1999 MWRA Annual Technical Workshop Summary

for

Meetings and Public Presentations Task 34
MWRA Harbor and Outfall Monitoring Program: 1998-2001

Submitted to

Massachusetts Water Resources Authority
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1999 MWRA Annual Technical Workshop
Battelle, Duxbury, MA
Benthic Monitoring and Fish/Shellfish Monitoring – April 9, 1999
Water Column Monitoring and Nutrient Cycling – April 12, 1999

Key Points and Conclusions

Benthic Monitoring

Benthic Monitoring Thresholds Approach/Rationale *(Mr. Ken Keay, MWRA)*

- Benthic thresholds are not done and completing them is a priority
- No changes to the benthic community are expected as a result of outfall discharges
- Focus on local or nearfield areas where any change is most likely to first be seen.
- Thresholds must be easy to apply and evaluate ecologically significant parameters.

1998 Sediment Profile Imaging *(Dr. Robert Diaz, VIMS)*

- Distribution of sediment textures at nearfield study area appeared to be dominated by physical processes, as indicted by the organisms sediment index (OSI)
- Surface features were dominated by biogenic activity.
  - Mounds and tubes were the dominant surface biogenic structures, and subsurface structures and organisms were common and widely distributed.
  - Well-developed fauna characterized as intermediate to advanced in successional stage.
- Sediments over much of the nearfield did not exhibit within-station variability with the silty-sand as the modal sediment type
- Three SPI images per station not enough to consistently estimate a 50% change in the RPD layer at all nearfield stations.

1998 Hardbottom Community *(Dr. Barbara Hecker, Hecker Environmental)*

- The structure of the hardbottom benthic community is controlled by location on the drumlins (concurrent depth), substratum type, local relief, and sediment drape.
- Most areas appear to be temporally stable.
- A number of areas are spatially heterogeneous.
- Differences between temporal and spatial variance are difficult to dissect.
- Some variability exists in the data. Hardbottom habitats are patchy in nature.
- Current program highly unlikely to be able to detect small shifts or changes in the composition of the hardbottom communities.
- The most likely "keystone" species would be *Lithothamnion* because it is very abundant, widely distributed, less patchy than *Asparagopsis*, and appears to be sensitive to sediment loading.

Infaunal Community Overview *(Dr. Roy Kropp, Battelle)*

The presentation focused on the findings of Blake *et al.*(1998) because 1998 data analysis was incomplete.

- Traditional ecological metrics (density, species numbers, diversity) were very similar among Nearfield and Midfield stations and, with the possible exception of species numbers, showed little or no apparent temporal trend. Species numbers may have showed an increasing trend with time.

- However, cluster analysis of the Nearfield and Midfield stations revealed two primary infaunal communities. One was typically associated with sandy substrates near the outfall and has been a relatively consistent feature for several years. The other was typically associated with siltier substrates located farther from the outfall.

- Cluster analysis of Farfield stations revealed two main types of infaunal community. One was comprised of stations in Cape Cod Bay. The second consisted of all the remaining Farfield stations. The geographic location and depth of the stations may offer a better explanation of the station groupings than measured sedimentary features.

Benthic Community Threshold Assessment *(Dr. Gene Gallagher, UMass – Boston)*

- At the community- and functional-group levels, thresholds will be based on significant changes in a "pooled" population of nearfield stations with respect to
  - Species diversity (richness and evenness
  - Change in indicator species
  - Change in frequency of functional groups
- This threshold assessment can be made quickly (within 1 week).
- A full assessment of change in species composition will be made at the end of each year. This requires a longer QA/QC process for species composition.

1998 Sediment Chemistry *(Dr. Carlton Hunt, Battelle)*

- Contaminant concentrations consistent with previous sampling years.
- Changes due to shifts in grain size and TOC
- Lower concentrations at some stations than values found in the early 1990s.

Fish and Shellfish Monitoring

Introduction to Fish and Shellfish Threshold *(Dr. Carlton Hunt, Battelle)*

- This area of the HOM program is mature and has been executed consistently since 1994.
- Thresholds are well established.

1998 Caged Mussel Studies

- Contaminant concentrations were consistent with or slightly lower than previous years.
- A site in Quincy Bay was added to the monitoring program in 1998. This site was added to evaluate the effects of the diversion of Nut Island discharges.
- A site in eastern Cape Cod Bay was added to the monitoring program in 1998. This site was added as an offshore reference site.

1998 Flounder and Lobster Chemistry Studies *(Ms. Lisa Lefkovitz, Battelle)*

- 1998 results are consistent with previous years
- Organic contaminant concentrations
  - Generally highest at the Discovery (Boston Inner Harbor) site and lowest at the eastern Cape Cod Bay site.
  - Generally decreased since 1992, particularly at the Discovery and Deer Island sites.
- Metals concentrations
  - More variable than organic contaminant concentrations and relatively constant between years
  - Mercury concentrations in flounder livers have decreased since 1992.

1998 Flounder Histopathology *(Dr. Michael Moore, WHOI)*

- Catch per unit effort of winter flounder generally higher than in recent years, particularly at Broad Sound and the outfall.
- Histopatholgy findings were consistent with previous years at all sites.

Water Column Monitoring and Nutrient Cycling

Modeling Results for 1993 and 1994 *(Mr. Jim Fitzpatrick, HydroQual)*

- When compared to observed data, the model appears to capture the major temporal and spatial features of phytoplankton biomass, as indicated by chlorophyll a, and dissolved inorganic nutrients in Massachusetts and Cape Cod Bays.
- The model also appears to capture the major temporal and spatial features observed in the dissolved oxygen data.
- Computed rates of bottom water dissolved oxygen are consistent with those estimated from the harbor outfall monitoring program data.
- the model approximately reproduces the seasonal and spatial features of sediment nutrient processes are indicated by comparing model computations against observed data for sediment oxygen demand, ammonia flux, nitrate flux, and phosphate flux.
- However, the model under-estimates dissolved silica fluxes in Massachusetts Bay.
- Model computations of DIN:DIP and DIN:Si ratios are consistent with the observed data and suggest that during the summer months primary productivity is limited by the availability of dissolved inorganic nitrogen.
- While the model appears to reproduce the major temporal trends in the observed data, particularly when viewed using seasonal averaging periods, the model does not reproduce species-specific algal blooms, such as were observed in the spring of 1992 and the fall of 1993.
- While the model partially reproduced the differences in bottom water minimum dissolved oxygen between 1992, 1993, and 1994, the model was unable to reproduce the minimum dissolved oxygen values observed in 1994.

1998 Physical Regime *(Dr. Rocky Geyer, WHOI)*

- Forcing conditions
  - warm winter,
  - very wet spring (particularly May and June)
  - persistent southerly (upwelling) winds in summer
- Oceanographic conditions
  - warm bottom water (early)
  - very low salinity at surface and bottom
  - high stratification
  - less warming of bottom water than normal
- 1998 may have seen some upwelling events that affect biological conditions

1998 Water Quality Overview *(Mr. Scott Libby, Battelle)*

- Lack of a Winter/Spring Bloom – The winter/spring period in Massachusetts and Cape Cod Bays is often characterized by the occurrence of a bloom in phytoplankton and chlorophyll. The presence of elevated nutrient concentrations, increasing light availability and water temperatures, and the onset of seasonal stratification establish conditions that are conducive for a bloom to occur in the bays. Other factors may play a role in the realization of a winter/spring bloom – zooplankton grazing, resident phytoplankton assemblage, and many other physical, chemical, and/or biological factors that have not been resolved. In the winter/spring period in 1998, no bloom was observed and elevated nutrient concentrations persisted in the surface waters until May. Nutrient and production data indicate that bloom conditions existed and that the phytoplankton community had started to bloom (nutrient drawdown between February and March and high productivity), but an increase in biomass was not achieved and a winter/spring bloom did not occur in Massachusetts Bay. In Cape Cod Bay, however, the data suggest that a bloom may have occurred prior to the first survey in February.

- July/August Upwelling – Physical and chemical data suggest that significant upwelling events occurred in July and August of 1998 and that these events input nutrients into the coastal surface waters. Evidence of this was observed at coastal stations along the south shore and in the western nearfield. The upwelling conditions, along with tidal transport from Boston Harbor, supplied nutrients to the nearfield that supported the high phytoplankton concentrations that were observed in August.
- September/October Fall Bloom – As with the winter/spring bloom, the fall bloom is not a consistent annual characteristic in the Bays. The intensity of the fall bloom and the phytoplankton species that bloom have varied from year to year during the baseline-monitoring period. In 1998, the fall bloom was not single species bloom, but rather a general increase in the numbers of a variety of chain-forming diatoms. The bloom was more clearly observed in the increased chlorophyll concentrations and productivity data that were collected.
- Extended Period of Stratification and DO decline – The onset of seasonal stratification was slightly delayed in 1998 compared to previous baseline monitoring years as was the overturn of the water column and the return to winter conditions. The water column was stratified until November throughout much of the nearfield and a deep halocline was present in December at the deeper eastern nearfield stations. The strength and duration of stratification are important factors in the decline of bottom water dissolved oxygen concentrations. Due to the persistence of stratified conditions in 1998, bottom water DO concentrations decreased over the entire June to December time period in the nearfield area. The delay in mixing, combined with a pulse of organic material from the atypical November/December bloom, led to the annual minimum in bottom water DO concentration (7 mg L^{-1}) observed in December. The DO minimum concentration was not extremely low in comparison to data collected during previous baseline monitoring years. Due to major storm events and the lack of an input of organic material from a winter/spring bloom, the bottom water DO concentrations observed in June were very high (11.2 mg L-1), which subsequently lessened the effect of the delay in returning to well-mixed winter conditions.
- November/December Elevated Ammonia and Phosphate Concentrations – In November and December 1998, anomalously high concentrations of ammonium and phosphate were observed in the western nearfield that correlated with high concentrations observed by the MWRA in Boston Harbor. The source of these nutrients was not determined, but may have been due to the transfer of south system sewage flows from Nut Island to the Deer Island facility, increased dredging operations in the harbor, an ecological change in biological utilization of nutrients in the Harbor, or other factors. It is suspected that the anomalously high NH_4 and PO_4 concentrations triggered a localized bloom that was observed in the nearfield in December.

