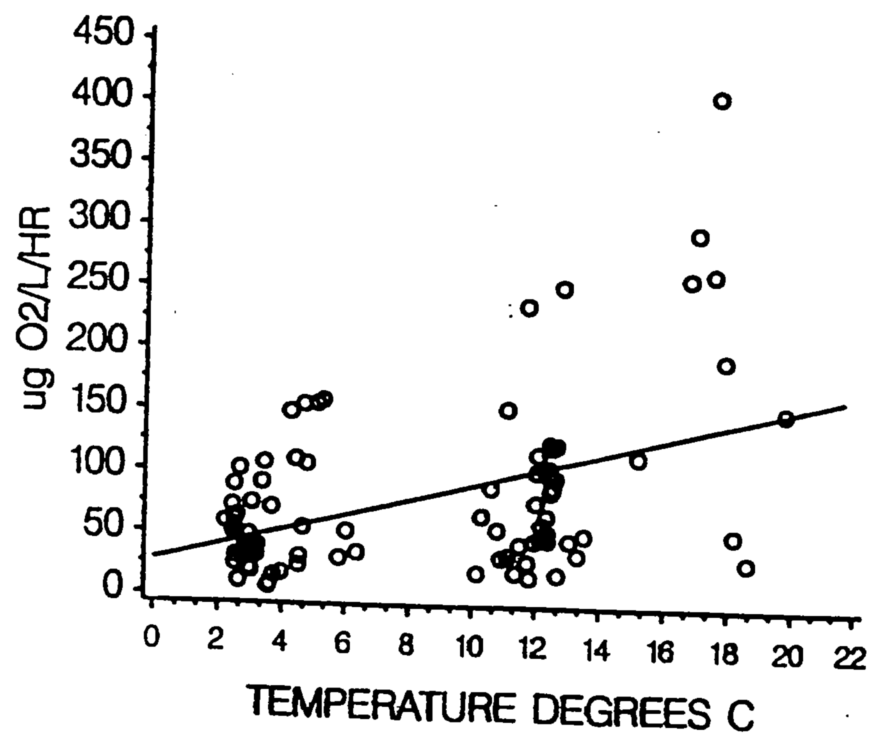
	Variable	Coef. Sign	Partial R_2
P_{max}-CHL	NO_2	-	0.06
	CHL	-	0.03
	Phycel	+	0.05
	Temp	-	0.10
	TDN	-	0.19
			0.43
P_{max}-V	CHL	+	0.70
	Phycel	+	0.02
	Temp	-	0.02
	TDN	-	0.03
	NO_2	-	0.01
			0.78
P_{max}-C	Phycel	+	0.59
	TDN	-	0.13
	Temp	-	0.02
	NO_3	-	0.01
			0.75

DISSOLVED OXYGEN PRODUCTIVITY 1992



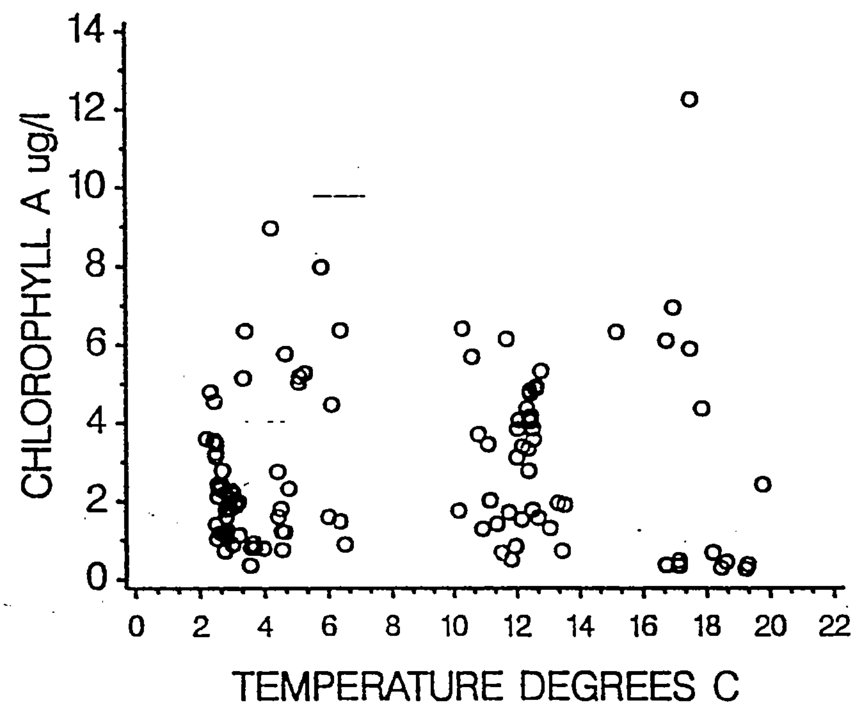
PMAX-V BY CHL

DISSOLVED OXYGEN PRODUCTIVITY 1992



PMAX-V BY TEMP

CHLOROPHYLL AND TEMPERATURE 1992



Conclusions

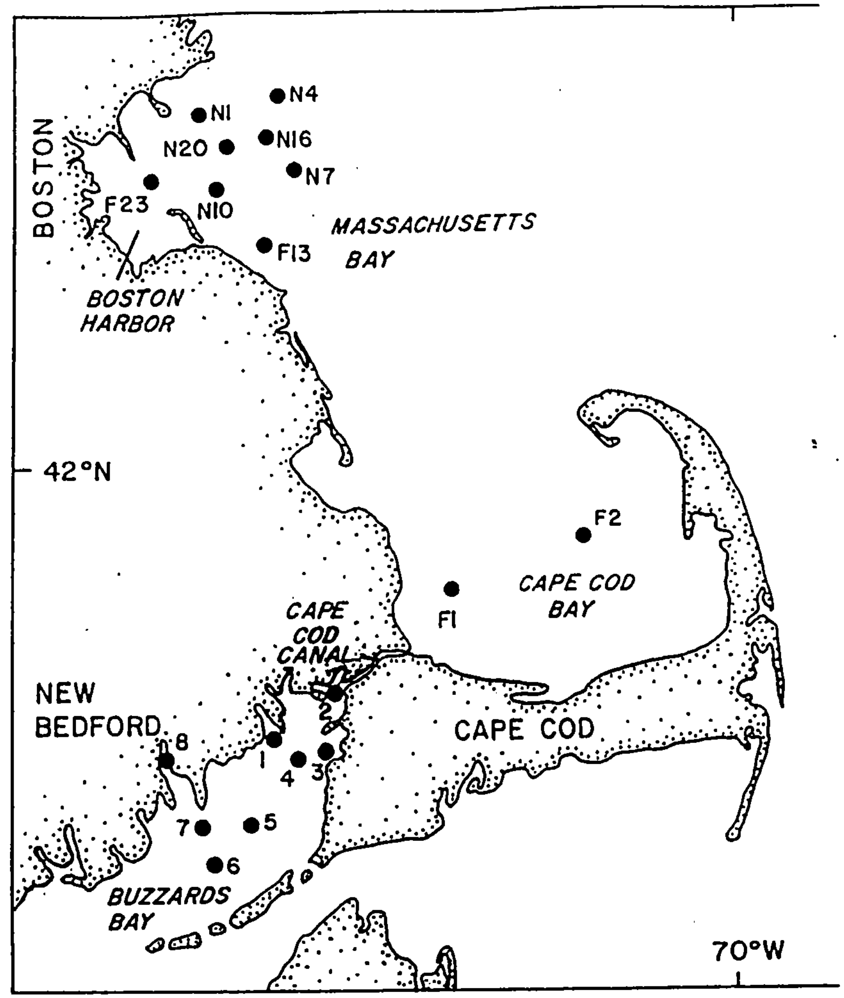
P_{max}-V in Massachusetts Bay is primarily a function of phytoplankton biomass and temperature.

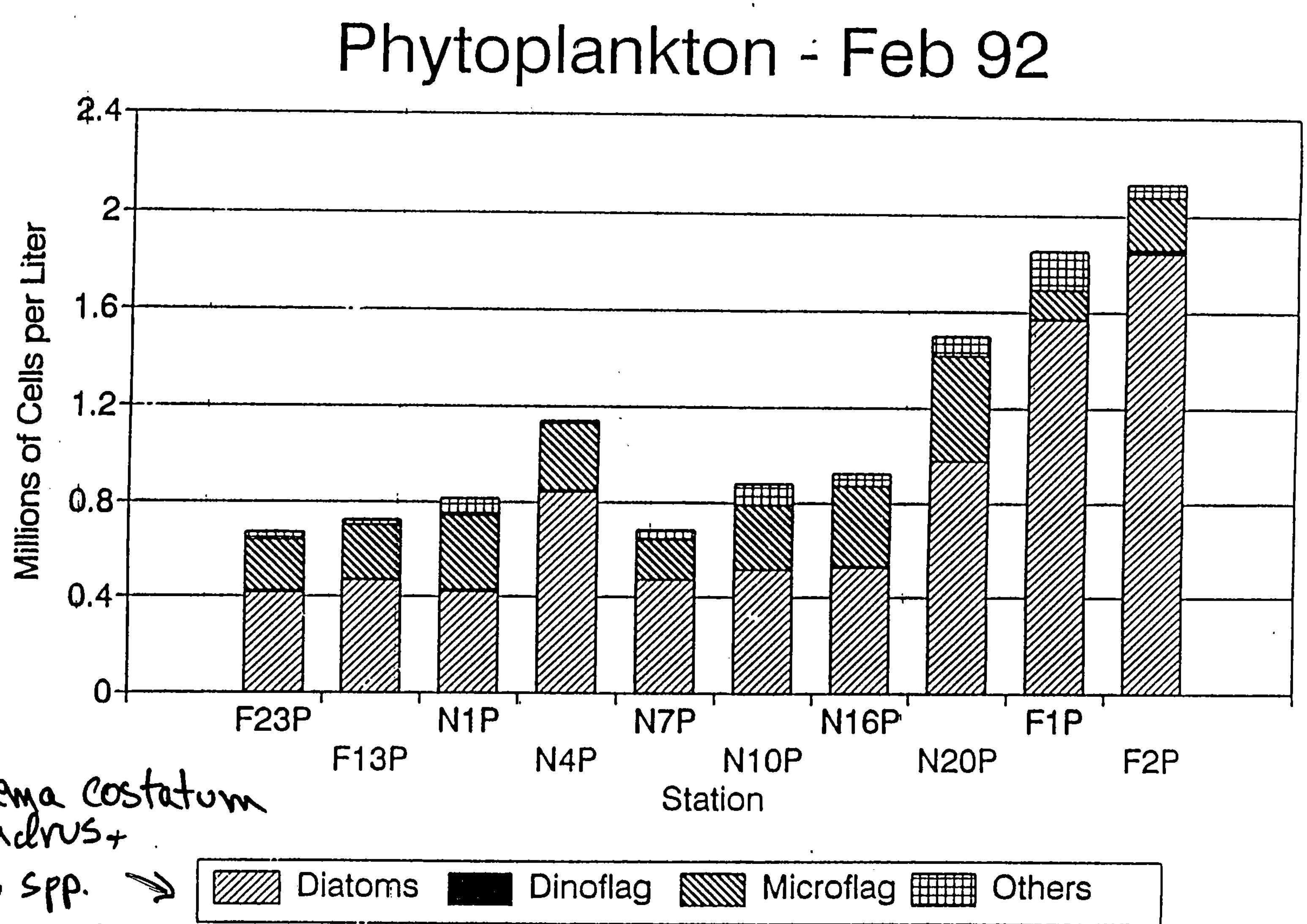
Most statistical relationships with nutrients are negative suggesting that when productivity is high ambient nutrients are low.

To detect changes in annual average Pmax between stations P_{max} must change by at least 80%; between cruises 40%, and between depths by 20%.

APPENDIX C-8

J. TURNER
UMD





Skeletonema costatum
Leptocylindrus +
Chaetoceros spp. →
Thalassiosira nordenskioldii

Figure 3-28 Total phytoplankton abundance, by taxonomic groups, at BioProductivity stations in February 1992. Data are given in Appendix I.

00129

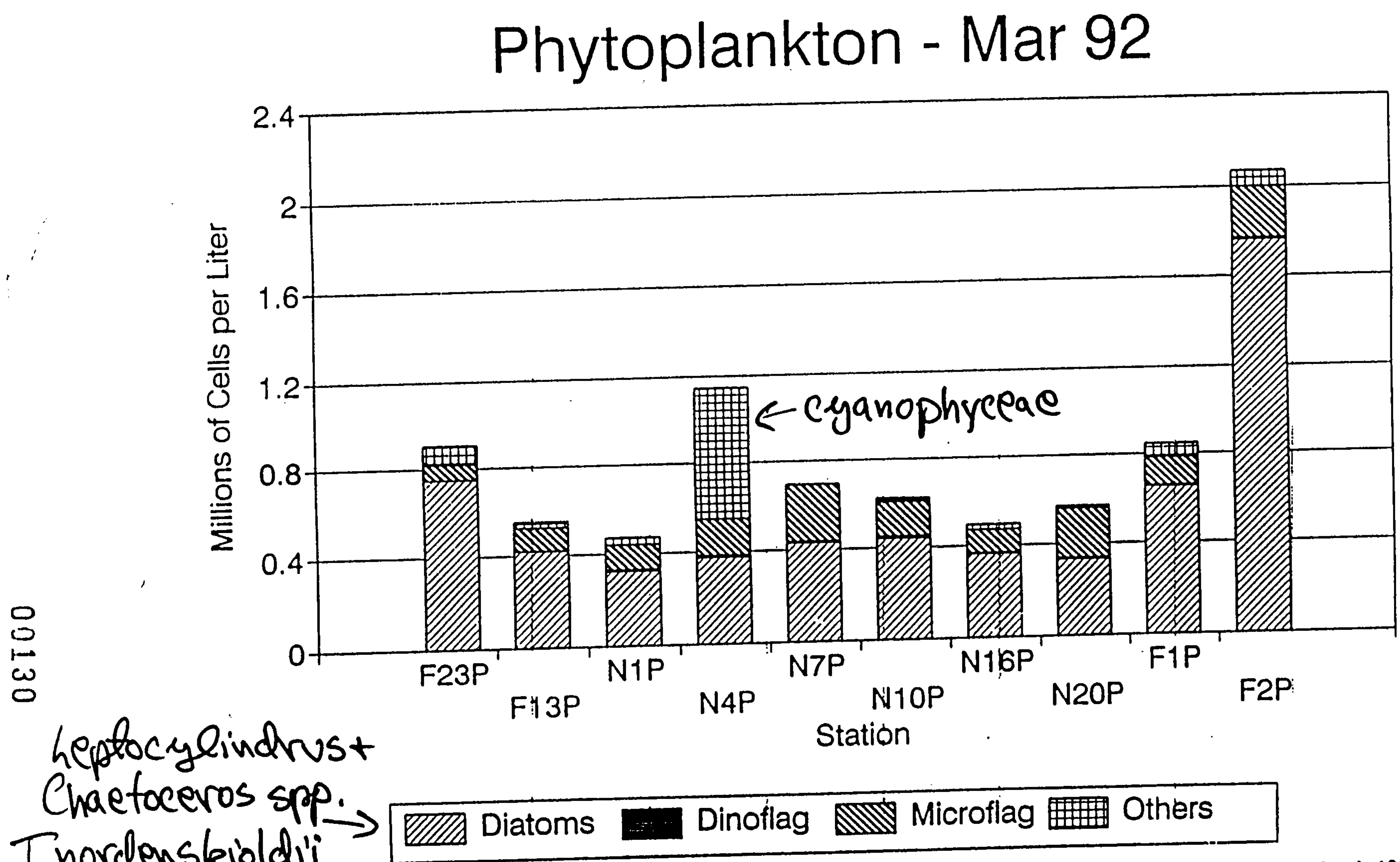


Figure 4-27 Total phytoplankton abundance in surface samples, by taxonomic groups, at BioProductivity stations in March 1992. Data are given in Appendix J.