1998 Plankton Overview *(Dr. Jefferson Turner, UMass – Dartmouth)*

- Whole-Water Phytoplankton Assemblage
  - Microflagellates and small cryptomonads were the numerical dominants.
  - Sustained increase in total phytoplankton abundance, from low levels in February through April to high levels in May through October, followed by declines in November and December.
  - No major winter/spring bloom or fall bloom
  - No confirmed nuisance algae blooms, although the fall *Pseudo-nitzschia pungens* records could have included some *P. multiseries.* Maximum abundance of *P. pungens* did not exceed 83×10^3 cells/L.
- Screened Water Phytoplankton
  - *Distephanous speculatum* (silicoflagellate) was dominant in February, followed by *Ceratium longipes* and *C. tripos.*
  - *C. longipes* and *C. tripos* dominant from March onward, followed by other dinoflagellates.
  - Sustained bloom of *C. longipes* and *C. tripos* was the major event

- Zooplankton
  - Dominated by copepod nauplii, adults, and copepodites of the small copepods *Oithona similis* and *Pseudocalanus* spp., with seasonal subdominant contributions from gastropod and bivalve veligers and a mixture of other normally occurring taxa.
  - Additional Cape Cod Bay stations samples during WF981, WF982, and WF984 extended total abundance recorded for F01 and F02.
  - Once outfall on line, expect the copepod abundance in the nearfield and farfield outside Boston Harbor will be dominated by *Oithona similis*, *Pseudocalanus* spp., and, to a lesser extent, *Paracalanus parvus*, *Centropages typicus*, *C. hamatus*, and *Calanus finmarchicus*.
  - Meroplankton abundance are "spikey" and more liekly related to reproductive cycles of the macrobenthic parents than to processes in the plankton.
- Zooplankton Threshold. Suggest abundance of *Acartia tonsa/A. hudsonica* > 50% of the total non-naupliar copepods (adults and copepodites)

1998 Productivity Overview *(Dr. Aimee Keller, URI)*

- Annual production at N04, N18, and F23 lower than in prior years
- Seasonal productivity pattern dominated by fall bloom
- No winter-spring bloom despite increased chlorophyll-specific production during typical bloom period
- Bloom failure not correlated with nutrient availability or light limitation
- Bloom failure may be related to warm winter temperatures and increased grazing by zooplankton
- Productivity significantly correlated with composite parameter (but variable across years)

1998 Nutrient Cycling in the *Harbor* *(Dr. Anne Giblin, Marine Biological Laboratory)*

- Sediment trends in the highly impacted sites in the northern Harbor may be showing some decrease in fluxes even with the amphipods present.
- Denitrification rates have gone up and down a bit with amphipod colonization but still not a major factor in removing anthropogenic nitrogen.
- DIN/DIP ratio may have shifted up but the majority of 1998 data still shows benthic fluxes still less than 16 (i.e., would contribute to nitrogen limitation).

Statistical Approach to Threshold Testing and Rule Setting *(Dr. Jeff Rosen, TPMC)*

- Currently evaluating ways to aggregate data and conduct statistical tests
- Must define rules for aggregating the data.

Introduction and Program Overview

The goals of the 1999 MWRA Annual Technical Review Workshop were to:

- Present, review, and discuss 1998 data in the context of historical understanding of the system,
- Provide a forum for discussing the 1998 results in the context of previous monitoring years and potential or predicted affects of the new outfall effluent to the Massachusetts Bay system,
- Debate the monitoring thresholds as appropriate,
- Develop themes and key presentations for the upcoming public OMSAP science meeting,
- Provide technical discussions that would enhance data interpretation in the annual reports,
- Convey progress toward outfall startup, post-discharge monitoring plan development, and reporting issues.

HOM Program Update

Many facility improvements have been made over the last 10 years, resulting in improvements in solids discharges. The improvements include the cessation of sludge discharges in December 1991, the new primary treatment facility startup in 1995, the new secondary treatment facility startup in 1997, and the diversion of Nut Island flows to the Deer Island facility in 1998. Each improvement was followed generally by a decrease in effluent solids and contaminants loadings. Since 1992 the total effluent nitrogen loading has remained at approximately 10,000-12,000 tons per year. Modeled average dilution of sewage effluent under winter conditions shows that, historically, the effluent from existing harbor outfalls entered the system, and that the effluent will enter the system from the new Massachusetts Bay outfall but will be diluted much more quickly than effluent from existing outfalls.

MWRA's discharge permit is the most environmentally protective permit ever issued. The Outfall Monitoring Plan and the Contingency Plan have been incorporated into the permit. With the effluent discharge from the Massachusetts Bay outfall scheduled to begin in the fall of 1999, plans are being finalized for meeting and responding to the permit requirements. Section 8.a.of Draft NPDES Permit #MA0103284 essentially requires the on-time delivery of data products:

> *the results of any monitoring required by the contingency plan shall be reported ...*(annually)*...except that if any parameter exceeds the corresponding early "caution level" or "warning level" the monitoring results shall be reported within ten (10) days after the results becomes available. The MWRA shall make all reasonable efforts to provide results within ninety (90) days after the sampling event, and MWRA shall obtain approval from EPA and the MADEP if the results will take longer than one hundred and fifty (150) days.*

To date, HOM3 has submitted data reports within the 90-day reporting requirement, with one exception (histology), and beaten the 1992-1997 average by two or more months for each report type. This performance confirms MWRA's ability to meet the permit-imposed deadlines.

In Section 8.b. of the draft permit describes the warning-level-reporting process.

> Section 8.a. Draft NPDES Permit #MA0103284: *If any parameter exceeds the "warning level" listed above in Section 8.a., the MWRA shall (1) determine whether there are any adverse environmental impacts from such exceedance, (2) evaluate the extent to which MWRA discharge contributes to such impacts, and (3) unless MWRA demonstrates by convincing evidence, to the satisfaction of EPA and the MWDEP, that the MWRA discharge does not contribute to such adverse environmental impacts, develop a plan and schedule to address such impacts...*

Toward this end, the following activities are in the process of being completed.

Outfall Monitoring Plan Status and Thresholds

- Revised draft of the OMP in development
- Focusing on completing threshold statements
- Threshold testing will be one theme for the June (Tentative) 1998 OMSAP Public Science Meeting
- Automation of the threshold and monitoring comparison process pending completion of thresholds (Task 30). Will reside within the database. Review data on upload and acceptance
- Requires strict protocols for the data aggregation and defined statistical testing protocols

Workshop Summary Organization

A list of workshop participants immediately follows this introduction. Key points are summarized and presented by speaker. A complete compendium of presentation materials is included at the end of the document.

Workshop Participants

April 9	April 12	Name	Affiliation
✓	✓	Mike Mickelson	MWRA
✓	✓	Ken Keay	MWRA
✓	✓	Mike Delaney	MWRA
✓	✓	Maury Hall	MWRA
	✓	Andrea Rex	MWRA
✓	✓	Joseph LoBuglio	MWRA
✓	✓	David Taylor	MWRA
✓	✓	Tara Toolan	MWRA
✓		Wendy Leo	MWRA
	✓	Doug Hersh	MWRA
	✓	Kelly Coughlin	MWRA
	✓	Dillon Scott	MWRA
✓	✓	Carlton Hunt	Battelle
✓	✓	Heather Trulli	Battelle
✓	✓	Wayne Trulli	Battelle
✓	✓	Roy Kropp	Battelle
✓		Lisa Lefkovitz	Battelle
	✓	Scott Libby	Battelle
✓	✓	Andy Parrella	Battelle
✓		Jeanine Boyle	Battelle
✓		Ellie Baptiste-Carpenter	Battelle
	✓	Liz Ferson	Battelle
✓		Bob Hillman	Battelle
✓		Don Rhoads	Consultant
✓		Barbara Hecker	Hecker Environmental
✓		Robert Diaz	Diaz and Daughters
✓		Tim Morris	Cove Corporation
✓	✓	Cathy Coniaris	NEIWPCC
✓		Gene Gallagher	U Mass – Boston
✓		Peggy Pelletier	U Mass – Boston
✓	✓	Brad Butman	USGS
✓		Marilyn Buchholz-ten Brink	USGS
	✓	Mike Moore	WHOI
	✓	Jefferson Turner	U Mass – Dartmouth
	✓	David Borkman	U Mass – Dartmouth
	✓	Jean Lincoln	U Mass – Dartmouth
✓		Nancy Maciolek	ENSR
✓		Jim Blake	ENSR
	✓	Kristyn Lemieux	ENSR
	✓	Steve Cibik	ENSR
	✓	Craig Taylor	ENSR
	✓	Brian Howes	CMAST – U Mass
	✓	Ted Loder	UNH
	✓	Rocky Geyer	WHOI
	✓	Anne Giblin	MBL
	✓	Charles Hopkinson	MBL
	✓	Jane Tucker	MBL
	✓	Aimee Keller	URI
	✓	Candace Oviatt	URI
	✓	Jim Fitzpatrick	HydroQual
	✓	Jeff Rosen	TPMC