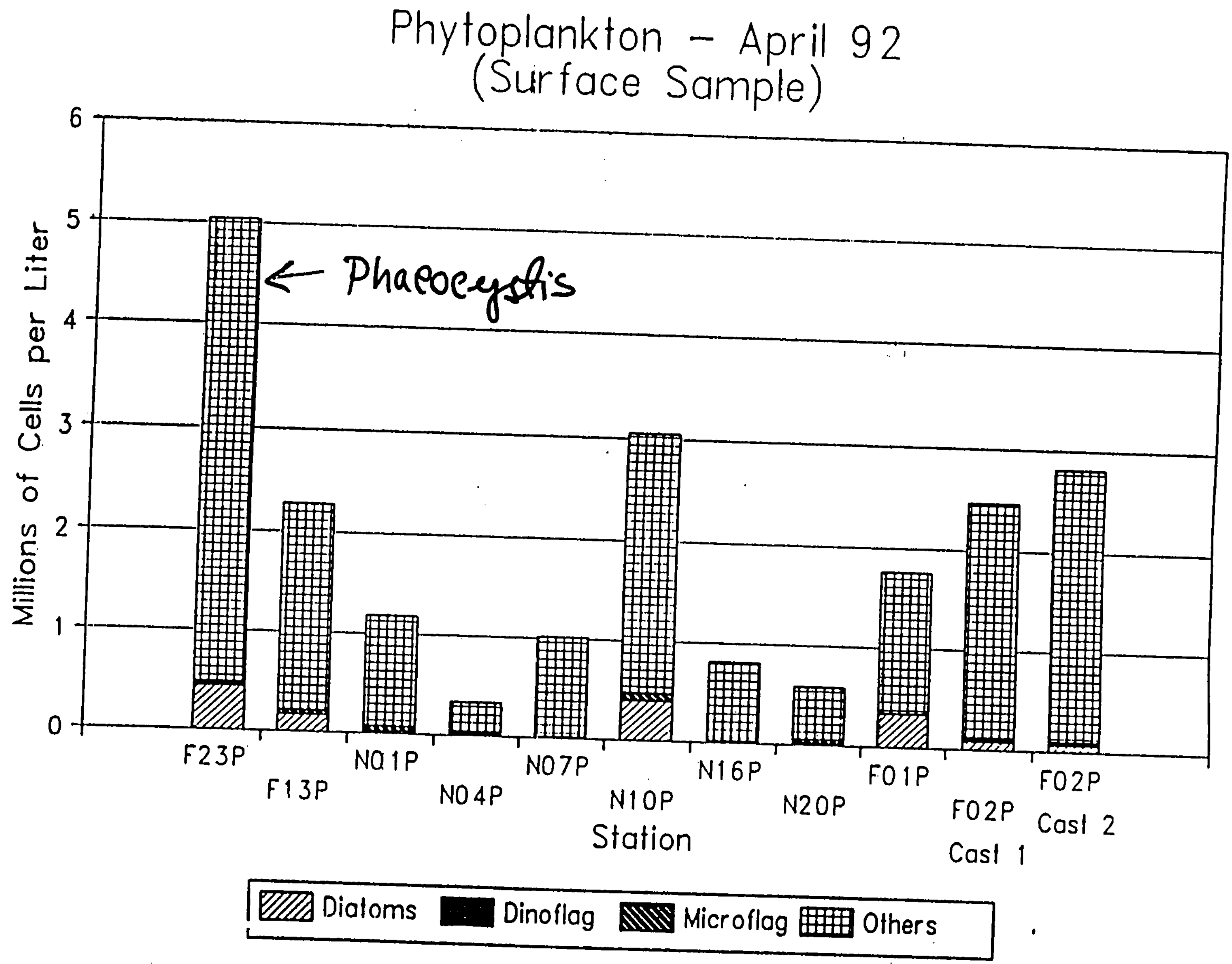


Figure 3-28 **Total phytoplankton abundance, by taxonomic groups, at BioProductivity stations in Apriol 1992. Data are given in Appendix F.**

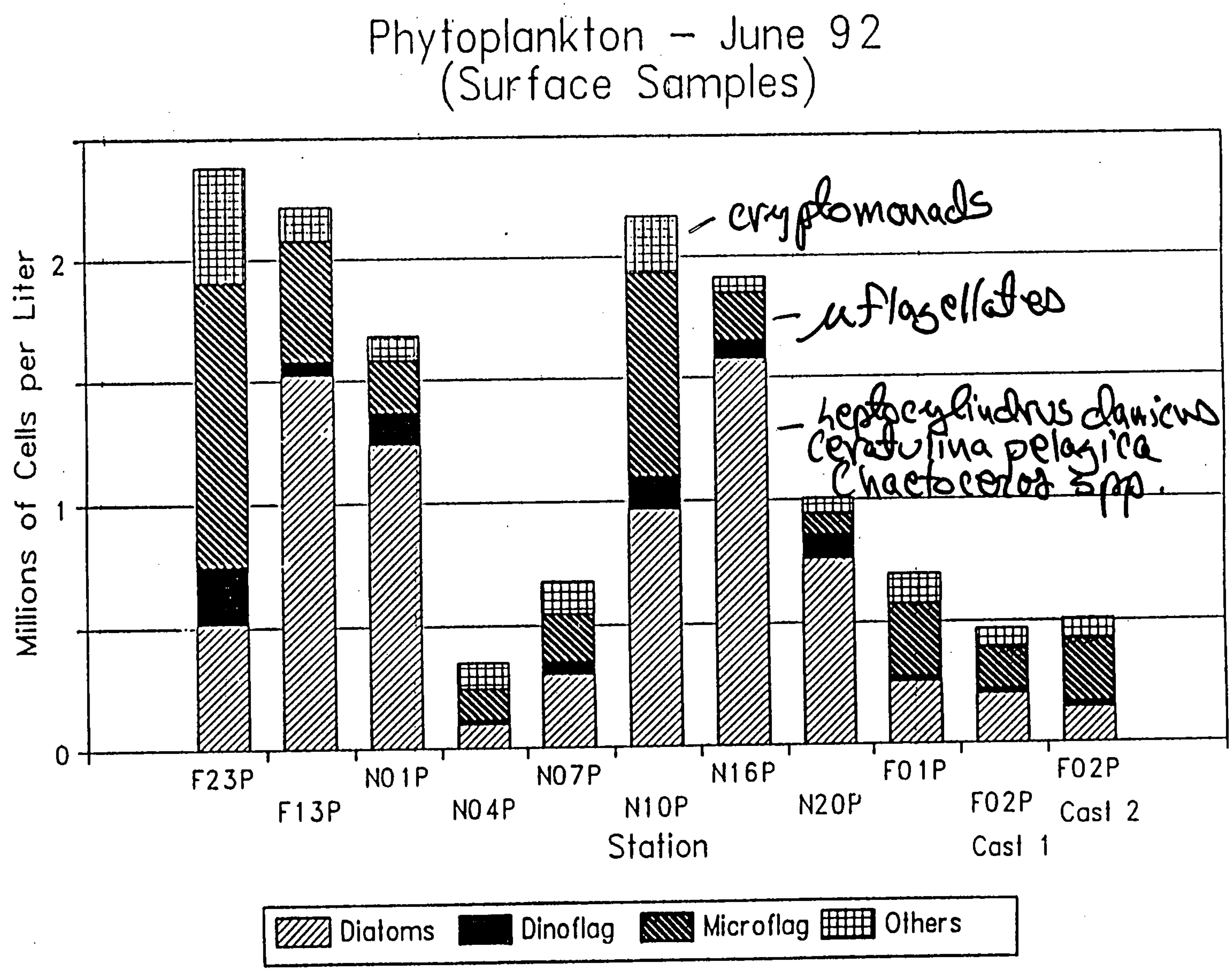


Figure 6-28 **Total phytoplankton abundance, by taxonomic groups, at BioProductivity stations in June 1992. Data are given in Appendix F.**

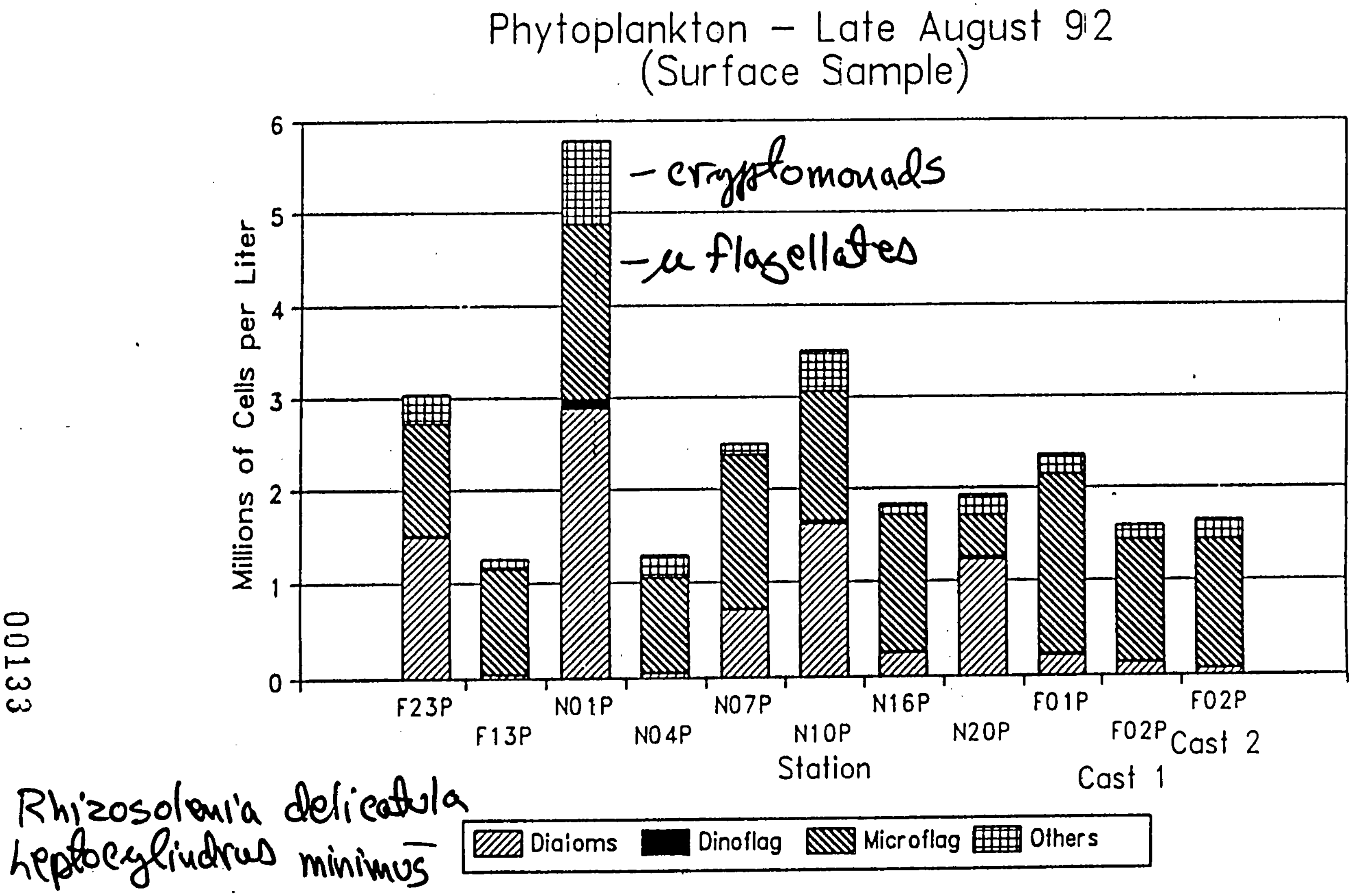


Figure 3-28 **Total phytoplankton abundance, by taxonomic groups, at BioProductivity stations in late August 1992. Data are given in Appendix F.**

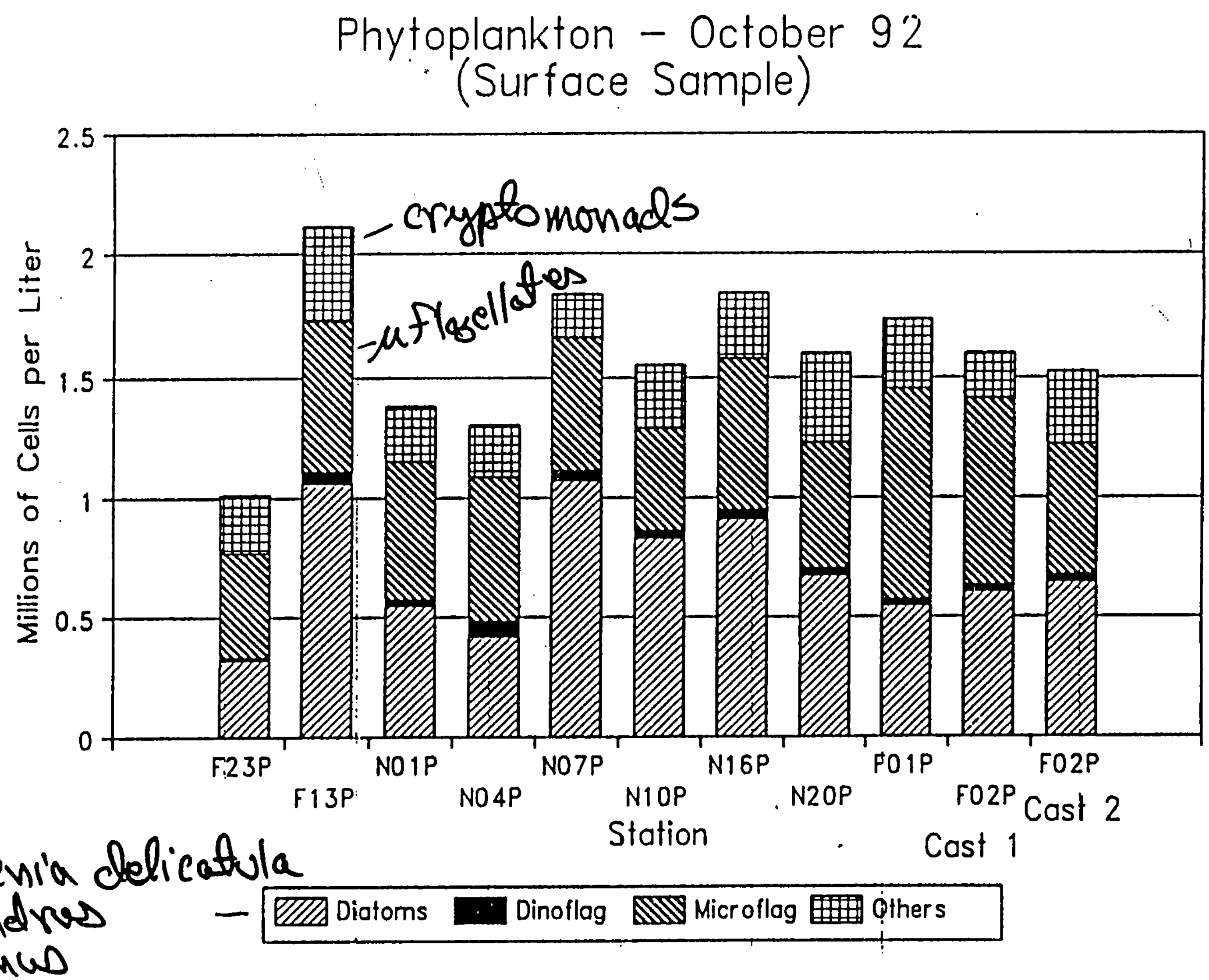


Figure 5-28 Total phytoplankton abundance, by taxonomic groups, at BioProductivity stations in October 1992. Data are given in Appendix F.

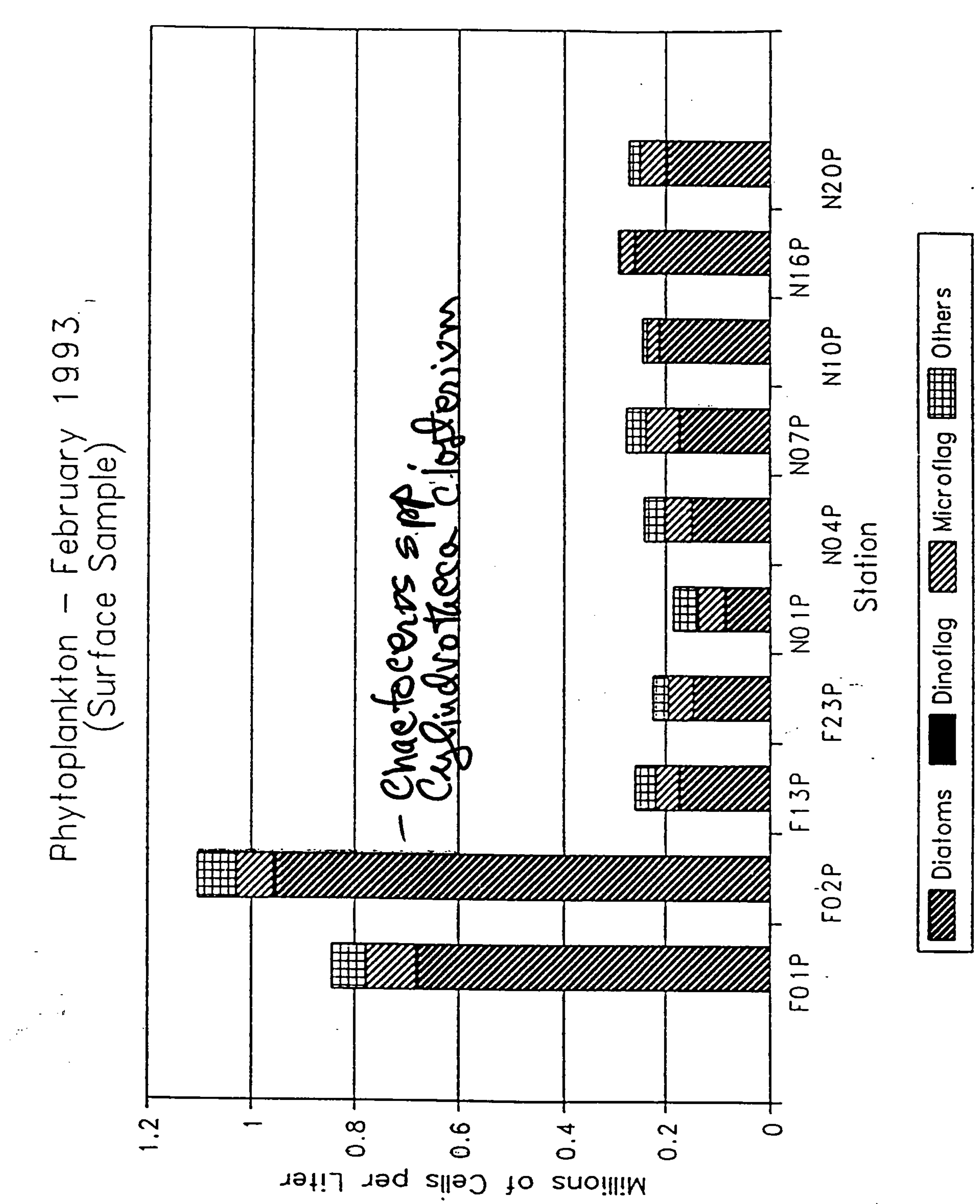


Figure 4-25. **Total phytoplankton abundance, by taxonomic groups, at BioProductivity stations in February 1993. Data are given in Appendix F.**

Summary

1) There was severe seasonal (between sampling periods) and year-to-year variability, in abundance and composition of phytoplankton and zooplankton communities.
2) Within a given sampling period, there was less such spatial variability between stations.
3) The phytoplankton roughly followed a pattern of diatom dominance in winter and early spring, followed by increased contributions by non-diatom (microflagellate and dinoflagellate) taxa in late spring and summer, with a diatom resurgence in fall. The largest bloom event of the two years was the bloom of the diatom *Asterionellopsis glacialis* in October, 1993.
4) There were several substantial blooms of potentially harmful phytoplankton species, including *Phaeocystis pouchetii* (April, 1992), *Ceratium longipes/C. tripos* (June-August, 1992, June-October, 1993), *Prorocentrum micans* (August, 1993), as well as presence of low quantities of *Alexandrium tamarense* and *Pseudonitzschia pungens*.
5) The zooplankton was usually dominated by copepod nauplii and copepodites and adults of small species (*Oithona similis* and *Paracalanus parvus*), but pulses of meroplankton such as barnacle nauplii, larval polychaetes or bivalve veligers could comprise a large proportion of the total zooplankton at a given time.
6) In one case there was an apparent negative interaction between phytoplankton and zooplankton, in that zooplankton abundance was much lower during the *Phaeocystis* bloom in April, 1992 than in April, 1993.
7) Although the large copepod *Calanus finmarchicus* appears to be important as a food source for right whales in Cape Cod Bay, the numerical importance of this copepod as a percentage of total zooplankton abundance is trivial.