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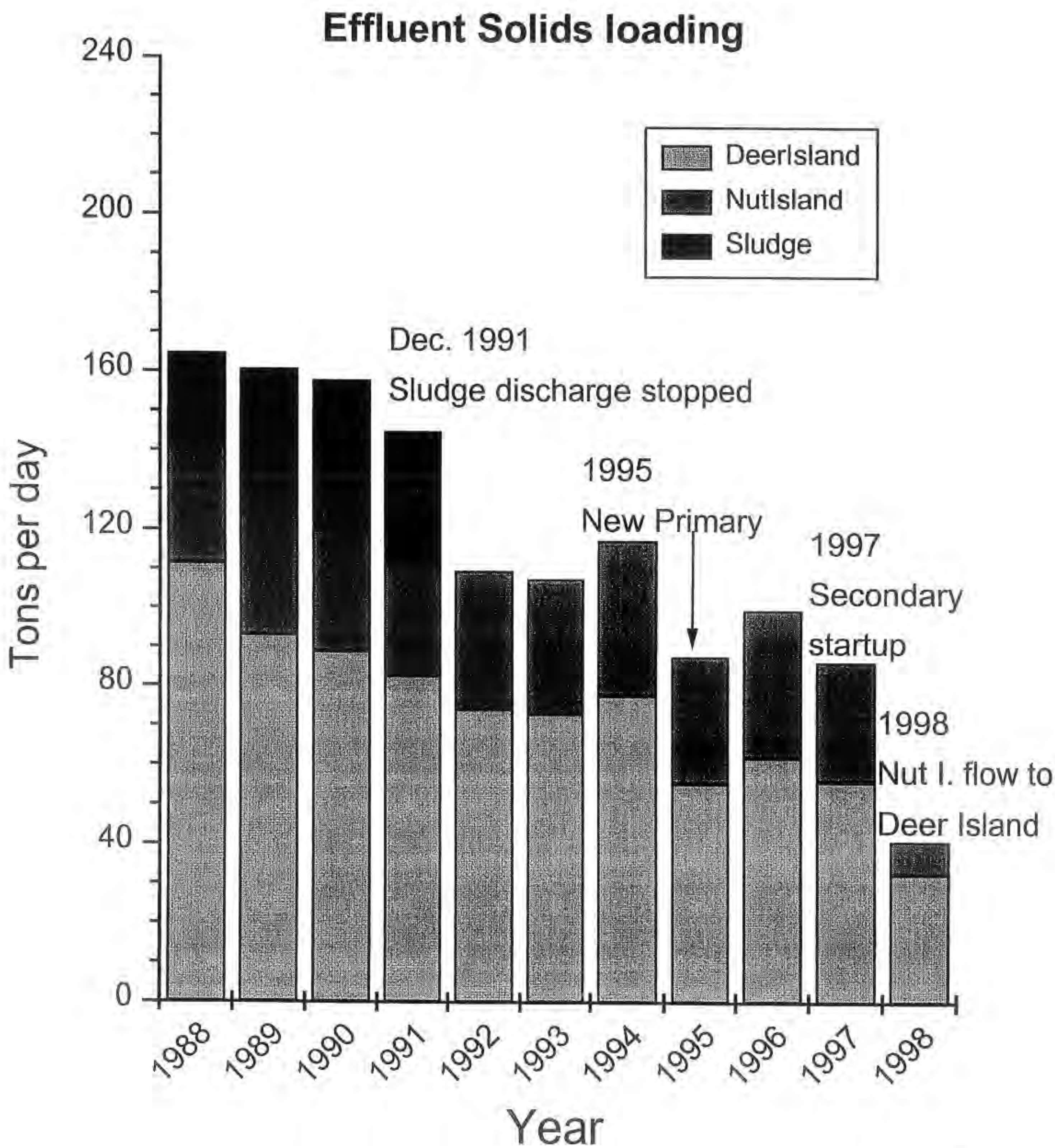
- Seasonal productivity pattern dominated by fall bloom
- No winter-spring bloom despite increased chlorophyll-specific production during typical bloom period
- Bloom failure not correlated with nutrient availability or light limitation
- Bloom failure may be related to warm winter temperatures and increased grazing by zooplankton
- Productivity significantly correlated with composite parameter (but variable across years)

1998 Nutrient Cycling in the *Harbor* *(Dr. Anne Giblin, Marine Biological Laboratory)*

- Sediment trends in the highly impacted sites in the northern Harbor may be showing some decrease in fluxes even with the amphipods present.
- Denitrification rates have gone up and down a bit with amphipod colonization but still not a major factor in removing anthropogenic nitrogen.
- DIN/DIP ratio may have shifted up but the majority of 1998 data still shows benthic fluxes still less than 16 (i.e., would contribute to nitrogen limitation).

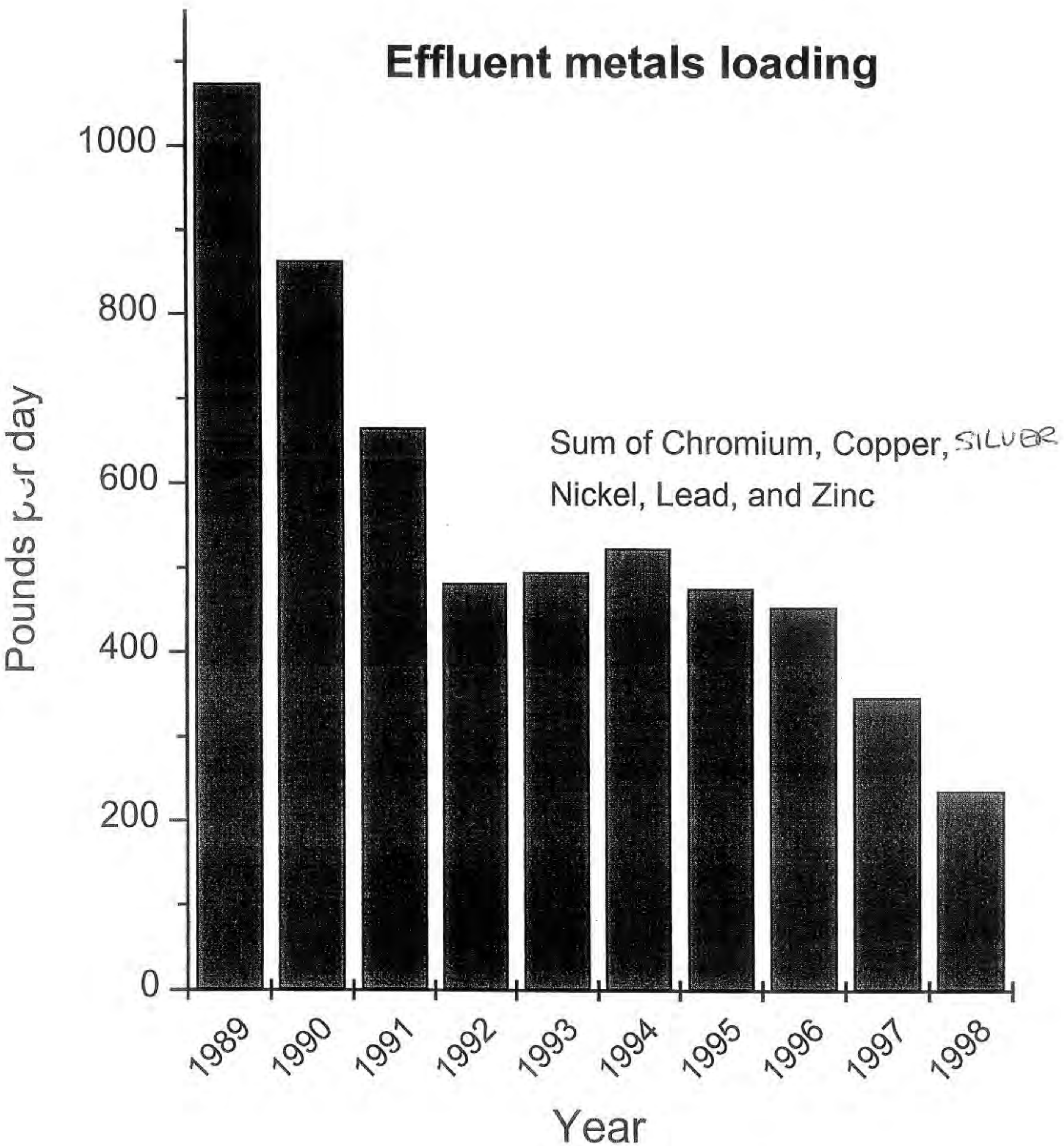
Statistical Approach to Threshold Testing and Rule Setting *(Dr. Jeff Rosen, TPMC)*

- Currently evaluating ways to aggregate data and conduct statistical tests
- Must define rules for aggregating the data.

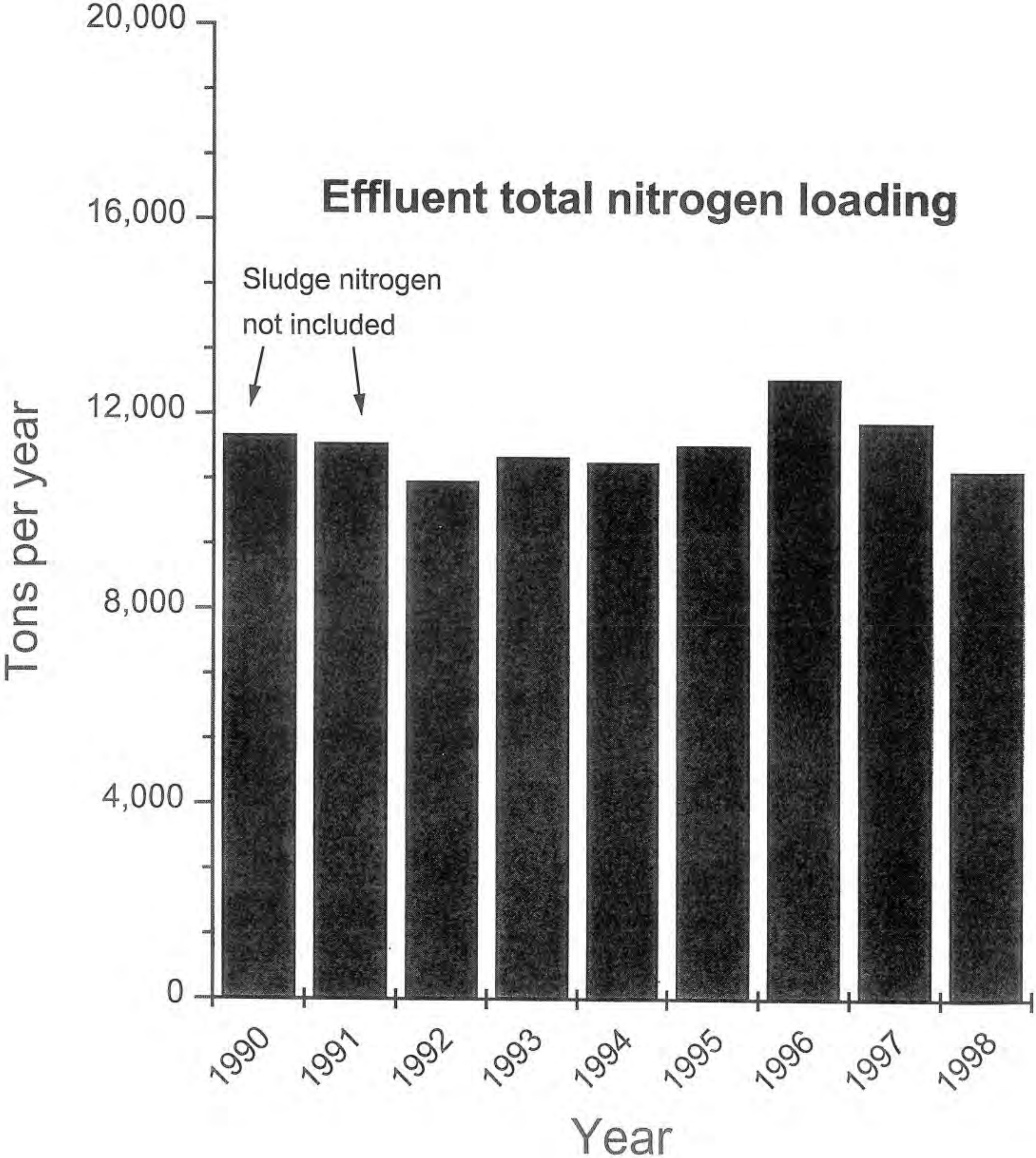


Effluent Solids loading
240
200
160
120
80
40
0
Tons per day
DeerIsland
NutIsland
Sludge
Dec. 1991
Sludge discharge stopped
1995
New Primary
1997
Secondary
startup
1998
Nut I. flow to
Deer Island
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year

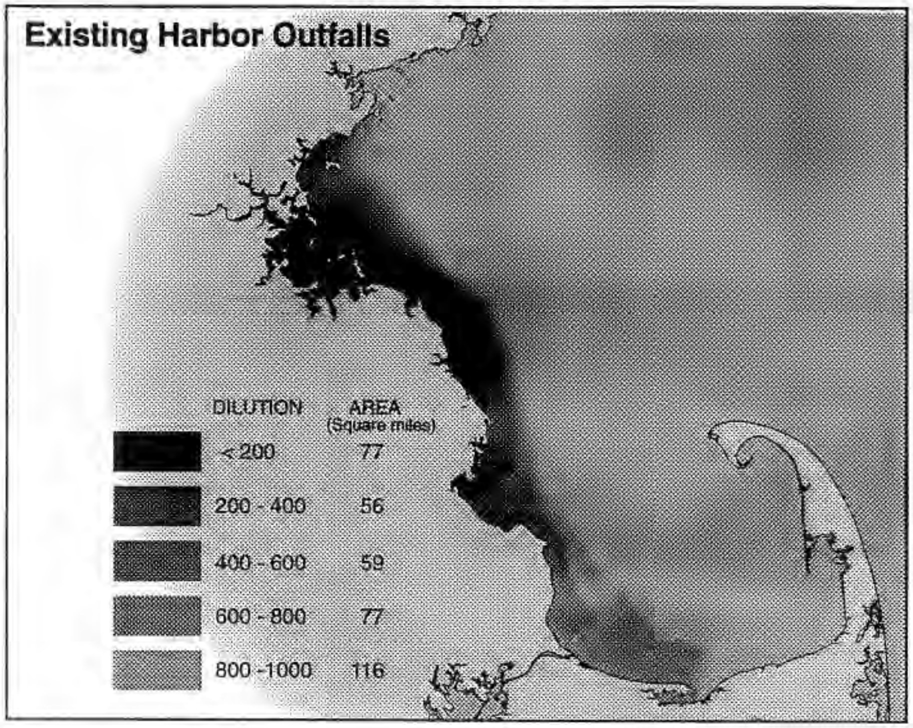
Overview – Benthic Monitoring (Day 1) *(Mr. Ken Keay, MWRA)*

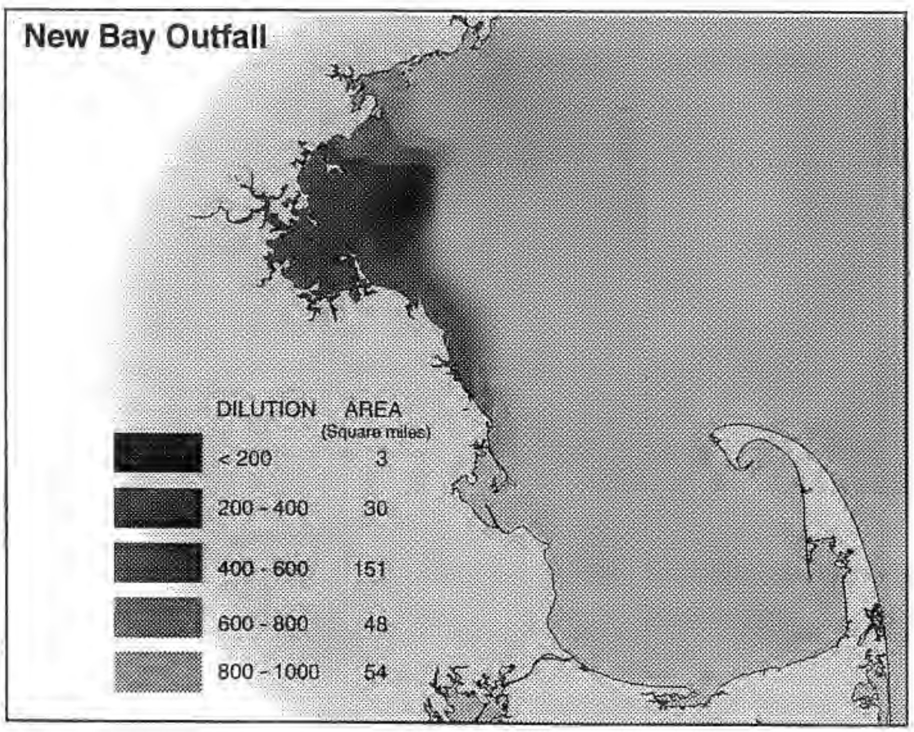


Effluent metals loading
Sum of Chromium, Copper, SILVER
Nickel, Lead, and Zinc
Pounds per day
1000
800
600
400
200
0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year


Effluent total nitrogen loading
Sludge nitrogen not included
Tons per year
20,000
16,000
12,000
8,000
4,000
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year

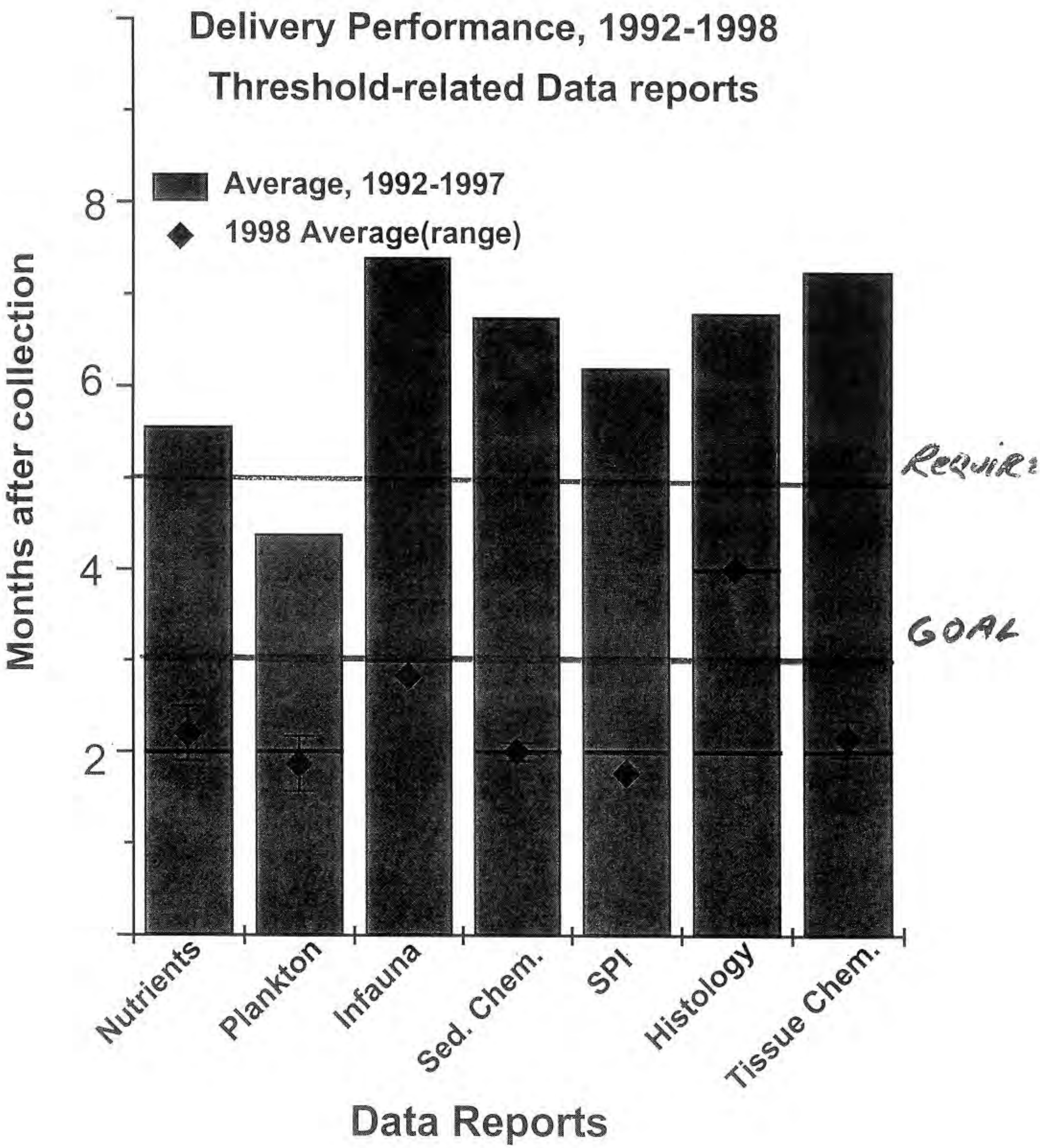
Average Modeled Dilution of Sewage Effluent, Winter Conditions





Draft NPDES permit #MA0103284, Section 8.a.

"The results of any monitoring required by the contingency plan shall be reported . ."(annually) ". except that if any parameter exceeds the corresponding early "caution level" or "warning level" the monitoring result shall be reported within ten (10) days after the result becomes available. The MWRA shall make all reasonable efforts to provide results within ninety (90) days after the sampling event, and MWRA shall obtain approval from EPA and the MADEP if the results will take longer than one hundred and fifty (150) days."