Speculations & Recommendations

1) The considerable fluctuations thus far recorded probably have already established the envelope of variability that might be expected after the new outfall comes on line.
2) Extreme unpredictable changes could still result from such events as introduction of exotic organisms via ballast water transport (recent documented examples include toxic Japanese dinoflagellates to Australian coastal waters, a Chinese copepod to San Francisco Bay, and North American ctenophores to the Black Sea).
3) Any modification to the sampling design could be improved by more frequent sampling in summer and fall, and addition of stations in Boston Harbor.

Figure 5-25. **Total phytoplankton abundance, by taxonomic groups, at BioProductivity stations in March 1993. Data are given in Appendix F.**

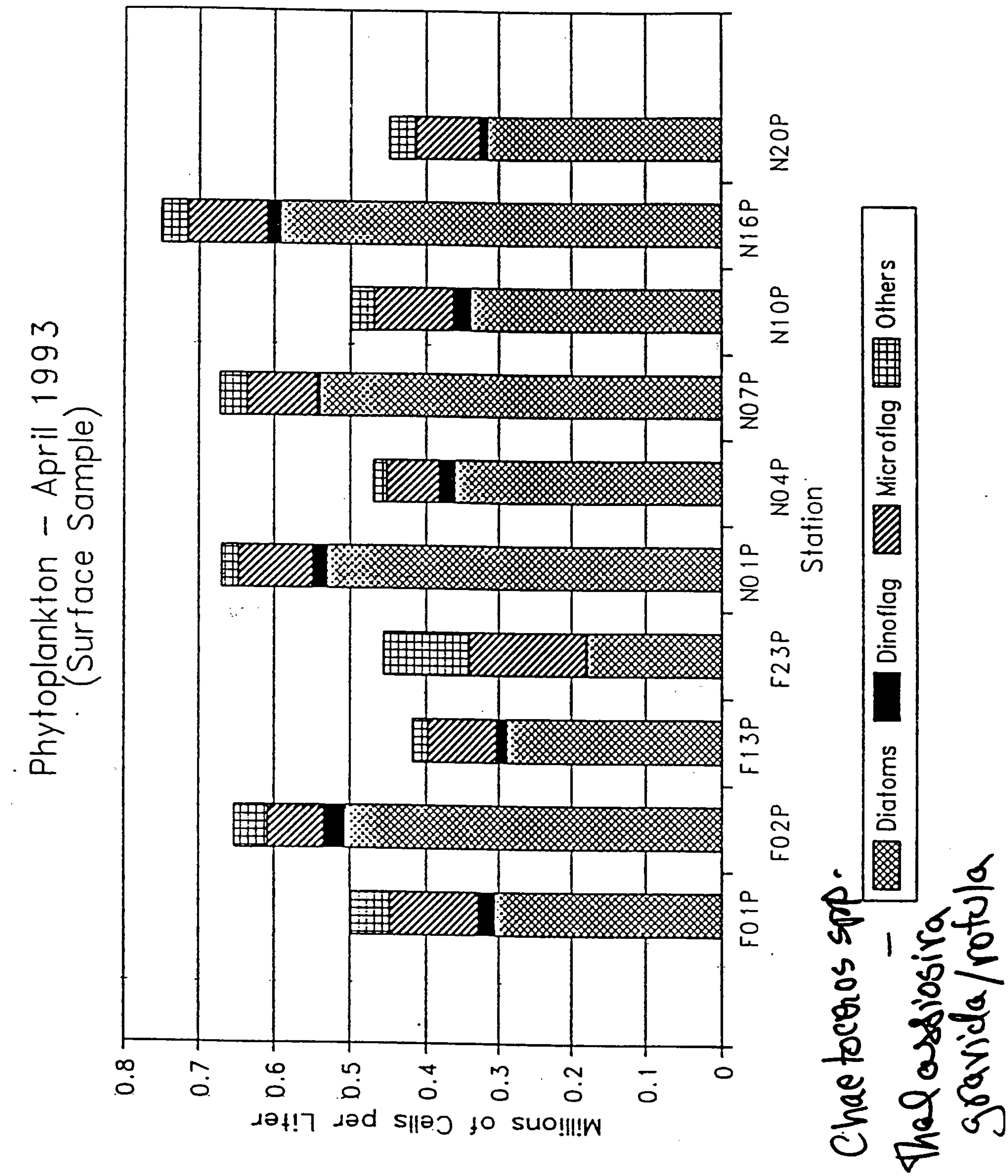
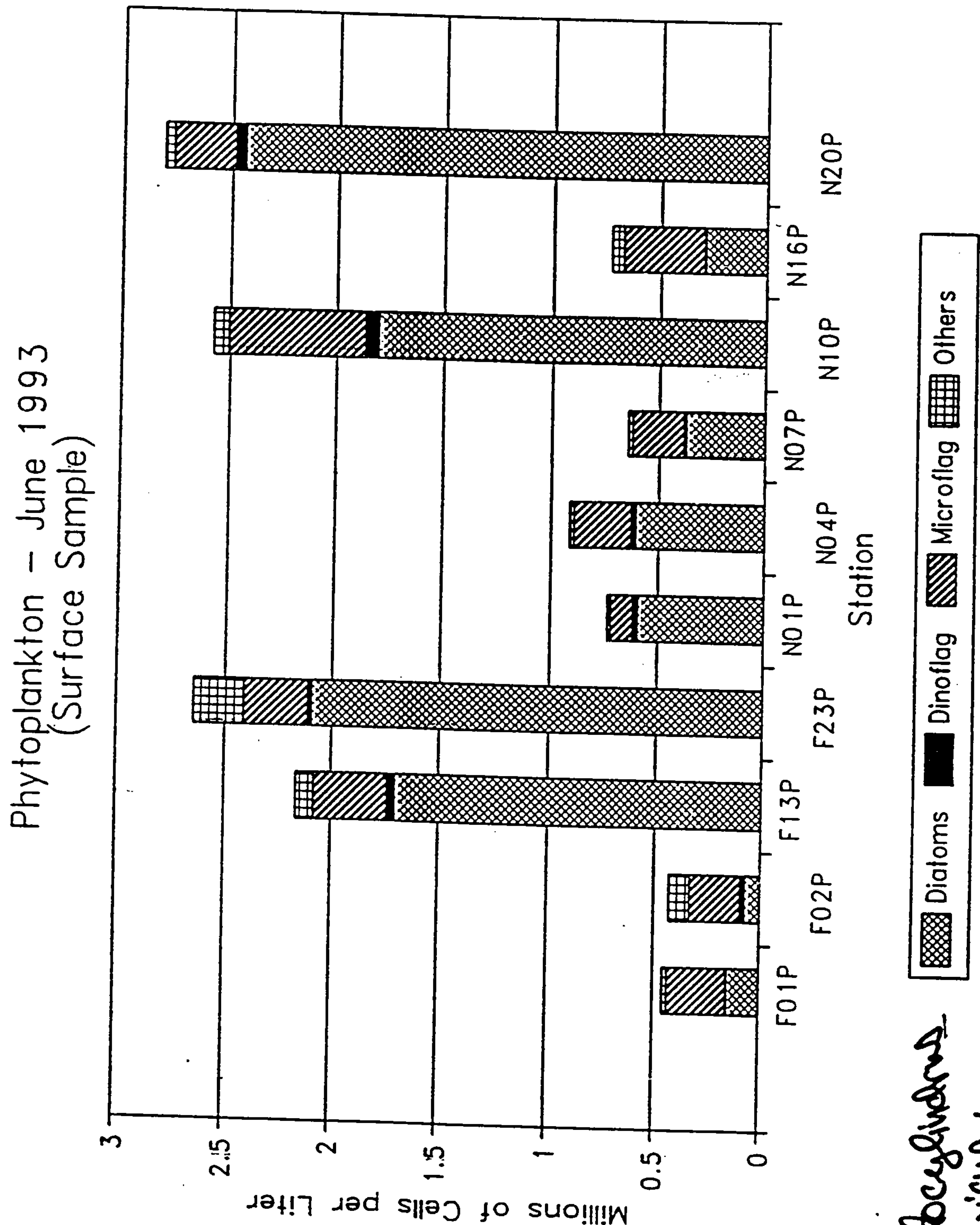


Figure 3-25. **Total phytoplankton abundance, by taxonomic groups, at BioProductivity stations in early April 1993. Data are given in Appendix F.**



Leptocylindrus danicus + Skeletonema costatum

Figure 3-25a. Total phytoplankton abundance, by taxonomic groups, at the surface of BioProductivity stations in June 1993. Data are given in Appendix F.

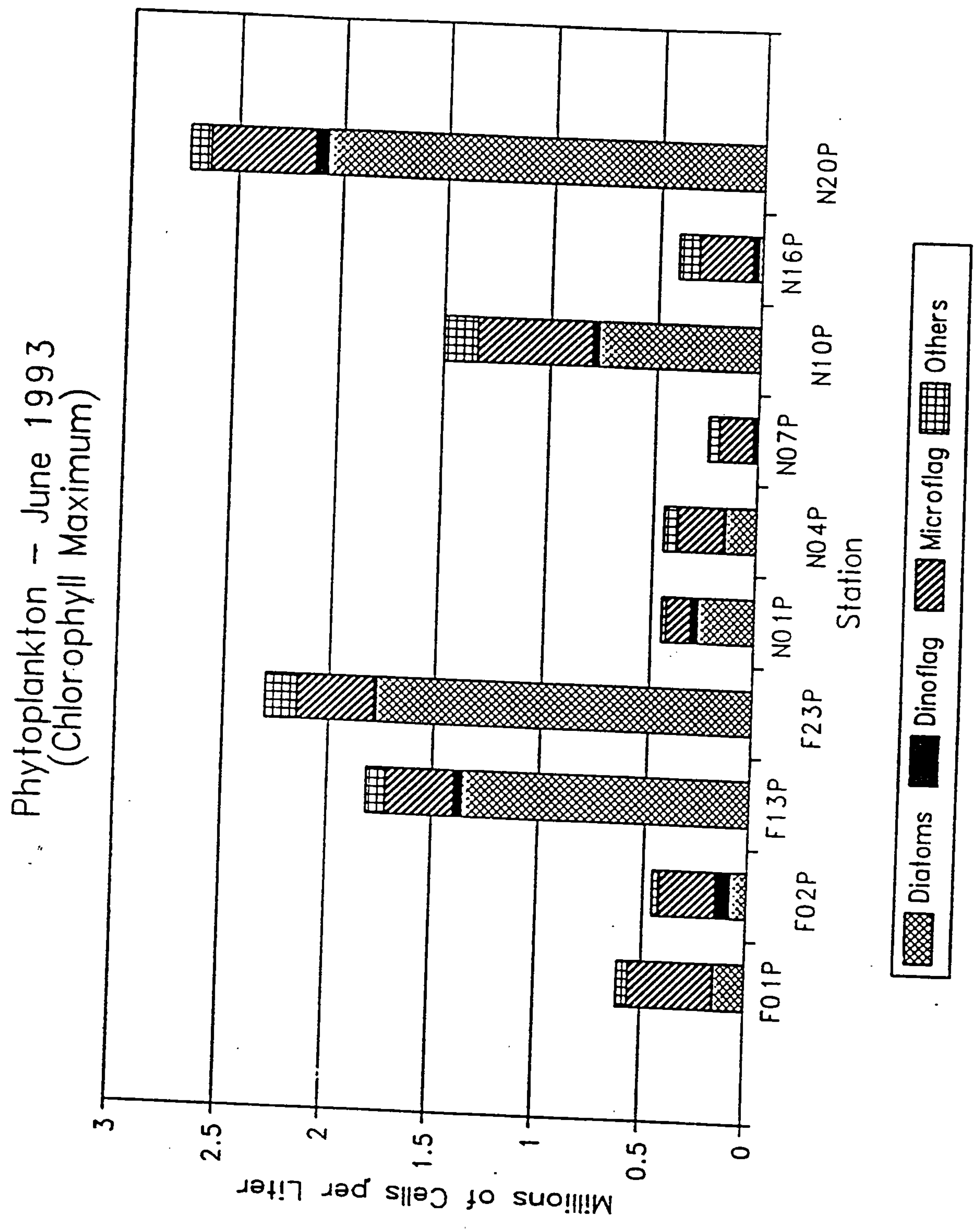
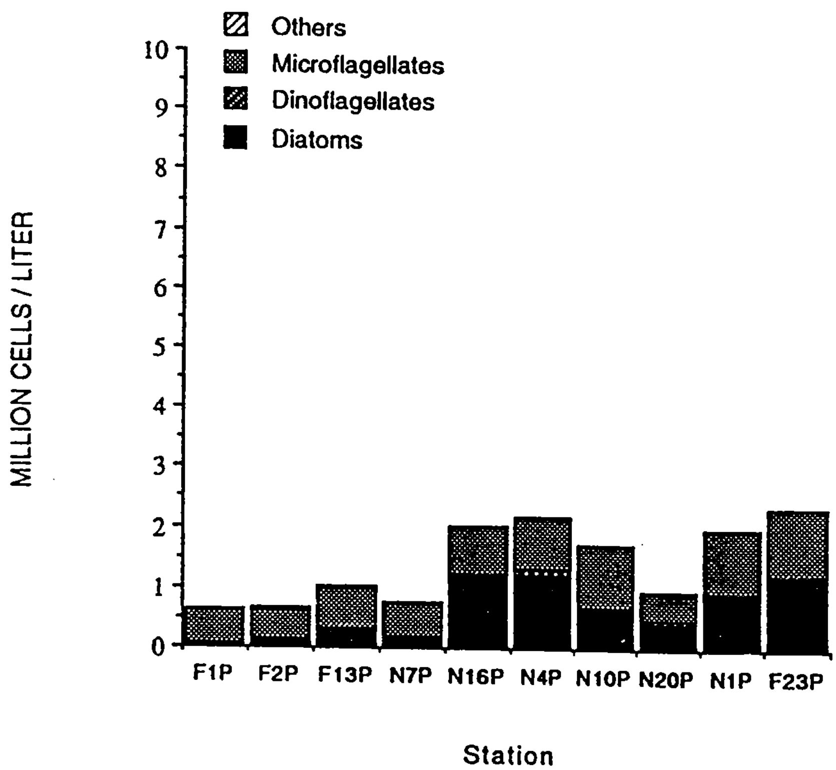
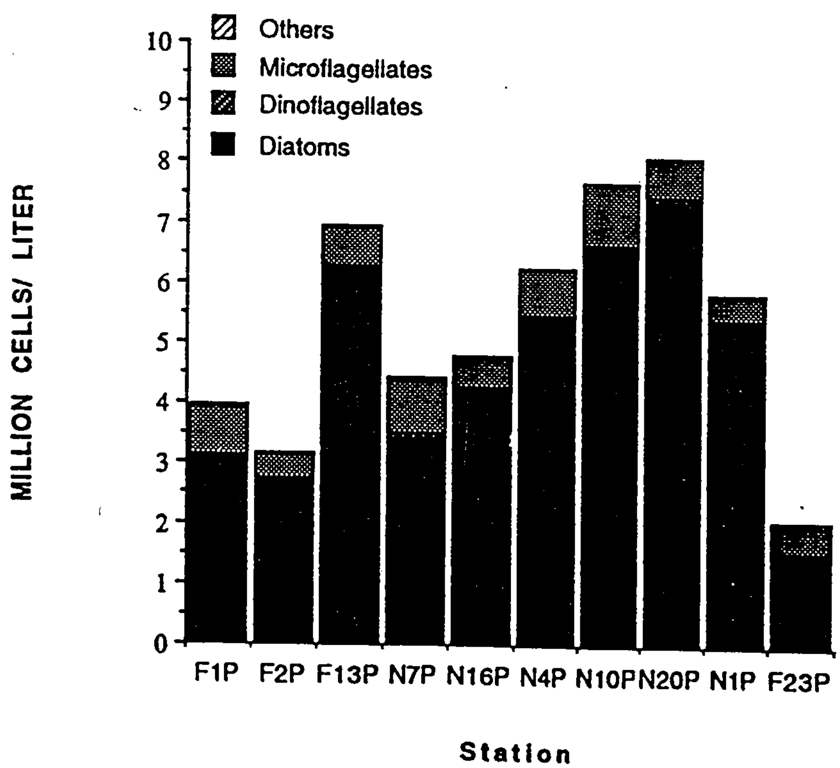


Figure 3-25b. **Total phytoplankton abundance, by taxonomic groups, at the chlorophyll maximum at BioProductivity stations in June 1993. Data are given in Appendix F.**