Delivery Performance, 1992-1998
Threshold-related Data reports
Average, 1992-1997
1998 Average(range)
Months after collection
8
6
4
2
Nutrients
Plankton
Infauna
Sed. Chem.
SPI
Histology
Tissue Chem.
Data Reports
REQUIRE
GOAL

Contingency Plan Process

```
      DO 100  i=1,many
C           i = years, j = Different thresholds
C           RDM = Routine Discharge Monitoring Data
C           CAUTN = Contingency Plan Caution level
C           WARN = Contingency Plan Warning level

            Do 200  j = 1,~50
            TRIGGR(i,j) = f(RDM(i))

                IF(TRIGGR(i,j) .lt. Cautn(j)) THEN
                     write (everywhere,*) ' NO PROBLEM'
                     OUTPUT = 'No Problem'

                ELSE IF(TRIGGR(i,j) >= CAUTN(j)) THEN
                     CALL EVALUATE(TRIGGR,CAUTN,i,j,OUTPUT)
                     CALL RESPONSE(MORE, CAUSAL, OUTPUT,
+                                        etc.)
                     IF(OUTPUT = 'No Problem') THEN
                     write (everywhere,*) ' NO PROBLEM'
                          GO TO  200

                ELSE IF(TRIGGR(I,J) > WARN(J)) THEN
                     CALL PROBLEM(OMTF, DEP, EPA, PUBLIC, etc.)
                ENDIF
200         CONTINUE
100   CONTINUE

      DON'T STOP
      DON'T END
```

Draft NPDES permit #MA0103284, Section 8.b.

"If any parameter exceeds the "warning level" listed above in Section 8.a, the MWRA shall: (1) determine whether there are any adverse environmental impacts from such exceedance, (2) evaluate the extent to which MWRA discharge contributes to such impacts, and (3) unless MWRA demonstrates by convincing evidence, to the satisfaction of EPA and the MADEP, that the MWRA discharge does not contribute to such adverse environmental impacts, develop a plan and schedule to address such impacts . . .".

Overview – Water Column Monitoring (Day 2) *(Dr. Mike Mickelson, MWRA)*

Environmental and man-made perturbations which affect valued ecosystem components

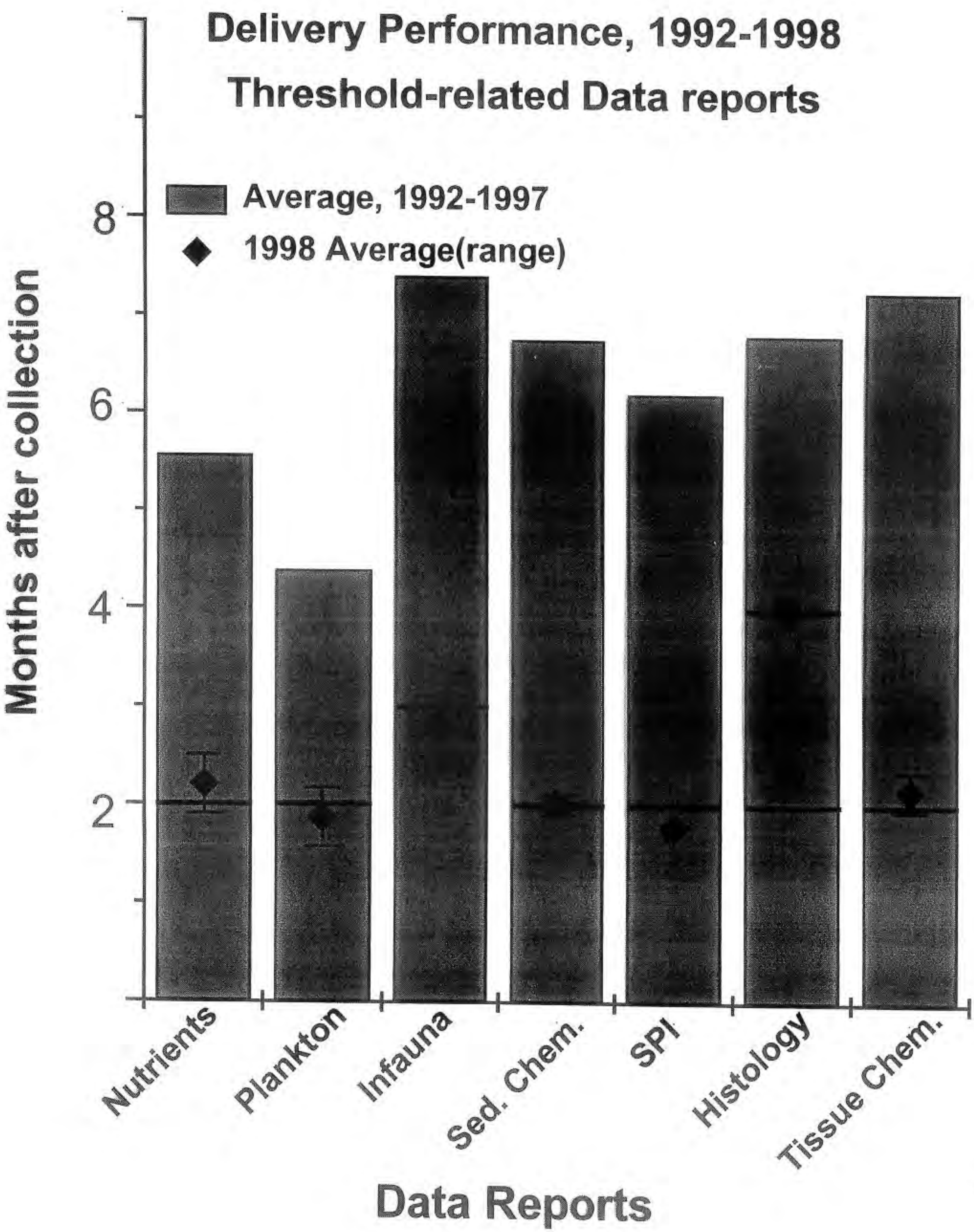
Those effects which are of
- local scale,
- understandable interaction, and
- conceivable relevance to outfall

are the basis of the Outfall Monitoring Plan

Outfall monitoring Plan.

The Contingency Plan identifies selected measurements to be used as thresholds for action.

The other measurements are just as important because they
- Explain impact of exceedance
- Explain cause of exceedance
- Demonstrate ability to detect changes that do occur
- Further understanding of the ecosystem



Delivery Performance, 1992-1998
Threshold-related Data reports
Average, 1992-1997
1998 Average(range)
Months after collection
8
6
4
2
Nutrients
Plankton
Infauna
Sed. Chem.
SPI
Histology
Tissue Chem.
Data Reports

Draft NPDES permit #MA0103284, Section 8.b.

"If any parameter exceeds the "warning level" listed above in Section 8.a, the MWRA shall: (1) determine whether there are any adverse environmental impacts from such exceedance, (2) evaluate the extent to which MWRA discharge contributes to such impacts, and (3) unless MWRA demonstrates by convincing evidence, to the satisfaction of EPA and the MADEP, that the MWRA discharge does not contribute to such adverse environmental impacts, develop a plan and schedule to address such impacts . . .".

Action list from EPA/MADEP permit for MWRA outfall T01

Monitor effluent

Ambient monitoring
- Plan and modify design
- Report results
- Model eutrophication
- Model the whale-prey food web
- Test diffuser dilution

Contingency Plan
- Report exceedances
- Simulate a problem

Monitor pathogen exposure of shellfish

Maintain and operate the treatment plant

Implement Best Management Practices

Pollution prevention
- Limit industrial discharges

Monitor sludge quality for agricultural use

Monitor CSO facilities and storm spills

Impose water conservation

Outfall Monitoring Plan: Development Status *(Dr. Carlton Hunt, Battelle)*

MWRA Outfall Monitoring Plan: Development Status

1998 Science Review Meetings

April 9 and 12, 1999

Battelle

Development status

- Revised draft of the OMP in development
- Focusing on completing threshold statements
- Threshold testing will be one theme for the June (Tentative) 1998 OMSAP Public Science Meeting
- Automation of the threshold and monitoring comparison process pending completion of thresholds (Task 30)
  - Will reside within the database
  - Review data on upload and acceptance
- Requires
  - Strict protocols for the data aggregation
  - Defined statistical testing protocols

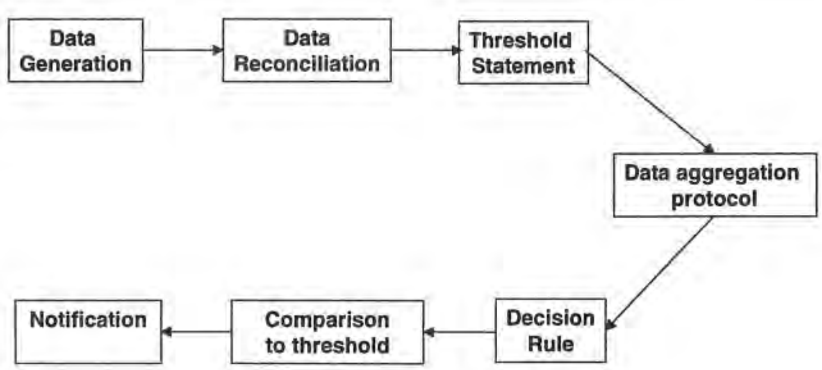
Battelle

Threshold Changes in the Last Year

■ Effluent	Removed floatable threshold (not in permit)
■ Water	
• Oxygen	Depletion rate threshold removed
• Chlorophyll	No changes
• Nuisance species	Modified Psuedonitzschia threshold
• Zooplankton	Modified threshold statement
■ Fish and Shellfish	
• Contaminants	Removed lipid based thresholds, clarify if do caution thresholds on dry or wet weight
• Histopathology	No changes
■ Seafloor	
• Benthos	Identified 5 candidate thresholds
• Contaminants	No changes
• Organic loading	No changes

Battelle

Threshold Testing Cycle



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Where are we in the process?