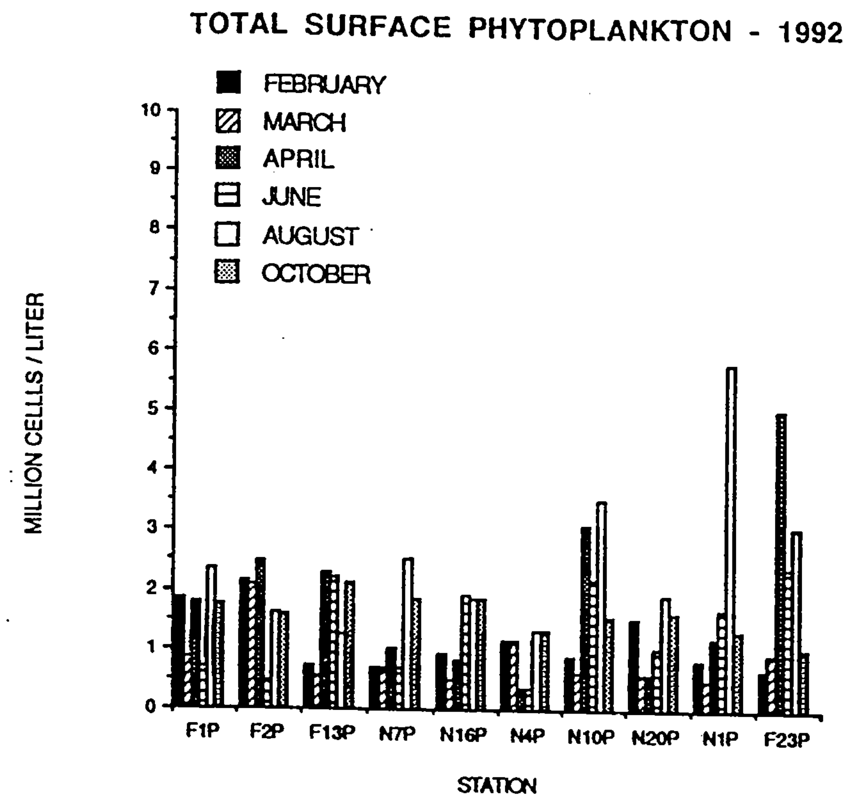
PHYTOPLANKTON AUGUST 1993

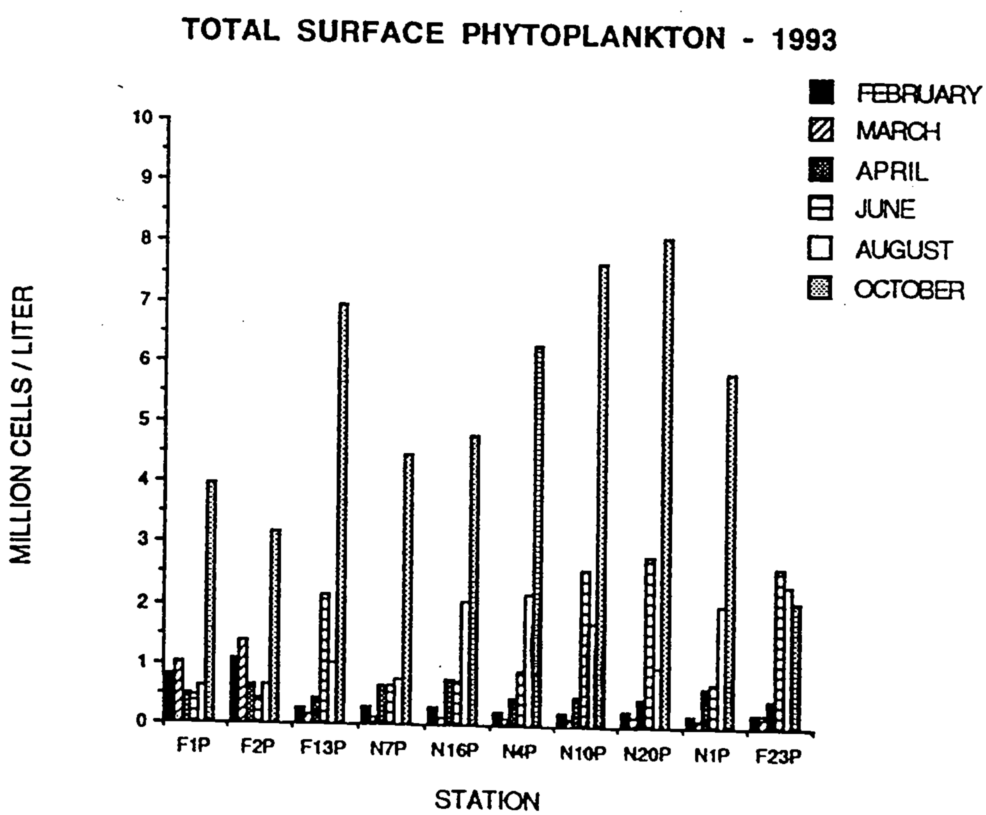


PHYTOPLANKTON OCTOBER 1993



00141


TOTAL SURFACE PHYTOPLANKTON - 1992
FEBRUARY
MARCH
APRIL
JUNE
AUGUST
OCTOBER
MILLION CELLS / LITER
0
1
2
3
4
5
6
7
8
9
10
F1P
F2P
F13P
N7P
N16P
N4P
N10P
N20P
N1P
F23P
STATION


TOTAL SURFACE PHYTOPLANKTON - 1993
FEBRUARY
MARCH
APRIL
JUNE
AUGUST
OCTOBER
MILLION CELLS / LITER
0
1
2
3
4
5
6
7
8
9
10
F1P
F2P
F13P
N7P
N16P
N4P
N10P
N20P
N1P
F23P
STATION

Vol. 100: 27–34, 1993 | MARINE ECOLOGY PROGRESS SERIES Mar. Ecol. Prog. Ser. | Published October 5

Plankton studies in Buzzards Bay, Massachusetts, USA. II. Nutrients, chlorophyll *a* and phaeopigments, 1987 to 1990

David G. Borkman*, Jefferson T. Turner**

Center for Marine Science and Technology, University of Massachusetts, Dartmouth, North Dartmouth, Massachusetts 02747, USA

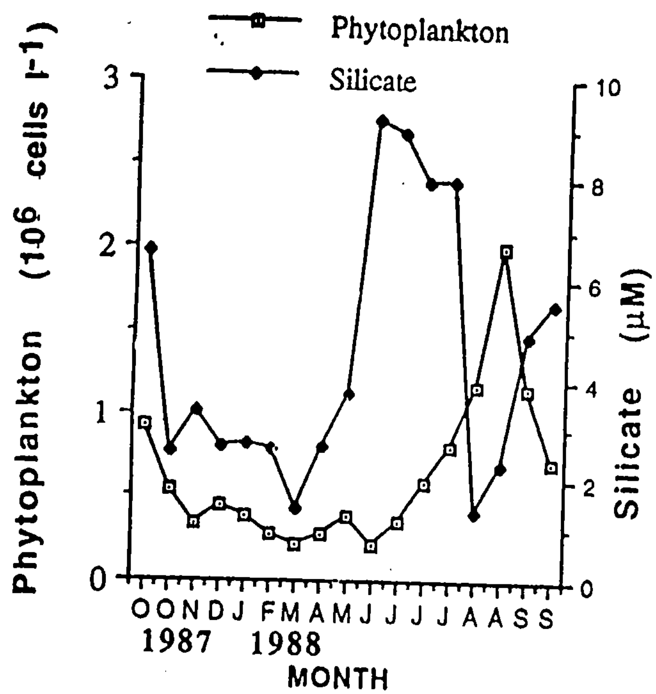


Fig. 9. Silicate (µM) vs total phytoplankton (cells × 10^6 l^{-1}), 1 October 1987 to 20 September 1988. Values are bay-wide means of surface values for each cruise (n = 18 for each value)

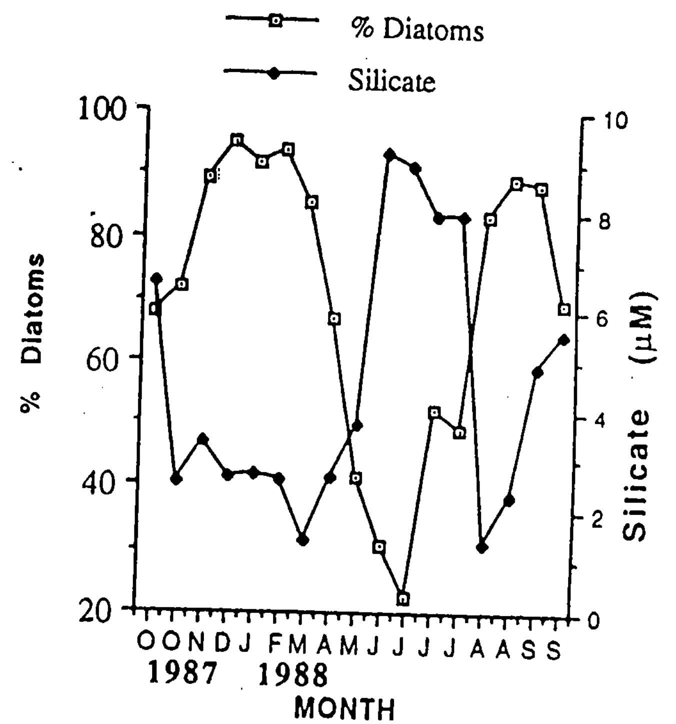
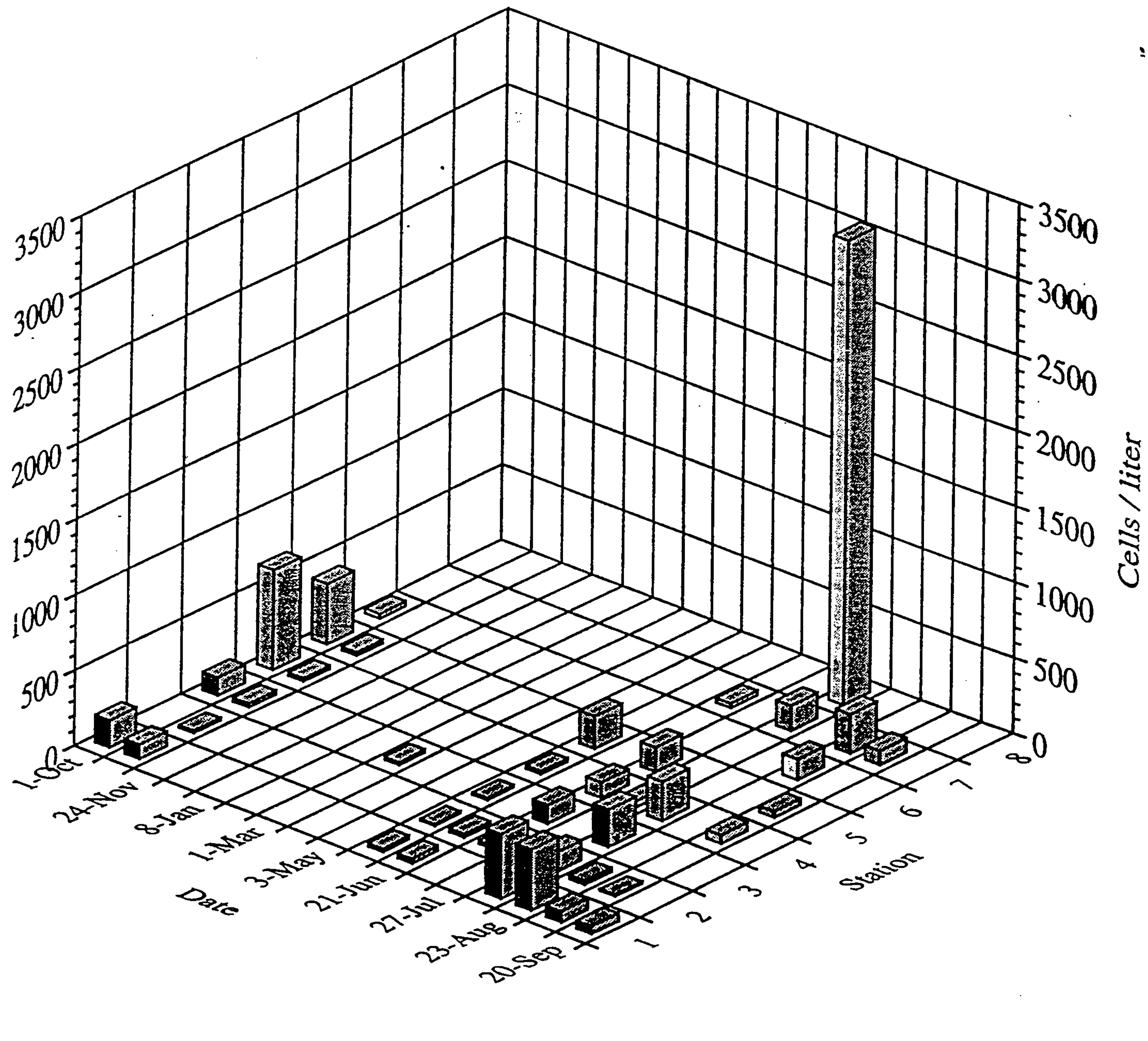


Fig. 10. Silicate (µM) vs percentage of total phytoplankton cells comprised by diatoms, 1 October

00143

THE TOXIC DINOFLAGELLATE *Alexandrium tamarense* WAS NOT RECORDED FOR SETTLED SAMPLES IN BUZZARDS BAY, BUT WAS RECORDED FROM ALL STATIONS IN JUNE-OCTOBER IN SCREENED SAMPLES (UP TO 3×10^3 cells l^{-1} in New Bedford Harbor).



Ceratium longipes/C. tripos JUNE BLOOM- SCREENED VERSUS SETTLED SAMPLES

In settled samples, *C. longipes* was recorded for only 3 chlorophyll maximum samples from Cape Cod Bay (144-200 x 10^3 cells l^{-1}), and in none of the surface samples.

In screened samples, *C. longipes* was present at all stations in surface samples (51-2,392 cells l-1) and chlorophyll maximum samples (62-158,118 cells l-1).

C. tripos was unrecorded in any settled samples, but was recorded for screened samples at the surface at all but one station (3-132 cells l^{-1}), and at the chlorophyll maximum at half of the stations (2-1,101 cells l^{-1}).

THUS, THE SETTLED SAMPLES WOULD HAVE INDICATED THAT THE BLOOM WAS RESTRICTED TO SUBSURFACE WATERS OF CAPE COD BAY, WHEREAS IN REALITY, IT WAS WIDESPREAD AT SURFACE AND CHLOROPHYLL MAXIMUM DEPTHS THROUGHOUT THE ENTIRE SYSTEM.

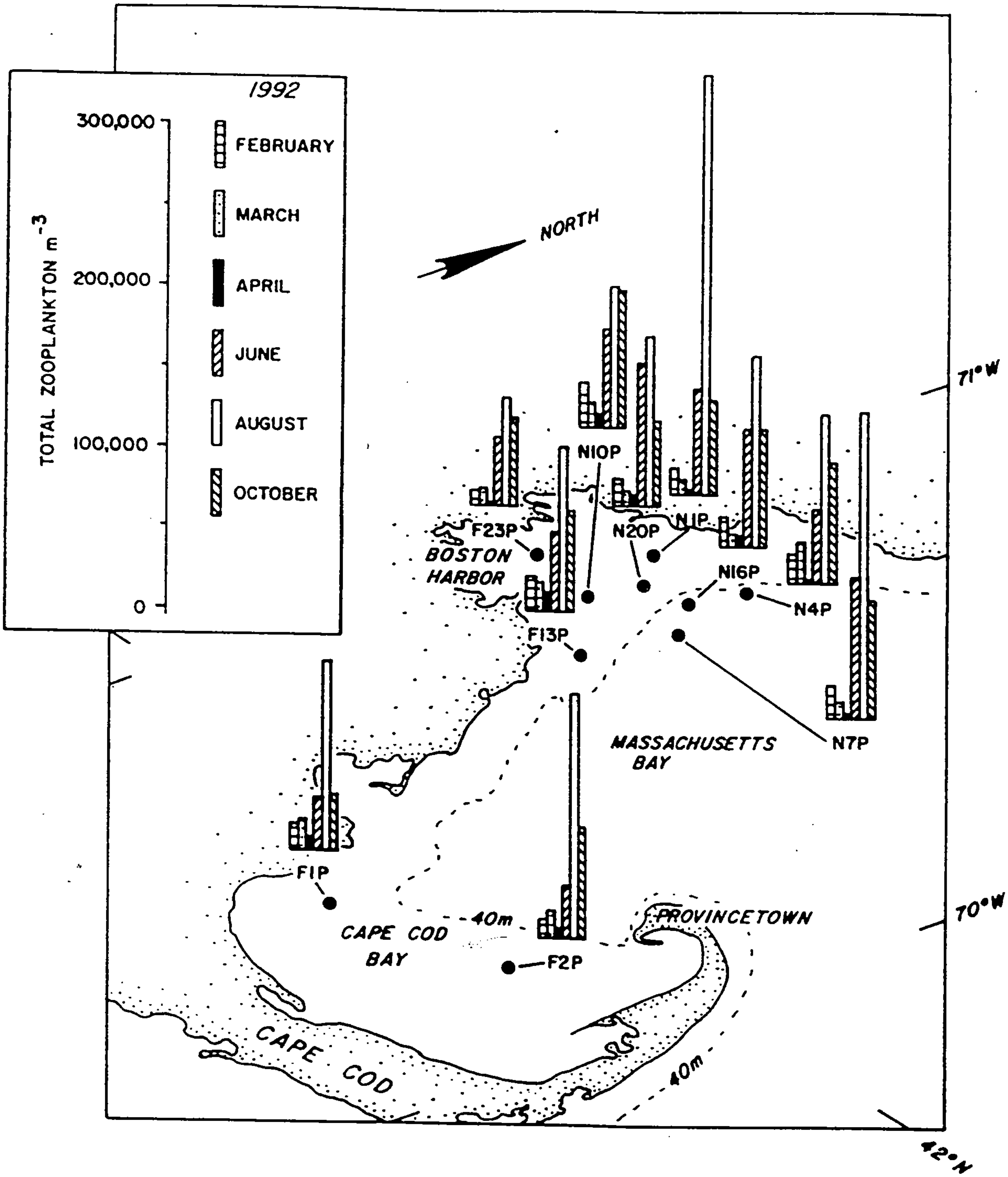

1992
300,000
200,000
100,000
0
TOTAL ZOOPLANKTON m^{-3}
FEBRUARY
MARCH
APRIL
JUNE
AUGUST
OCTOBER
NORTH
71°W
70°W
42°N
N10P
F23P
N20P
N1P
N16P
N4P
BOSTON
HARBOR
F13P
N7P
MASSACHUSETTS
BAY
F1P
40m
PROVINCETOWN
CAPE COD
BAY
F2P
CAPE COD
40m

Fig. 1

Table 2. Percentages of total zooplankton abundance comprised by copepod nauplii, copepods (adults + copepodites) and other (non-copepod) taxa. Ranges of percentages are followed by mean percentages in parentheses.

Month	% Copepod Nauplii	% Copepods (Adults + Copepodites)	% Other Taxa
February	6.8-44.7 (18.8)	23.6-70.8 (45.6)	9.7-69.6 (35.6)
March	18.4-45.0 (31.7)	30.3-54.8 (41.9)	13.5-51.3 (26.4)
April	1.2-41.8 (18.2)	45.1-80.1 (55.6)	9.0-49.0 (26.2)
June	12.8-44.6 (35.2)	42.7-84.1 (57.8)	0.7-16.9 (7.0)
August	21.6-43.5 (31.6)	56.7-78.4 (67.9)	0.0-2.9 (0.5)
October	9.1-38.2 (28.1)	52.0-81.5 (66.9)	0.5-14.0 (5.1)

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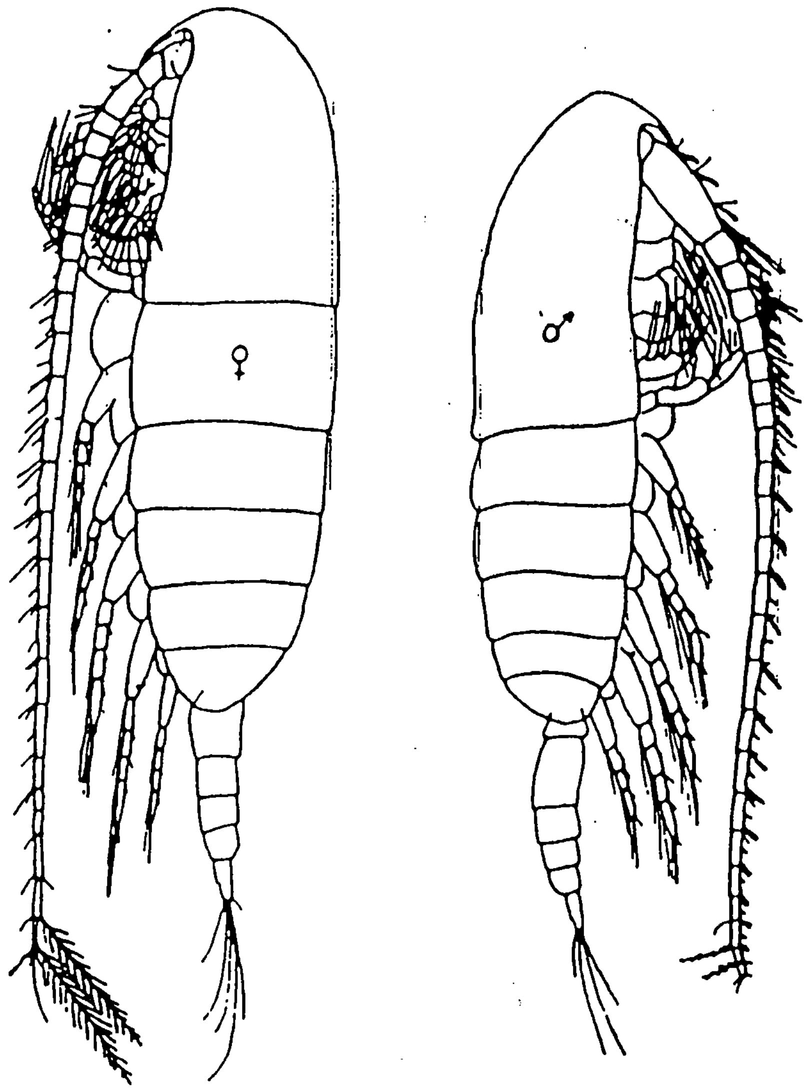
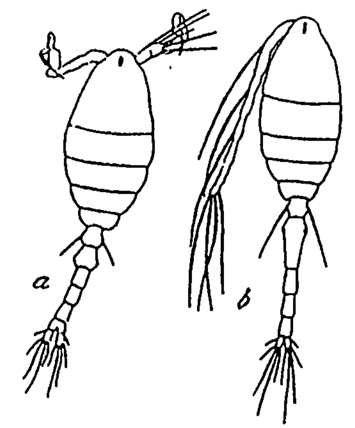


a

Figure 189.—*Oithona similis*: a, Male, dorsal; b, female, dorsal;



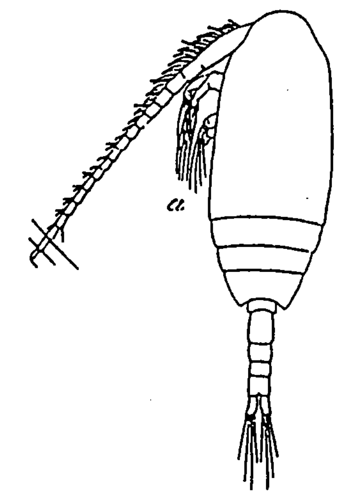


Figure 21.—*Paracalanus parvus*:

Fig. 2.66. (a) *Calanus finmarchicus* ♀ 2.7–5.4 mm; ♂ 2.4–3.6 mm (Rose, 1933).

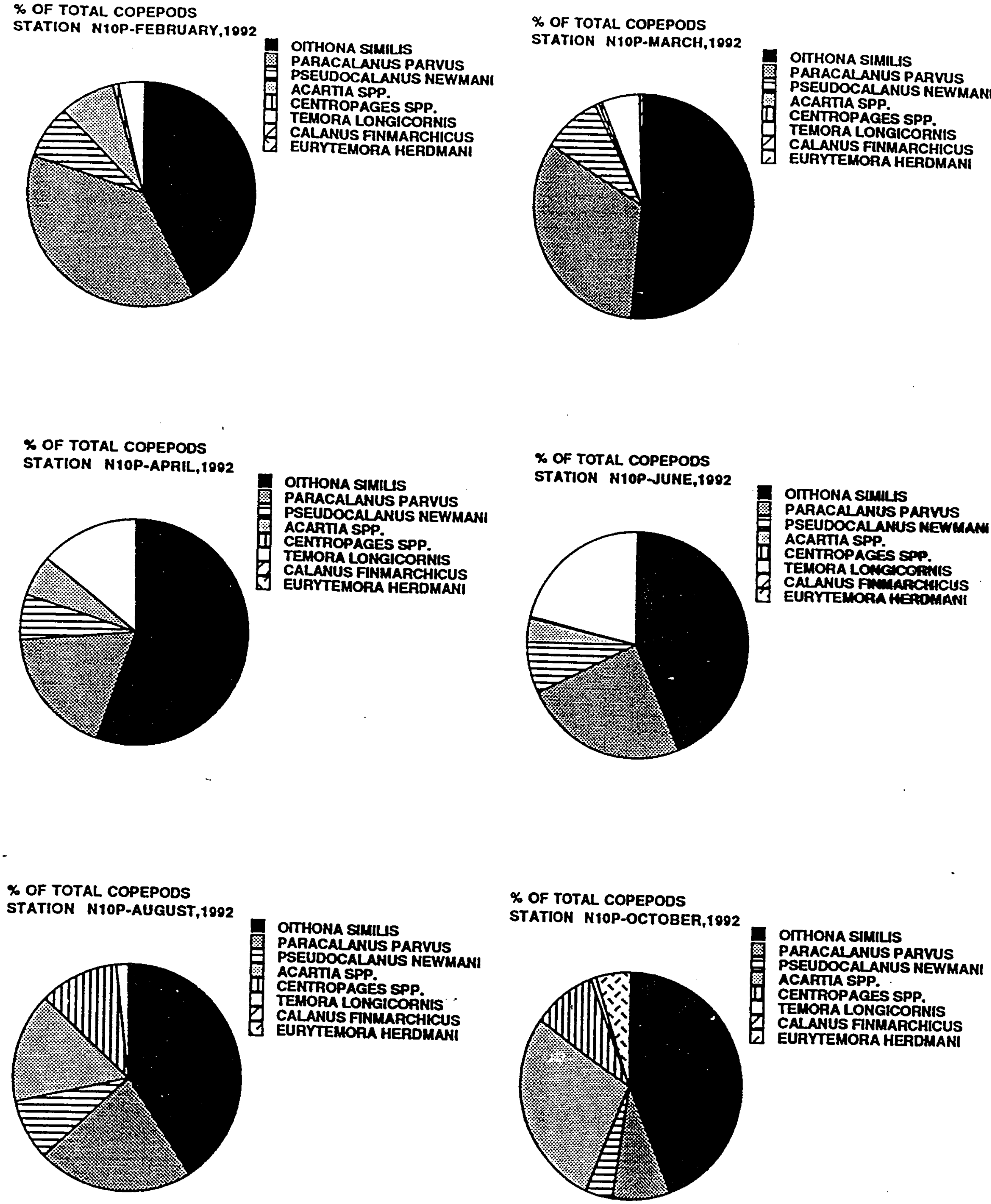

% OF TOTAL COPEPODS
STATION N10P-FEBRUARY,1992
OITHONA SIMILIS
PARACALANUS PARVUS
PSEUDOCALANUS NEWMANI
ACARTIA SPP.
CENTROPAGES SPP.
TEMORA LONGICORNIS
CALANUS FINMARCHICUS
EURYTEMORA HERDMANI
% OF TOTAL COPEPODS
STATION N10P-MARCH,1992
OITHONA SIMILIS
PARACALANUS PARVUS
PSEUDOCALANUS NEWMANI
ACARTIA SPP.
CENTROPAGES SPP.
TEMORA LONGICORNIS
CALANUS FINMARCHICUS
EURYTEMORA HERDMANI
% OF TOTAL COPEPODS
STATION N10P-APRIL,1992
OITHONA SIMILIS
PARACALANUS PARVUS
PSEUDOCALANUS NEWMANI
ACARTIA SPP.
CENTROPAGES SPP.
TEMORA LONGICORNIS
CALANUS FINMARCHICUS
EURYTEMORA HERDMANI
% OF TOTAL COPEPODS
STATION N10P-JUNE,1992
OITHONA SIMILIS
PARACALANUS PARVUS
PSEUDOCALANUS NEWMANI
ACARTIA SPP.
CENTROPAGES SPP.
TEMORA LONGICORNIS
CALANUS FINMARCHICUS
EURYTEMORA HERDMANI
% OF TOTAL COPEPODS
STATION N10P-AUGUST,1992
OITHONA SIMILIS
PARACALANUS PARVUS
PSEUDOCALANUS NEWMANI
ACARTIA SPP.
CENTROPAGES SPP.
TEMORA LONGICORNIS
CALANUS FINMARCHICUS
EURYTEMORA HERDMANI
% OF TOTAL COPEPODS
STATION N10P-OCTOBER,1992
OITHONA SIMILIS
PARACALANUS PARVUS
PSEUDOCALANUS NEWMANI
ACARTIA SPP.
CENTROPAGES SPP.
TEMORA LONGICORNIS
CALANUS FINMARCHICUS
EURYTEMORA HERDMANI

Fig 4

% OF TOTAL COPEPODS
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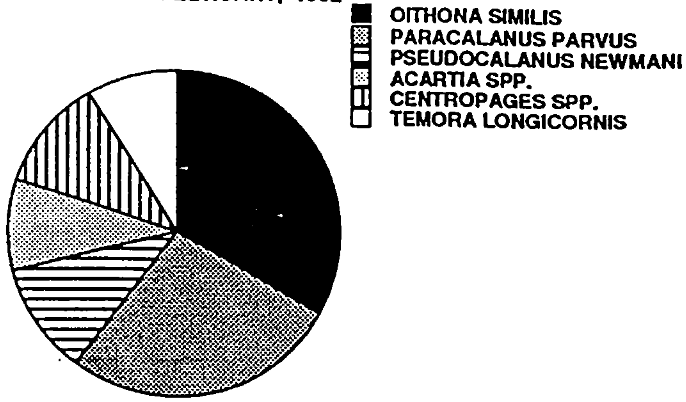

% OF TOTAL COPEPODS
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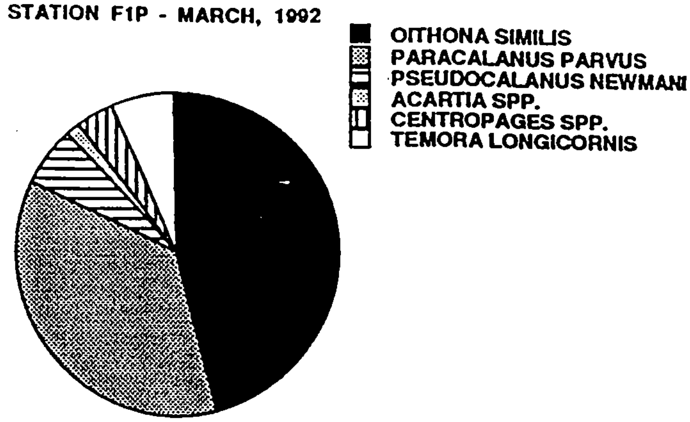

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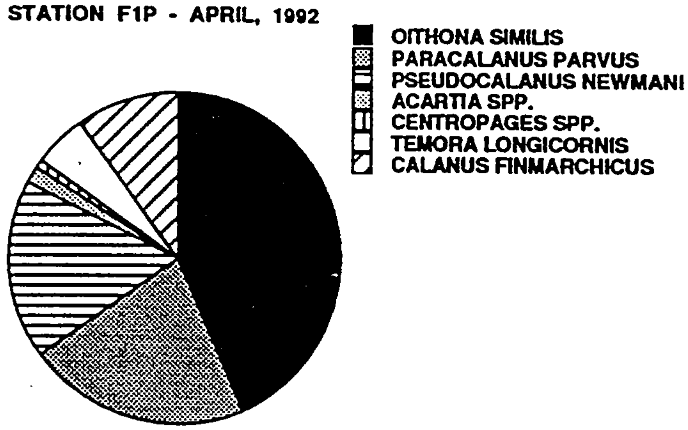

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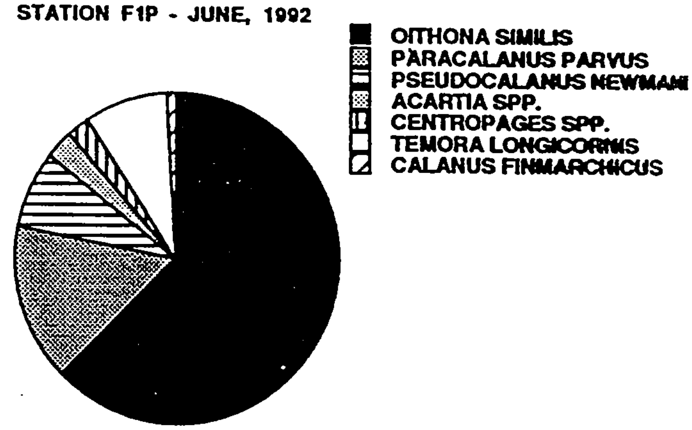

% OF TOTAL COPEPODS
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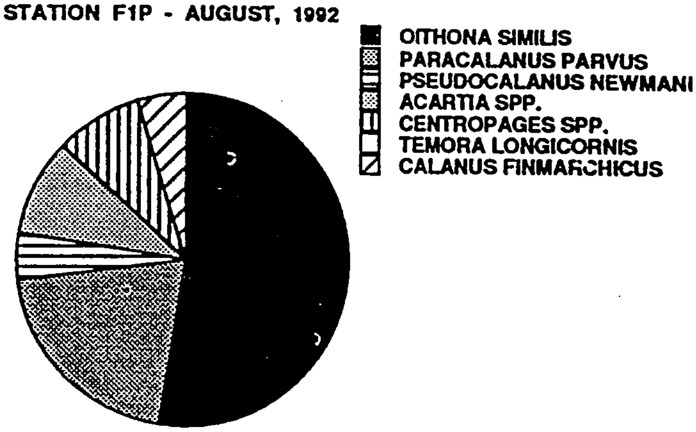

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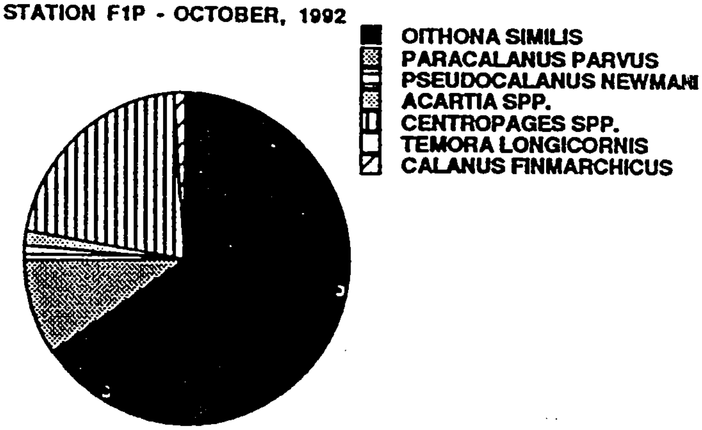