■ Effluent	Data Reconciliation; Threshold Statement; Test protocol; Decision Rule
■ Water	
• Oxygen	Data Reconciliation; Threshold Statement; Test protocol; Decision Rule
• Chlorophyll	Data Reconciliation; Threshold Statement; Test protocol; Decision Rule
• Nuisance species	Data Reconciliation; Threshold Statement; Test protocol; Decision Rule
• Zooplankton	Data Reconciliation; Threshold Statement; Test protocol; Decision Rule
■ Fish and Shellfish	
• Contaminants	Data Reconciliation; Threshold Statement; Test protocol; Decision Rule
• Histopathology	Data Reconciliation; Threshold Statement; Test protocol; Decision Rule
■ Seafloor	
• Benthos	Data Reconciliation; Threshold Statement; Test protocol; Decision Rule
• Contaminants	Data Reconciliation; Threshold Statement; Test protocol; Decision Rule
• Organic loading	Data Reconciliation; Threshold Statement; Test protocol; Decision Rule

Battelle

Threshold Work in Progress

- Water
  - Evaluating statistical approach to means testing and the development of 95th percentile testing
  - Evaluating the data aggregation protocols and statistical test (Decision rules)
  - Evaluating incorporation zero values that dominate the database into the testing
- Fish and Shellfish
  - Decision on wet versus dry weight for caution thresholds
- Seafloor
  - Working on decisions rules on the diversity thresholds and threshold statements
  - Evaluating the compositional and functional thresholds

Battelle

Activities and Schedules

- Complete draft synthesis reports for 1998: May - June time frame
- Complete threshold statements, data aggregation and decision rules - early June
- Develop rapid threshold review protocols - June - July
- Complete draft Outfall Monitoring Plan - June
- Develop presentations for the OMSAP public science meeting: May - June

Battelle

Meeting goals

- Review and discuss 1998 data
- Debate the thresholds as appropriate
- Develop themes and key presentations for the June OMSAP public science meeting

Battelle

Draft
4/8/99

Table. Summary of thresholds against which monitoring data will be compared to evaluate whether significant environmental change occurs in Massachusetts and Cape Cod Bays.

Area/ Location	Parameter	Threshold #	Caution Level	Warning Level	Baseline /Permit Condition
Effluent (prior to entrance into the outfall tunnel)					
	Total nitrogen	E-1	Total nitrogen loading >12,500 tons/year	Total nitrogen loading >14,000 tons/year	
	Chlorine, residual	E-2	None	631 μg/L average daily 456 μg/L average monthly	
	PCBs	E-3	None	PCB (as Arochlor) limit =0.0045 ng/L monthly	
	Toxicity	E-4	None	Acute: effluent LC50 < 50% for shrimp; Chronic: effluent NOEC for fish growth and sea urchin fertilization < 1.5% effluent	
	CBOD	E-5	None	>40 mg/L weekly >25 mg/L monthly	
	Fecal coliform Bacteria	E-6	None	14,000 fecal coliforms/100 ml at point of dechlorination (weekly mean, monthly 90th percentile, and 24 consecutive hours)	
	Total Suspended Solids	E-7	None	45 mg/L weekly 30 mg/L monthly	
Treatment plant performance	Non trigger parameters listed in Part one of the permit e.g., pH, Flow; selected contaminants; selected nitrogen species; settable solids; cyanide; Volatile organic compounds; etc	E-8	More than 5 violations of permit requirements/year. Note: Specific conditions for each of these non trigger parameters can be found in Part I of the MWRA Discharge Permit	Operating in violation of the expected permit requirements more than 5% of the time per year. e.g., pH <6 or >9 at any time; flow >436 MGD for dry day	

Prest
4-8-99

Table. Summary of thresholds against which monitoring data will be compared to evaluate whether significant environmental change occurs in Massachusetts and Cape Cod Bays.

Area/ Location	Parameter	Threshold #	Caution Level	Warning Level	Baseline /Permit Condition
Water Column					
Bottom water Nearfield; Stellwagen Basin	Dissolved oxygen concentration	W- 1	Survey mean DO is less than 6.5 mg/L for any one survey during stratification (June-Oct.)	Survey mean DO is less than 6 mg/L for any one survey during stratification (June-Oct.)	No exceedances during baseline period. Range in monthly means is across baseline period (1992 – 1998) is xx – xx mg/L
Nearfield	Chlorophyll level	W-2	Annual mean Nearfield concentration greater than 1.5x baseline annual mean	Annual mean Nearfield concentration greater than 2x baseline annual mean.	Baseline through 1997: (Gong 1998) Mean = 1.95 ± 0.47 mg/L Caution = 2.92 mg/L Warning = 3.89 mg/L
Nearfield	Chlorophyll level	W-3	Seasonal (Spring, Summer, Fall) Nearfield mean concentration exceeds 95th percentile of the baseline seasonal distribution	None	Baseline through 1997: Gong 1998) Mean Spring: 1.61±0.63 mg/L Summer: 1.30 ±0.5 mg/L Fall: 2.45± 1.11 mg/L Threshold (caution/warning) Spring: 2.68/3.35 mg/L Summer: 2.61/2.83 mg/L Fall: 4.95/5.66 mg/L
Nearfield	Nuisance algae abundance	W-4	Seasonal (Spring, Summer, Fall) mean concentration of *Alexandrium tamerenses* or *Phaeocystis pouchetii* exceeds 95th percentile of the baseline seasonal mean. Seasonal (Spring, Summer, Fall) mean concentration of confirmed *Pseudo-nitzschia multiseries* exceed 500,000 cells per liter.	None	Under development

Draft
4-8-99

Table. Summary of thresholds against which monitoring data will be compared to evaluate whether significant environmental change occurs in Massachusetts and Cape Cod Bays.

Area/ Location	Parameter	Threshold #	Caution Level	Warning Level	Baseline /Permit Condition
Nearfield	Zooplankton abundance	W-5	The abundance of *Acartia tonsa/A. hudsonica* becomes greater than 50% of the copepodite plus adult copepod abundance in a Nearfield sample. Alternative: Nearfield abundance of copepodites and adult stages of *Calanus, Pseudocalanus, Centropages typicus, Oithona* does not decrease by more than 50% of the baseline mean and the abundance of copepodites and adult stages of *Acartia, Eurytemora, Centropogas hamatus* does not increase by more than 50% of the baseline mean.	None	Under development
Farfield	PSP extent in the Farfield	W-6	Any new incidence at a state PPS monitoring station having no previously reported incidence	None	PPS has never been observed at 3 of 18 monitoring stations
Plume	Initial dilution	W-7	None	Effluent dilution under stratified and unstratified conditions less than predicted by EPA as basis for NPDES permit	Dilution is expected to be 70:1 at a distance of 60m from the diffusers. Plume tracking studies in December 1999 and June 2000 will confirm dilution

Draft
4-8-99

Table. Summary of thresholds against which monitoring data will be compared to evaluate whether significant environmental change occurs in Massachusetts and Cape Cod Bays.

Area/ Location	Parameter	Threshold #	Caution Level	Warning Level	Baseline /Permit Condition
Fish and Shellfish					
Outfall site	Mercury	FS-1	Annual mean mercury dry-weight concentration in flounder, lobster, and caged mussel meat greater than twice the baseline mean.	Annual mean mercury concentration in flounder, lobster, and caged mussel meat greater than 0.8μg/g wet weight	Baseline Mean through 1998 (wet weight): Flounder = 0.0.085 ppm Lobster = 0.154 ppm Caged Mussel = 0.022 ppm Caution Level Flounder = 0.17 ppm Lobster = 0.0.31 ppm Caged Mussel = 0.044 ppm
Outfall site	PCB	FS-2	Annual mean PCB dry-weight concentration in flounder and meat greater than twice the baseline mean.	Annual mean PCB concentration in flounder, lobster, and caged mussel meat greater than 1.6 μg/g wet	Baseline Mean through 1998 (wet weight): Flounder = 38.1 ppb Lobster = 17.1 ppb Caution Level Flounder = 76.2 ppb Lobster = 34.1 ppb
Outfall site	Lead	FS-3	Annual mean dry-weight lead concentration in caged mussel meat greater than greater than twice the baseline mean.	Annual mean lead concentration in caged mussel meat greater than 3 μg/g wet weight	Baseline Mean through 1998 (wet weight): Caged Mussel = 0.43 ppm Caution Level Caged Mussel = 0.86 ppm
Flounder Outfall Site	Liver disease incidence	FS-4	Flounder liver disease (CHV) greater than harbor baseline prevalence (1991-1998)	None	Baseline Mean Through 1997 = 24.9

Draft
4-8-99

Table. Summary of thresholds against which monitoring data will be compared to evaluate whether significant environmental change occurs in Massachusetts and Cape Cod Bays.

Area/ Location	Parameter	Threshold #	Caution Level	Warning Level	Baseline /Permit Condition
Sea Floor					
Nearfield	Depth of Redox potential discontinuity	B-1	Redox potential discontinuity declines to less than 0.5 x baseline depth in the nearfield	None	Baseline mean Approximately 3.5 cm
Nearfield	Toxics	B-2	Nearfield mean surface sediment contaminant concentrations greater than 90% of the EPA's Equilibrium Partitioning Sediment Guideline (formerly sediment quality criteria)	Nearfield mean surface sediment contaminant concentrations greater than EPA's Equilibrium Partitioning Sediment Guideline or NOAA Effects range Median (ER-M) value	Under development OMP will include a table of the most recent marine ERM-M values
Nearfield	Benthic diversity	B-3	Diversity threshold Diversity does not decrease more than n… of the baseline …. J' (Evenness) Log α (Richness) $E(S_{10})$ (Evenness & Richness) Exploring: the pooling versus separation of the sand and mud communities		Under development
Nearfield	Benthic Compositional	B-4	The sum of n (n = 4 to 6?) indicator species becomes more than x % of a community. Should x be percent of community OR an increase relative to baseline?	The sum of n (n = 4 to 6?) indicator species becomes more than 50 % of a community?	Under development
Nearfield	Benthic Functional group (Ecologically significant measure)	B-5	Exploring:		Under development
Nearfield	Benthic Families approach (Ecologically significant measure)	B-6	Exploring:		Under development

Benthic Monitoring

Benthic Monitoring Thresholds Approach/Rationale *(Mr. Ken Keay, MWRA)*

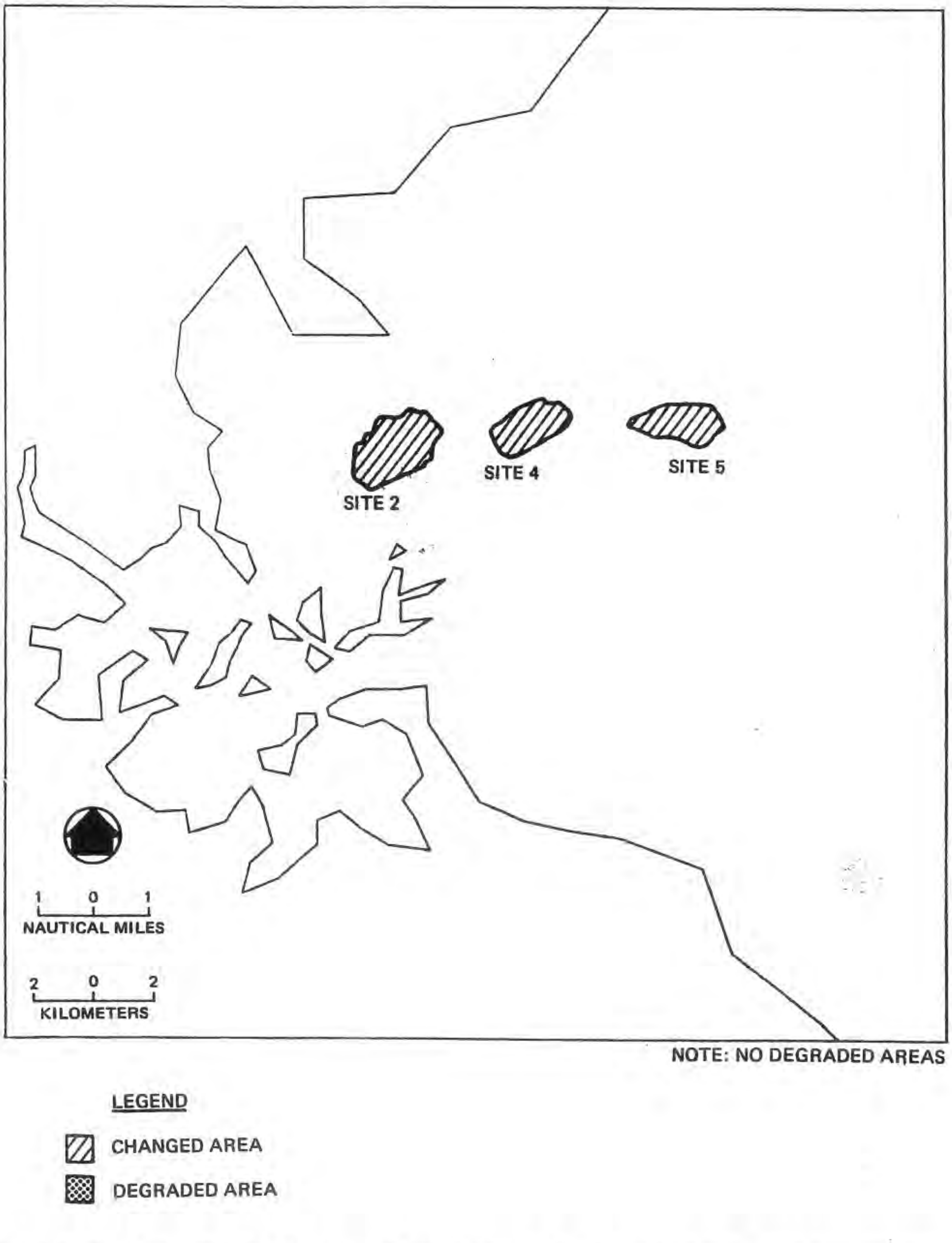


FIGURE 5.1.3.b. AREAS OF PREDICTED CHANGED AND DEGRADED BENTHIC COMMUNITIES DUE TO ORGANIC ENRICHMENT UNDER STRATIFIED CONDITIONS WITH SECONDARY TREATMENT FOR ALL SITES.

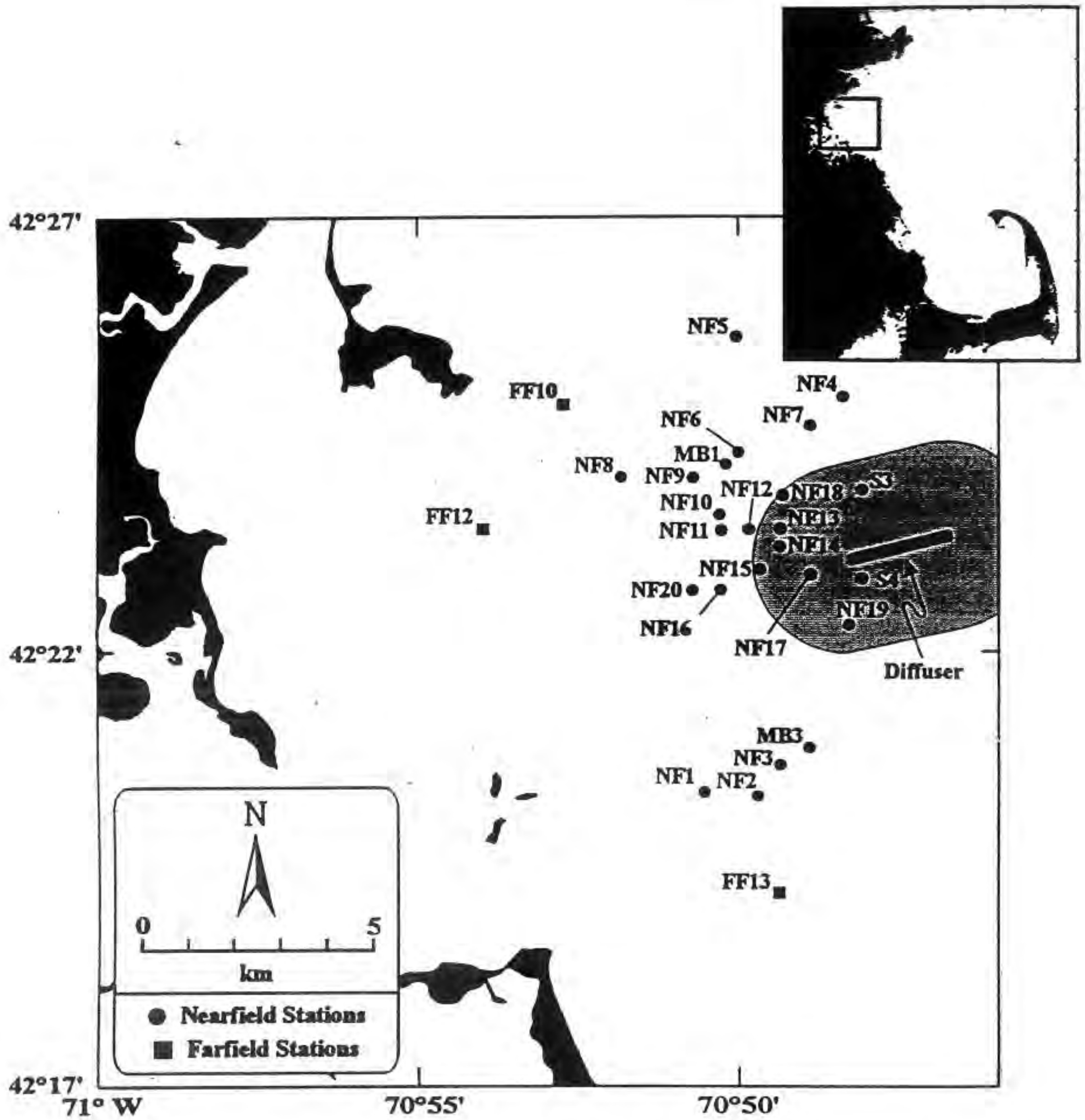
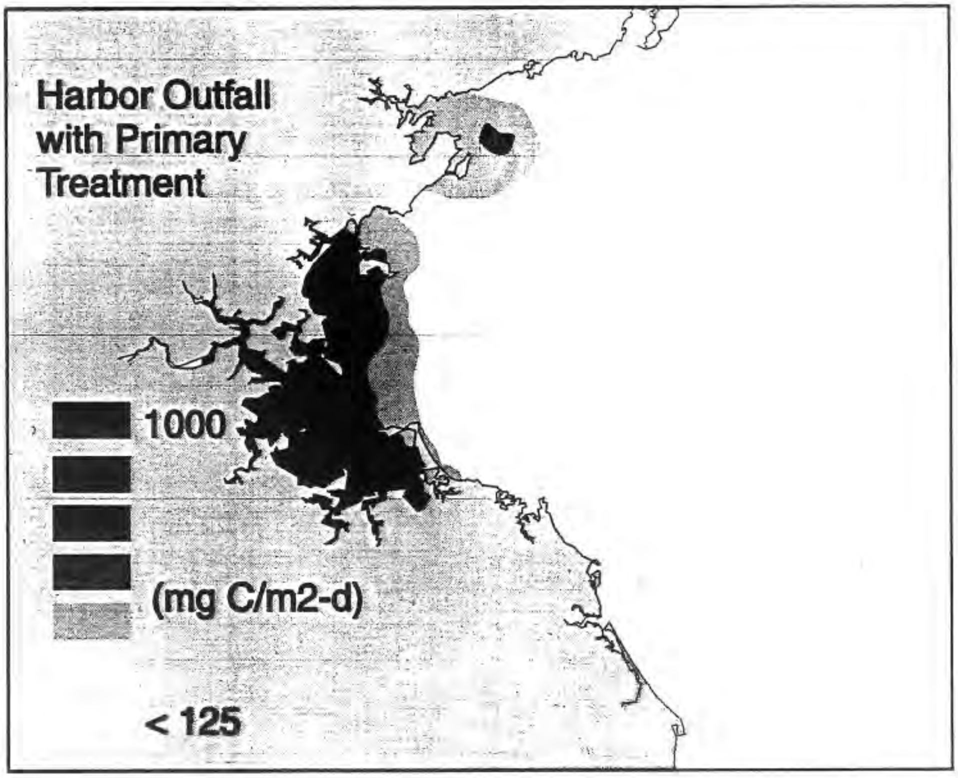
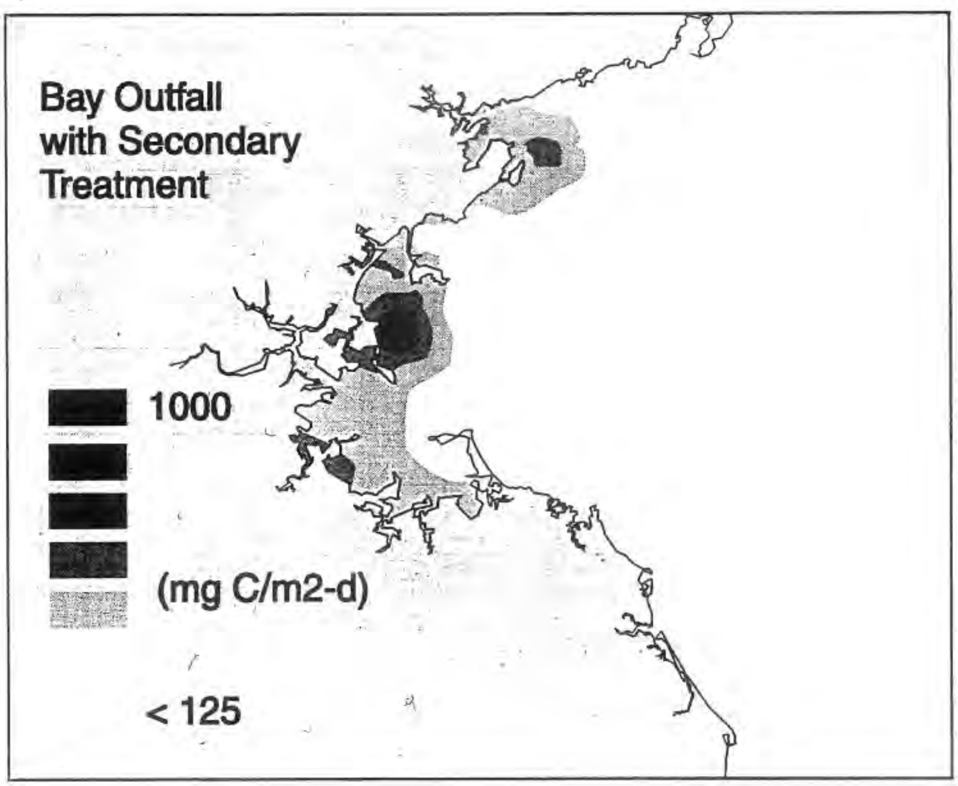
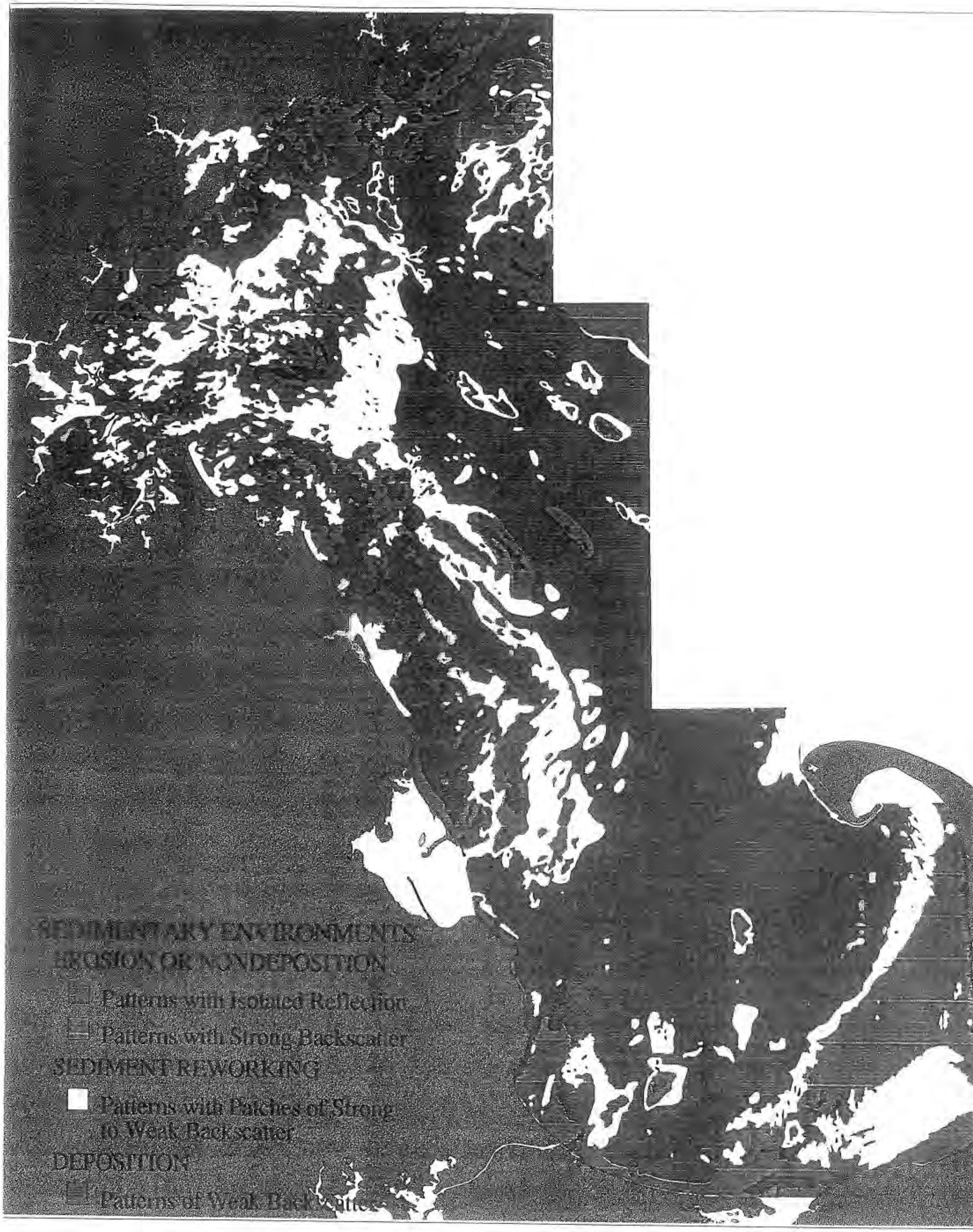