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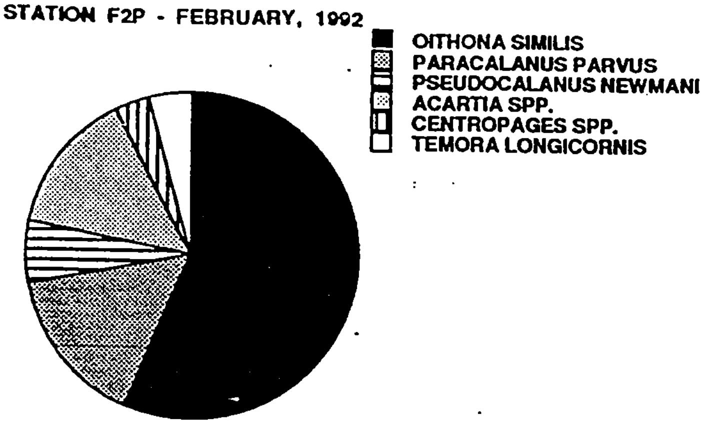

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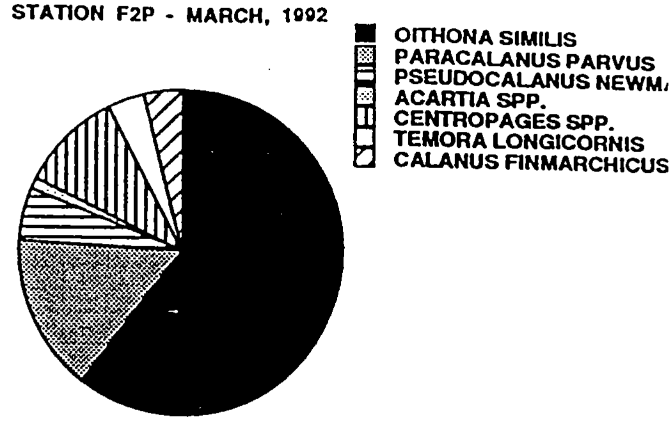

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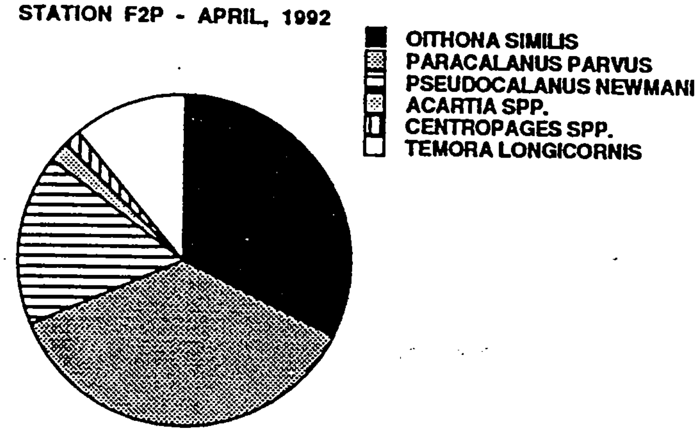

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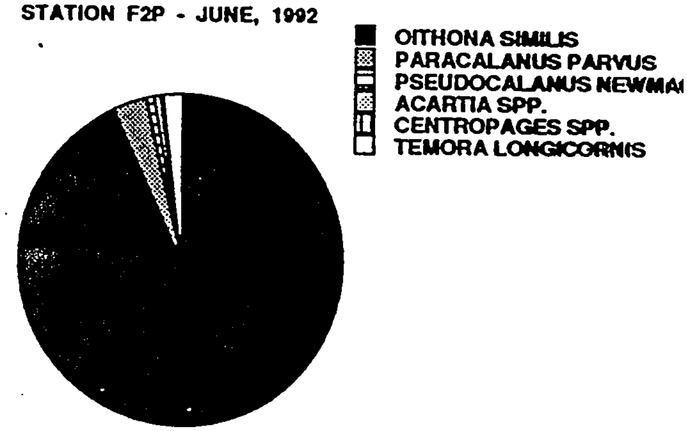

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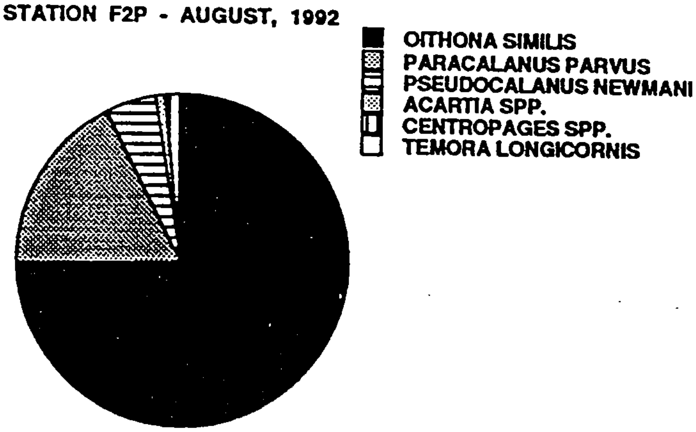

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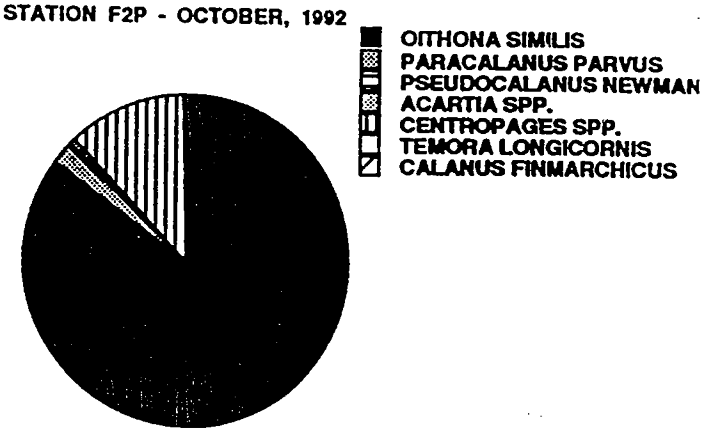

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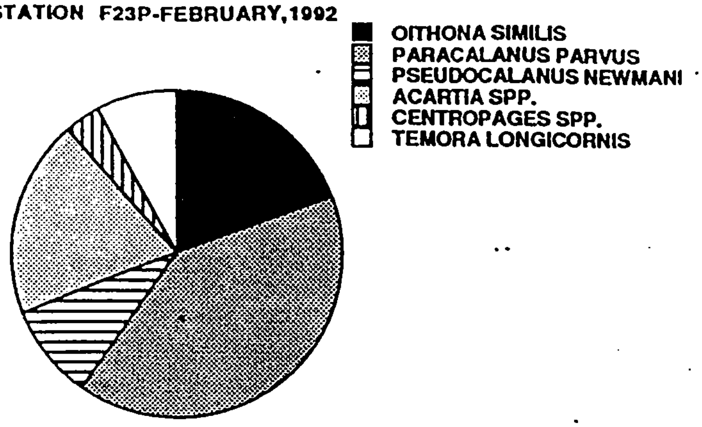

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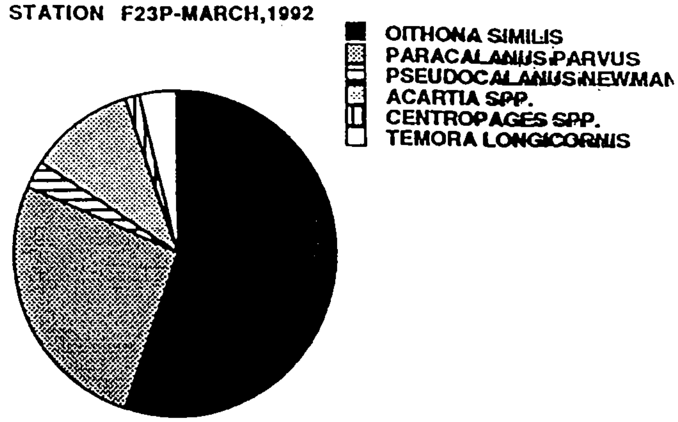

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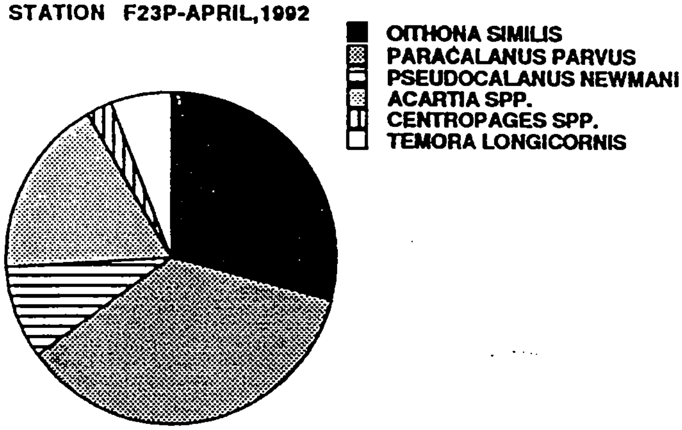

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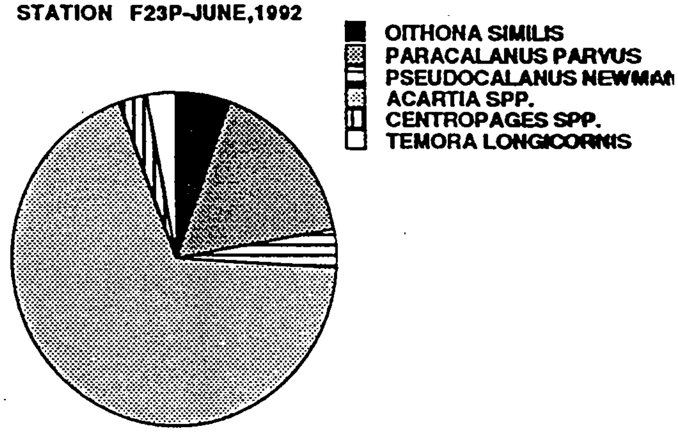

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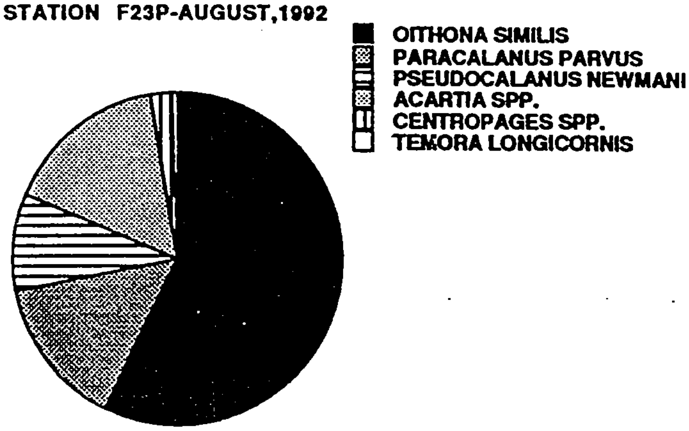

% OF TOTAL COPEPODS
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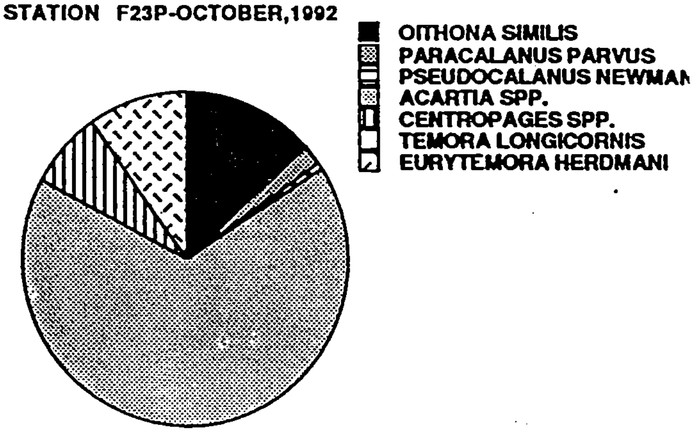
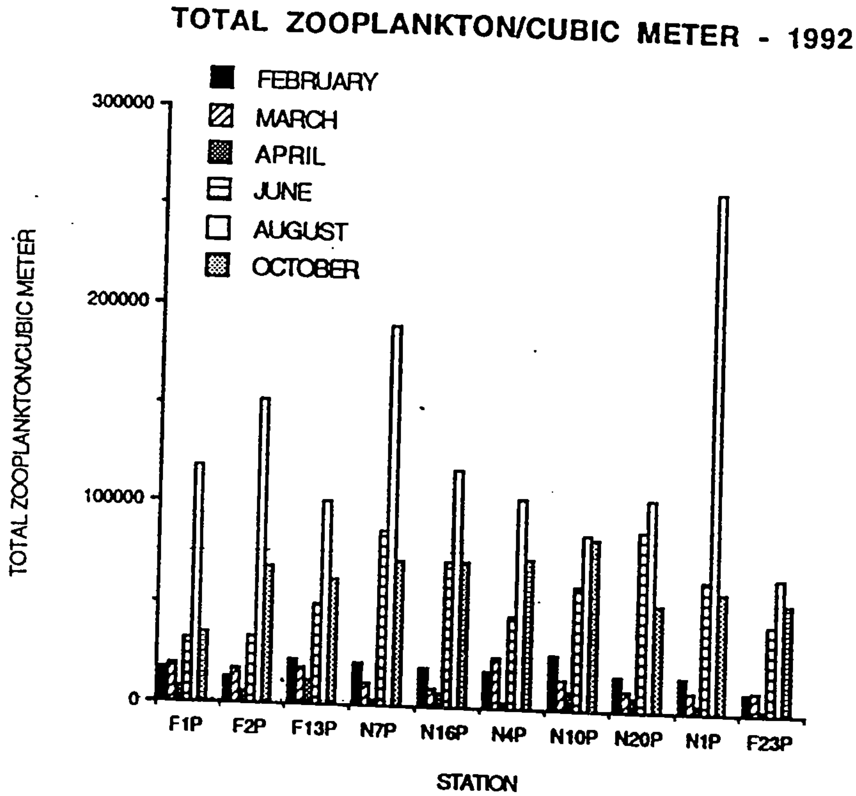
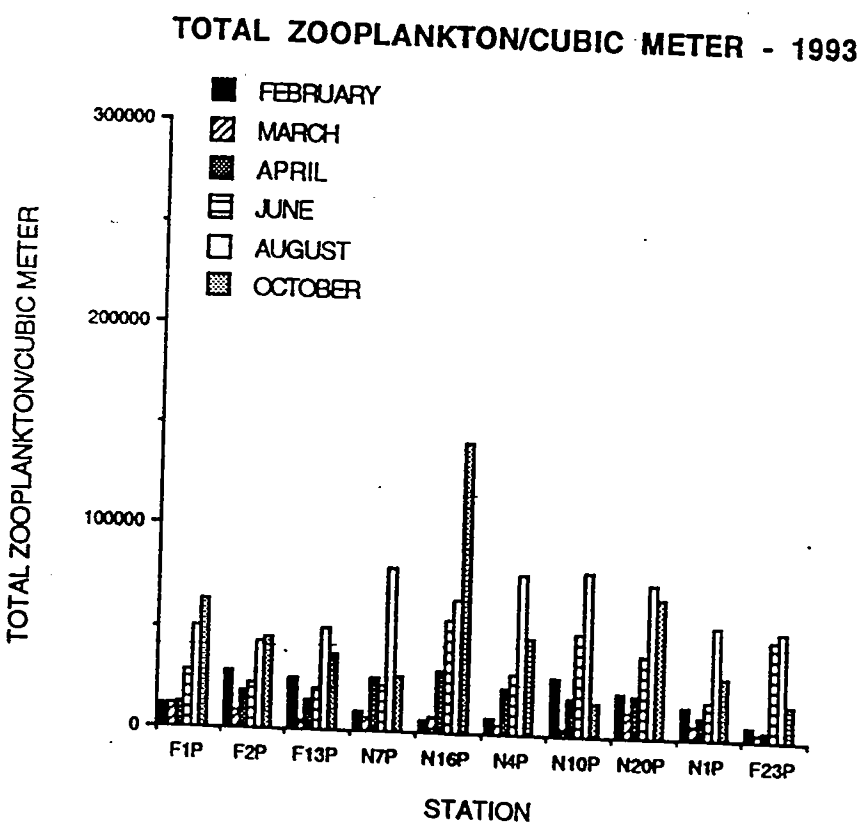



TOTAL ZOOPLANKTON/CUBIC METER - 1992
FEBRUARY
MARCH
APRIL
JUNE
AUGUST
OCTOBER
300000
200000
100000
0
TOTAL ZOOPLANKTON/CUBIC METER
F1P
F2P
F13P
N7P
N16P
N4P
N10P
N20P
N1P
F23P
STATION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FEBRUARY
MARCH
APRIL
JUNE
AUGUST
OCTOBER
300000
200000
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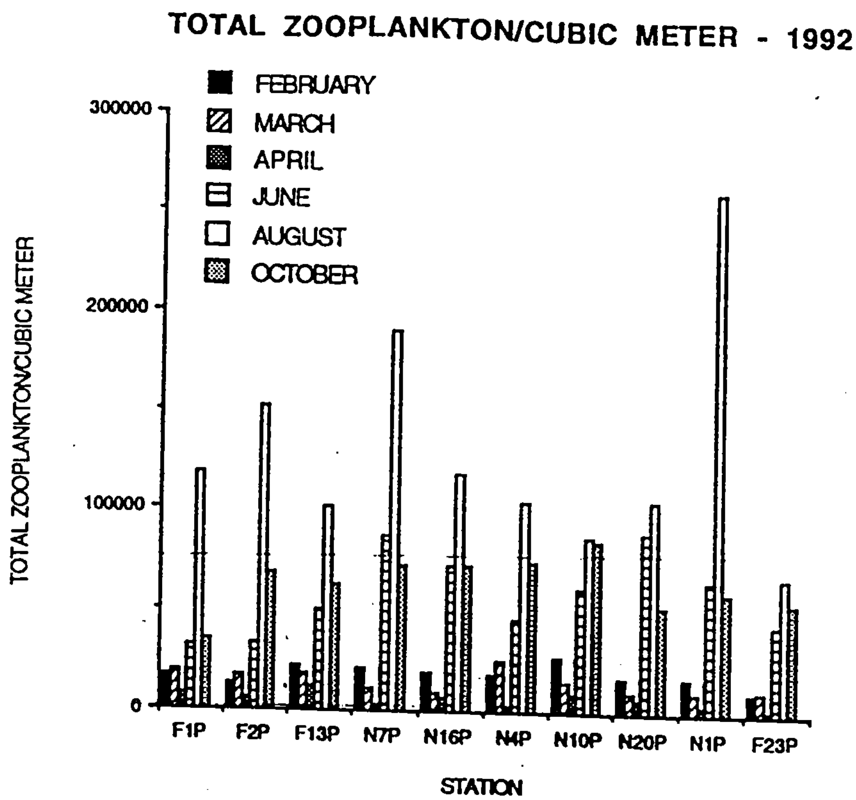
0
TOTAL ZOOPLANKTON/CUBIC METER
F1P
F2P
F13P
N7P
N16P
N4P
N10P
N20P
N1P
F23P
STATION


TOTAL ZOOPLANKTON/CUBIC METER - 1992
FEBRUARY
MARCH
APRIL
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OCTOBER
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TOTAL ZOOPLANKTON/CUBIC METER
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F2P
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N10P
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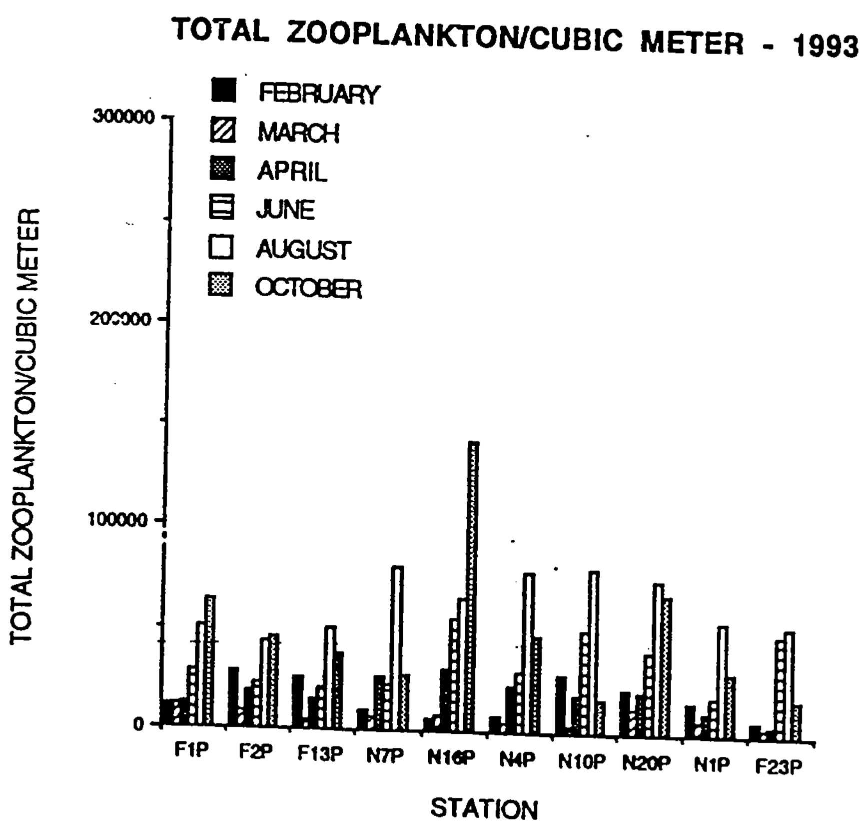
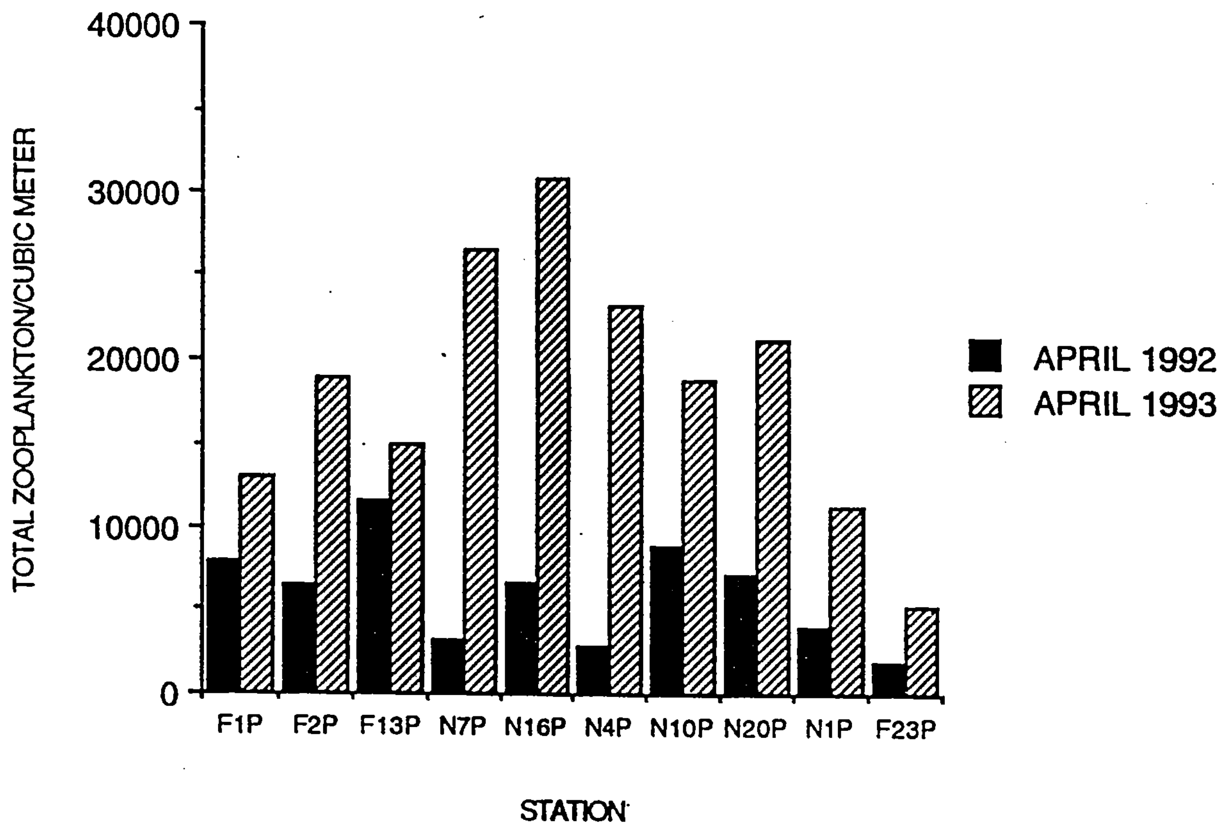
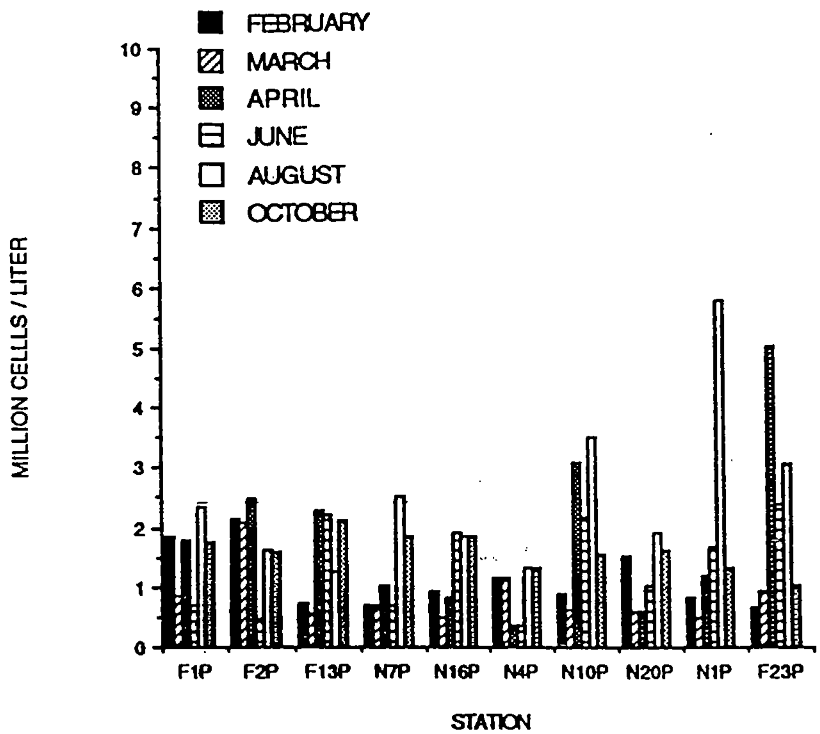
N1P
F23P
STATION


TOTAL ZOOPLANKTON/CUBIC METER - 1993
FEBRUARY
MARCH
APRIL
JUNE
AUGUST
OCTOBER
300000
200000
100000
0
TOTAL ZOOPLANKTON/CUBIC METER
F1P
F2P
F13P
N7P
N16P
N4P
N10P
N20P
N1P
F23P
STATION

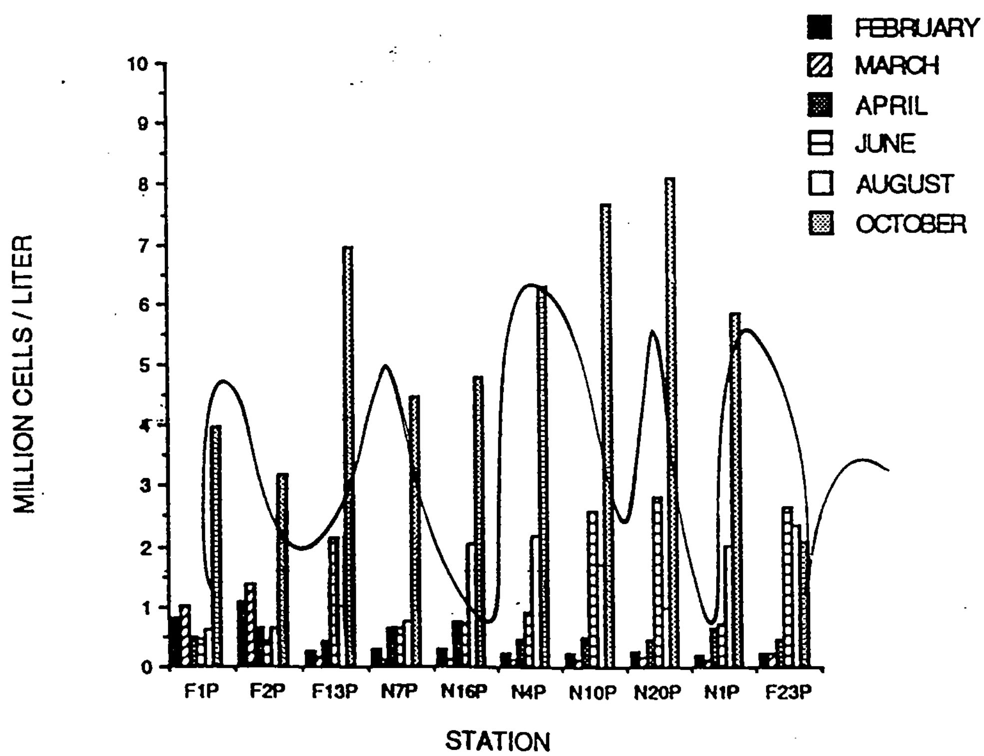
TOTAL ZOOPLANKTON - APRIL, 1992 versus APRIL, 1993



TOTAL SURFACE PHYTOPLANKTON - 1992



TOTAL SURFACE PHYTOPLANKTON - 1993



APPENDIX D

WRITTEN COMMENTS

K. Sellner Comments on MWRA Sewage Outfall Meeting, 1/20/94

1) Overall, I think the case was made fairly convincingly that there would only be an impact immediately at the diffuser. So I concur that a less intense spatial array of stations should be set up, perhaps along transects crossing over the diffuser. I am not as convinced that a simple "X" is the correct arrangement. I think an "H" like transect is more desirable, with the cross bar of the H arising from the Harbor-farfield transect, the western leg of the H from south of Cape Ann over the diffuser to but not into Cape Cod Bay and the eastern leg of the H more offshore with stations in the farfield to serve as "boundary" conditions for the HydroQual model. This leg need not be a transect but a number of stations far offshore parallel to the western leg of the H more inshore. However, I would definitely (1) identify exactly what Hydroqual needs as well as (2) seek statisticians' comments of data compatibility for 92 and 93 data with future data collected in the new design.

2) I do feel, unfortunately, that DiToro is correct, that a model is nearly our only means of predicting what should happen and a check to see whether public-alarming events might ever be attributed to the outfall.

3) Because your community identified toxic blooms as a critical concern, savings gained through reducing nearfield station number should be allocated to a nearshore sampling effort for toxic bloom algae.

4) Tow-yo data: This data should not be collected *unless* Jack Kelly can outline how results will be compared pre- and post-outfall. Whatever is proposed should be critically reviewed by a statistician (e.g., R. Alden, ODU) or biologists competent in the use of continuous profiles (e.g., C. Davis' statisticians, D. Mackas or Ken Denman, Canada Ocean Sciences, BC). The latter oceanographers have published extensively on spectral analysis for distributions of T, salinity, chl and ZP in shelf and oceanic waters.

These data, as well as the variability in nutrients summarized by Jack Kelly, might be a function of the intrusion or presence of different water masses in the region. Are there any salinity-T signatures for distinct water masses that would suggest that the variability is a function of advection or circulation in the region? Can the data be normalized to salinity, even with small salinity differences between areas? Several of the cross sectional plots in Kelly's reports certainly resemble distinct water masses over the shelf. Can Rocky Geyer help here? If a salinity-normalization could be derived, then much of the variability might disappear.

5) SOD and nutrient flux measurements have been collected in dark incubations yet light might reach the bottom in several of the experimental areas. Either accept the Giblin et al. rates as maximum or resolve to fund SOD and nutrient flux measurements by simulating diel light fields expected in these depths; total flux and SOD are likely to decline due to uptake of released nutrients by an active autotrophic assemblage in surficial sediments as well as aeration of surface sediments due to low but positive diurnal photosynthetic production of DO.

6) The supply of oxidizable substrate to the benthos must drive SOD and provide the reservoir of N & P recycled to the overlying waters. Sed traps should be deployed at depths below the pycnocline and deep chl max but as far above the bottom as possible, particularly during the spring and fall diatom and biomass maxima as well as during the summer when maximum productivity is expected. Traps should be, at a minimum, subsampled for chl. In addition, Giblin et al. should be encouraged to collect several additional subcores from their box cores and freeze these for subsequent chl analysis, the oxidizable substrate for SOD. They told me there extremely taxed as it is so perhaps frozen cores could be transferred to Battelle for chl analysis in the aerobic layer. Depth for processing should be decided in discussions with Giblin et al. Walter Boynton, CBL, University of MD, can provide some details on these analyses and assist in resolving sampling depths for chl analysis in the cores, etc.

7) ZP data: I disagree with the position that some estimate of ZP grazing is impossible with Turner's data. "Ballpark" estimates of grazing pressure can be derived by using a range of literature filtration rates as a function of particle number and temperature for the dominant taxa. Granted, it's a crude estimate but it would give you some feel for ZP as a player or non-entity at least in herbivory in the region. Even with Oithona's omnivorous nature unclear, a range of filtration rates on algal prey could be examined.

8) Temporal coverage should definitely include the spring, summer and fall, the latter two seasons perhaps providing the sediment diatom chl for SOD and nutrient regeneration in the region. See 5 and 6 above as well.

9) Primary Productivity: This parameter should be measured with 14C inoculations for samples collected through the euphotic zone (from the rosette bottles) and placed in the incubator at the light levels from which they were collected. Short-term incubations should be undertaken with depth integrated rates compared to rates estimated from the Cloern model. If rates for the 2 methods are similar for samples from the Harbor, Nearfield and Farfield for spring, summer and fall, then model-derived estimates can be used, scrapping the 14C measurements. Pmax, Ik and alpha could be collected *if* pre- and post-comparisons of physiological parameters is a goal as an index of change in the community's response. However, from Doering's data, the results don't look too promising in that there would have to be huge changes in these photosynthetic parameters, a function of the physiology not the methodolgy as his P-I data in the few graphs seen at the meeting and in the reports look very tight.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Northeast Fisheries Science Center
166 Water Street
Woods Hole, MA 02543-1097

January 27, 1994

MEMORANDUM FOR: Dr. Carlton Hunt
Battelle Ocean Sciences

FROM: Dr. David Dow *Dr. David Dow*
NOAA/NMFS/Northeast Fisheries Science Center - Woods Hole Laboratory

SUBJECT: Follow-up Comments on the January 20, 1994 MWRA Harbor Outfall Monitoring Program Review for Nutrients

Thank you for inviting me to the workshop. In as much as I was filling in for John Catena (NOAA/NMFS/Northeast Regional Office) and have not been involved in either of the two previous workshops, I hope that my comments are not redundant in regards to previously discussed issues. Hopefully, these constructive comments will provide you with some food for thought and be germane to the MWRA Harbor Outfall Monitoring Program.

One of my major concerns is that the workshop audience was dominated by scientists with few regulators present and no obvious environmental activists. Since the MWRA outfall monitoring program has become politicized, especially as a follow on to the release of the conservation recommendations in NMFS' biological opinion on the impact of the outfall on endangered marine mammals in Massachusetts/Cape Cod Bays, it would have been productive to have more discussion of compliance issues (NPDES permit; dissolved oxygen standards; qualitative evaluation of potential eutrophication standards; size of discharge zone; etc.) and public concerns (aesthetics of ecosystem; swimmable, fishable water quality; inshore seafood safety concerns; right whales; etc.). It is one thing for the scientists to agree upon water column or benthic monitoring parameters that can be measured and utilized as meaningful indicators of change in the system as a consequence of the outfall pipe coming online, but it is a challenge to convert these to indices that address the concerns of the public. Some discussion should be devoted to converting these monitoring parameters to indices of ecosystem health (Peters, 1986; Wallin and Hakanson, 1991; Sherman and Solow, 1992) or to employ the parameters as a component of an ecological risk assessment procedure (Schobben and Scholten, 1993; Harris et al., in press). This process would convert the monitoring results to something which can be interpreted by the public and which has a reality for environmental managers. Since an audience dominated by scientists is not likely to feel comfortable conducting this activity, you might want to devote a separate workshop to this subject with the appropriate audience.

Having previously worked at NASA conducting remote sensing research, it appeared to me that there were unrealistic expectations of the operational usefulness of the new ocean color scanner, SeaWiFS (sea-viewing, wide-field-of-view sensor) in providing synoptic coverage on an interval of every 2-3 days that would be required to track phytoplankton blooms and transient upwelling events. Nominally the SeaWiFS satellite will provide global coverage every two days (Hooker et al., 1993) with a scan angle of $\pm 58.3^\circ$ about nadir (centerline of satellite path), where the scan plane can be tilted -20°, 0°, or 20° in order to avoid specular reflection. The signal received by the satellite is influenced by events in the atmosphere (primarily absorption and scattering) and the water column (absorption by particles and dissolved organic matter and diffraction by particles in different size ranges), so that only 10% of the signal received by the satellite emanates from the water, while the other 90% represents atmospheric returns or reflection from the water surface. The satellite employs the blue and green wavelengths to estimate the pigment concentration in the top 1/5 of the euphotic zone (the actual depth of water column sampled is wavelength dependent with a maximum penetration in the open ocean at the blue wavelengths around 443 nm). For the Coastal Zone Color Scanner (CZCS) this limited the chlorophyll retrieval accuracy in surface waters to $\pm$ 40% (Sathyendranath, 1986) with a precision (coefficient of variation) of 48% (Smith, 1984). The SeaWiFS sensor possesses 8 bands with narrower spectral bandwidths than the CZCS sensor (6 bands), plus the SeaWiFS dynamic range is 10 bits rather than 8 bits, so that it should have slightly better retrieval accuracy and precision.

The SeaWiFS has a 1.1Km spatial resolution at nadir with a swath width of 2800Km ($\pm$ 58.3° from nadir) for LAC (local area coverage) data which would presumably provide the synoptic satellite data to be utilized for monitoring of ocean color in Massachusetts and Cape Cod Bays. Operational LAC data will be expensive to obtain. In addition quantitative assessment of pigments via satellite is most accurate within $\pm$ 35° of nadir. Given the constraints of cloud cover (saturates SeaWiFS sensor and causes shadow problems) in the nearshore region (accentuated by differences between water and air temperature near land), it is my opinion that weekly coverage is the best one is likely to obtain. The summer periods of deep chlorophyll maxima in the nearfield monitoring area will be underestimated from satellite ocean color data and the periodic intrusions of water from Boston Harbor will yield much greater absorption of wavelengths by particulate and dissolved organic matter than is the case for the oceanic water used to develop the satellite-derived chlorophyll estimation algorithms. The models predict that the nearfield is the only area that is likely to be influenced by the MWRA outfall pipe and weekly synoptic sampling by satellite may not be timely enough. This sampling regime would be adequate for the farfield monitoring area, but the models predict no impact in this region (except possibly for transient events).

The one final area of concern is the apparent failure of the HydroQual water quality model to address the impact of dissolved organic nitrogen (DON) from the effluent of primary-treated sewage being released at the outfall location. I am not an expert in this area, but it would appear that the model view of particulate organic nitrogen (PON) fueling the cycle of nitrification/denitrification in the sediments should be augmented by DON released in the bottom waters fueling this nitrogen flux. If the model shows that DON should be considered as well as PON, then the field sampling program on benthic nitrogen fluxes may want to measure DON and PON concentrations.

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cc: George Grice
John Catena

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Suite 2
Chelmsford, Massachusetts 01824
Telephone (508) 453-4300
Fax (508) 453-7260

MEMORANDUM

FILE NUMBER: 300
DATE: February 1, 1994
FROM: J. Cura
TO: Carleton Hunt
SUBJECT: Nutrient Indicators Workshop

This memorandum presents my thoughts on the recent "Key Nutrient Indicators Workshop." As I indicated at the meeting, Massachusetts Bay is currently in a steady state condition with the nitrogen loading from Boston Harbor, and that moving the outfall to a new location would not affect the total loading. Therefore, we should be specific concerning the objectives of the program.

In my opinion, bay-wide eutrophication is unlikely to be affected by a change in outfall location. However, there may exist the opportunity for local changes near the outfall. I think the current monitoring program, with its emphasis on near field effects and some monitoring of far field stations, addresses the question of potential local changes.

I think several of the statements made at the meeting support this opinion. Specifically:

> According to Dom Ditoro, the models do not project increases in chlorophyll, either in the bay generally or in the near field;
>
> Jack Kelly indicated that approximately 88% of the current loading from Boston Harbor is entering Massachusetts Bay, in the current outfall position; and,

The often-expressed concern that most of the nitrogen load is coming from the Gulf of Maine, north of Cape Ann.

In addition, the historical phytoplankton and chlorophyll data which I reviewed some time ago (Cura, 1991 - Massachusetts Water Resource Authority (MWRA) Technical Report # 1) indicates that Massachusetts Bay has not been subject to nuisance phytoplankton blooms, unusual productivity, or unusual timing of blooms. There are occasional *Phaeocystis* blooms, but these are widespread beyond Massachusetts Bay and have been noted in the historical record since before the construction of the treatment plant. Monitoring by MWRA (Dave Townsend and more recently, Jeff Turner) indicates that neither the distribution, species composition, nor abundance of phytoplankton has changed recently relative to the historical record.

In addition, I made some calculations regarding the relative magnitude of nitrogen sources to Massachusetts Bay, which I presented at a NEERS Meeting in the autumn of 1992. The calculations demonstrate that on a bay-wide basis, the loading of nitrogen from onshore sources, (including the MWRA discharges) is small relative to the estimated load from north of Cape Ann.

This analysis was done by calculating nitrogen loadings from river input, NPDES discharges, coastal CSO and coastal runoff, groundwater from Cape Cod, and transport of nitrogen from north of Cape Ann to Massachusetts Bay. These calculations are provided in the attached materials.

Calculation of Nitrogen Loadings from Various Sources to Massachusetts Bay

1.0 River Loadings

River load = river flow x total Nitrogen concentration

River flow obtained from USGS gauging stations, or calculated based on drainage area, multiplied by 1.7 cfs per square mile.

Total nitrogen concentration from state water quality monitoring programs:

e.g.

Mystic River	30 observations from 1982 to 1987
Charles River	31 observations from 1982 to 1987

Summed loading from all rivers south of Cape Ann

Annual nitrogen loading from rivers to Massachusetts Bay = 2.7×10^3 metric tons nitrogen/year.

2.0 Coastal NPDES discharges

Coastal NPDES loading = annual flow x total nitrogen concentration

Flow and nitrogen data obtained from discharge monitoring reports and permit applications

Coastal NPDES loading = 1.55×10^4 metric tons total nitrogen/year

Note: includes Nut Island sludge (1.1×10^3 metric tons)
MWRA discharge = 1.1×10^4 metric tons

3.0 Nitrogen from Coastal Runoff and CSO's

Coastal runoff/CSO = total nitrogen in runoff within 0.5 Mile of coast + total nitrogen in CSO's

Flow in CSO's from NOAA's NCPDI data base

Runoff from urban areas calculated from land use and runoff coefficient from NCPDI data base

Non-urban runoff calculated from US Department of Agriculture model

Mean nitrogen data in stormwater obtained from EPA's national urban runoff program

Mean nitrogen data in CSO's obtained from mwra studies

Coastal runoff/CSO's = 8.45×10^1 metric tons nitrogen/year

4.0 Nitrogen Loading from Groundwater on Cape Cod

Estimated by two methods:

Method 1 estimate = Median measured nitrate concentration x flow

Median calculated from 498 samples taken by Barnstable County Health Department 1989-1990

Flow from estimates of groundwater recharge (estimated at 50% precipitation)

2.24×10^2 metric tons nitrogen/year

Method 2 followed Valiela et al. = 3.22×10^2 metric tons nitrogen/year

5.0 Nitrogen from Atmospheric Source

Dry deposition = deposition velocity x concentration

Galloway, et al. (1987) provide measurements of deposition velocity and measured concentration

Wet deposition = concentration x precipitation

Measured concentrations provided by NADP (1989)

Atmospheric loading = 4.48×10^3 metric tons nitrogen/year

6.0 Nitrogen from North of Cape Ann

To calculate the import of nitrogen to Massachusetts Bay from coastal waters north of Cape Ann, I made several assumptions, which appear to be justified based on the Massachusetts Bay program physical oceanography project:

Most of the flow into Massachusetts Bay occurs between Cape Ann and Stellwagon bank along a 25 km transect

Average current across transect = 2.5 cm/second

Average depth across transect = 50 meters

I calculated volumetric transport on an annual basis as:

Transect length x depth x current speed x one year.

Volumetric flow = 9.85×10^{11} m3/yr

Note that this flow yields a residence time of approximately 70 days, which is in the range estimated by the Massachusetts Bay Physical Oceanography Program.

I then calculated nitrogen concentrations from stations off Cape Ann provided by Bigelow Laboratory.

Included DIN and PON

Calculated depth averaged nitrogen to 50 meters

Calculated seasonal averages as:

January - March	14.4 uM DIN	5.5 ug/l PON
April - June	4.8 uM DIN	5.5 ug/l PON
July - September	5.5 uM DIN	33 ug/l PON
October - December	5.0 uM DIN	26 ug/l PON

Monthly loading = monthly [n] x monthly flow

Annual nitrogen load from Gulf of Maine north of Cape Ann = 1.26×10^5 metric tons of nitrogen

This simple analysis shows that:

An estimated 85% of the total nitrogen to Mass Bay is the import of nitrogen from coastal waters outside Mass Bay;

coastal runoff/CSO loadings and groundwater are insignificant sources bay-wide (although both may be important in eutrophication of poorly flushed coastal coves or harbors);

rivers which discharge directly to Massachusetts Bay and atmospheric loadings are minor sources of nitrogen;

all NPDES discharges account for about 10% of the nitrogen load to Massachusetts Bay, and most of this is from the MWRA discharge. This is a very small contribution to the total nitrogen demand in the bay, and indicates that, on a bay-wide basis, the MWRA discharge is unlikely to result in eutrophication of the bay.

I think that potential eutrophication problems in Massachusetts Bay are more likely to be in the small coastal coves and estuaries, due to local stormwater or groundwater discharges.

HARVARD SCHOOL OF PUBLIC HEALTH

Department of Population and International Health

MEMORANDUM

From: Charles J. Puccia

To: Michael Mickelson, Carlton Hunt, Michael Connor,

February 2, 1994

Subject: Comments on Monitoring Workshop

For ecosystems exhibiting large variability, monitoring confronts two issues. One issue must reconcile the implications of variability in terms of ecological dynamics; the workshop language called this understanding "meaningful change" in the ecosystem. The other issue concerns the need for an overwhelming amount of data to get a "baseline" for highly fluctuating ecosystems. Here, the monitoring strategy, coupled to analytical methods, devises invariant measures from the data. This permits detecting real change and not "normal" variation.

Highly variable ecological systems might arise for many reasons. Among the hypotheses that might apply include: 1. A high nonlinearity exists in the relationships of the organisms to the physical environment; 2. There are frequent, strong "inputs" or perturbations; 3. These systems are far from equilibrium; 4. The ecosystems have time-delays or have "chaotic" behavior; 5. These are ecosystems with populations that respond quickly to environmental cues, but slowly to biotic action.

With a goal of maximum information and optimizing time and money, the workshop dilemma distilled to a choice between two monitoring plans:

a. One that increases the number of variables, but includes fewer sampling sites.

b. One that increases the number of sampling sites but searches for fewer variables.

The choice will depend on several conditions, including: The reason for the large variability; An ability to imbed the current data into that gained by using new sampling sites; The methods employed in the data analysis.

Without hypotheses as to the causes of the variability, or the expected outcome as to the likely kinds

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of changes to occur in Massachusetts Bay, then a first guess as to a monitoring strategy would be to use a hierarchial approach. This approach nests sites with the widest possible differences within a habitat. Within a site the choices would be to accentuate the greatest differences among microhabitats, organisms, and time-periods. This seems consistent with the needs of the water quality modeling, at least from the comments made by Dom DiToro.

In addition, from the analytical side, some simple correlation analysis among components might prove interesting. It should be possible, for example, to show what types of correlation patterns might be expected concerning dinoflagellate blooms. For now, the initial analysis can be done to show possible diffusion effects. Often correlation coefficients are related to phase-shift. A correlation analysis of the same variable at different sites may be indicators of rates of diffusion of effect. To compare the data of the near-field and far-field sampling under existing conditions might prove interesting.

Different analytical strategies can help discern the cause of the variability within the outfall pipe study area. The exact analysis requires more thought than possible here, and perhaps worth a follow-up discussion.

These comments are intended to generate thoughts, and certainly without more detail and discussion cannot begin to give specifics on a monitoring program. I suspect some if not all these comments may appear incomplete. It is not my intention to confound an already difficult task, appearances to the contrary! If warranted, I would be willing to expand on these comments, and welcome suggestions.

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January 21, 1994

Dr. Michael Connor
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Dear Mike,

As a follow-up to yesterday's meeting, I have a few comments. I really enjoyed the meeting and was impressed with the monitoring team and what they have accomplished. As you know, the public concerns are quite straightforward and deal with swimming, eating seafood, protecting marine life, and maintaining aesthetics. I think the combination of general monitoring and specific monitoring (eg. red tide studies, plume tracking) is the best approach. From the data that was presented, I think the general monitoring could be modified to increase temporal resolution using moorings, increase spatial resolution by using satellite imagery and extensive towyoing, and decrease fixed-station sampling in the near field.

I recommend that the crossed-transect concept be adopted. The along-shore transect should follow approximately the 40m isobath from Cape Ann into Cape Cod Bay. This transect should include approximately 15 fixed stations. The towyoed CTD/fluormeter should be done along the length of this transect (the towyoing would take about 10 h at five knots). This will greatly increase the length-scale of sampling, which is necessary since you basically have a flow-through system, while at the same time providing important fine-scale information. The cross-isobath transect should extend from Boston Harbor across the northern tip of Stellwagon Bank and include about 10 fixed stations. Again, the towyoing should be done along the entire length of this transect. Additional boundary stations between the tip of Stellwagon Bank and Cape Ann should also be occupied. The cruise track would then start in Boston Harbor and extend eastward through the outfall site, across Stellwagon Bank, then northwest to Cape Ann, and then southerly along the 40m isobath into Cape Cod Bay.

Although effects of the outfall are unlikely to be seen as far south as Cape Cod Bay, certain wind conditions could potentially favor rapid plume transport to that area. If you think about the vertical section you will have from the towyo along the 40 m isobath, it would be unwise to terminate this section too soon, and Cape Cod Bay will provide an important end-point. There are, of course, political reasons for extending the transect into Cape Cod Bay, but, these aside, I think there is good scientific justification for doing so. As discussed, the primary productivity measurements should be limited to a few estimates of vertical variability vs light.

With regard to temporal scales of sampling, the crossed-transect sampling should be done every 2-3 weeks, and this sampling should be augmented with moored CTD/fluorometers to obtain high frequency data. These moorings should be placed at the center and on the arms of the cross. The sensors could be placed at the surface and at 20 m. Jim Irish (WHOI APO&E) gave me some rough costs for such moorings. The mooring itself will run about 40K and each CTD/fluorometer package (from Chelsea Instruments) is about 25K. So that comes to 105K per mooring. The sensors should last about 3 months before fouling and at that point will need to be swapped for clean sensors. The mooring hardware should be serviced at about the same interval. Jim also recommends having replacement sensors for each sensor package so that the on-site servicing can be done quickly. That would mean another 50K per mooring for a total cost of about 155K for each mooring. Even if you can only afford one or two moorings, the high frequency data obtained would be critical for interpreting the fixed-station and towyo data.

Satellite remote sensing should be an integral part of the monitoring study. Synoptic, baywide IR and ocean color (from SeaWifs) information will prove invaluable. These images will provide insights into inflow of GOM water mass and phytoplankton as well as transport and phytoplankton/particulate load throughout the bays. Although the chlorophyll maximum is below the surface during the stratified period, Sea Wifs may still be able to "see" it (I sent a message to Jim Bisagni at Rhode Island about this). Also, the system is unstratified for most of the year.

Finally, I suggest you consult with Andy Solow (WHOI) on the proper statistical design of the sampling program, given the data you've collected thus far. He might suggest you keep everything the same as your current plan for comparative purposes or perhaps align stations better with the circulation patterns in the bay. A meeting with Andy, Signell, Hydroqual, and Kelly is probably needed. I have talked with Jim Bisagni (NOAA Narragansett) and he could provide you with the satellite images from SeaWifs as part of his Gulf of Maine study (though it would not be free). His number is (401) 782-3313.

Thanks again for an informative and constructive meeting.

Sincerely,

Cabell

Cabell S. Davis
Associate Scientist