Figure 4. Location of near and farfield stations at midfield distances from the diffuser. The shaded area is the locus of points at a 2 km distance from the outfall. The inset shows the midfield study area location within Massachusetts and Cape Cod Bays.

Modeled deposition of particulate organic carbon (August)






SEDIMENTARY ENVIRONMENTS
EROSION OR NONDEPOSITION
Patterns with Isolated Reflection
Patterns with Strong Backscatter
SEDIMENT REWORKING
Patterns with Patches of Strong to Weak Backscatter
DEPOSITION
Patterns of Weak Back

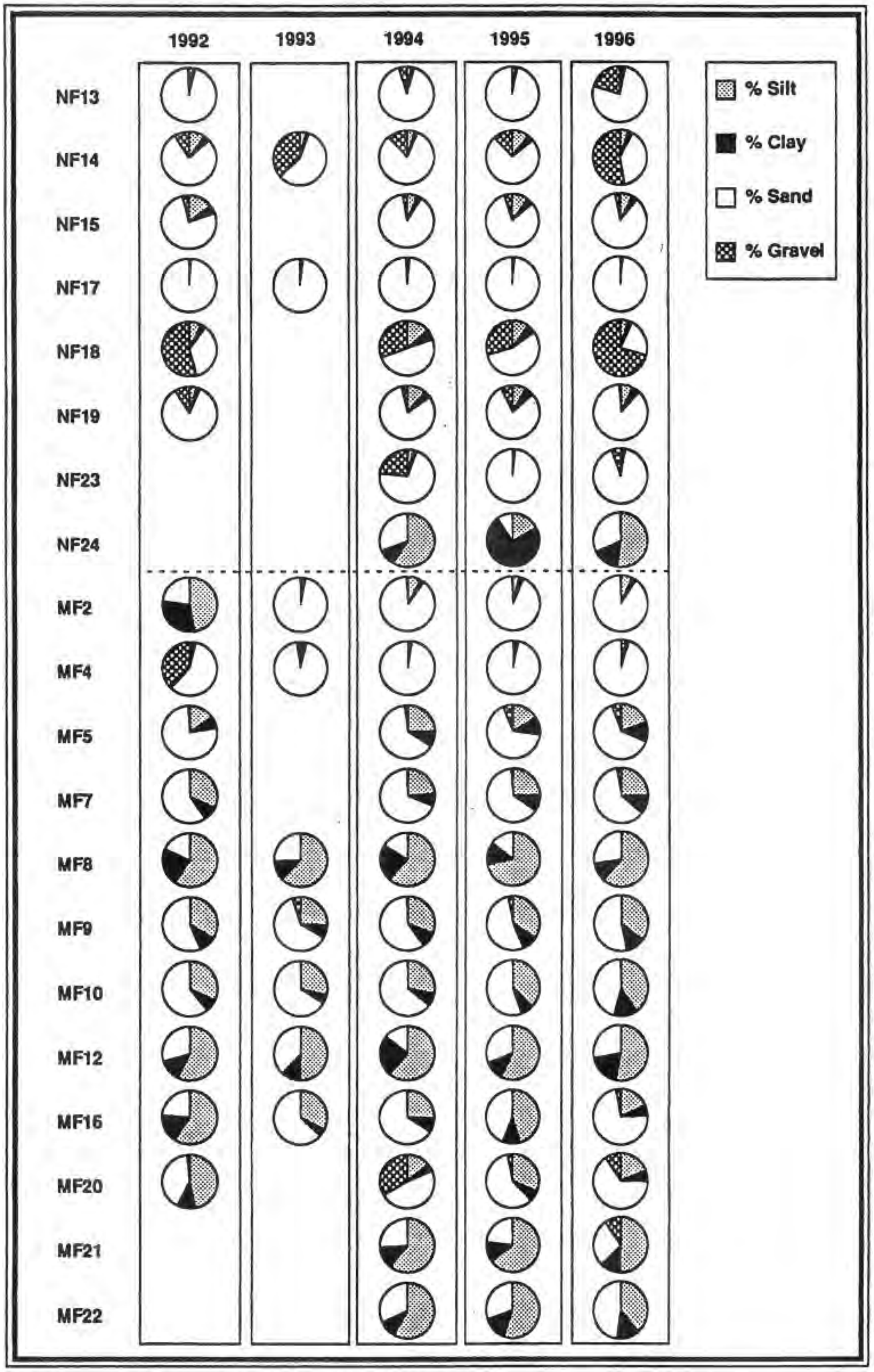


Figure 39. Sediment composition at nearfield and midfield stations for the period 1992-1996.

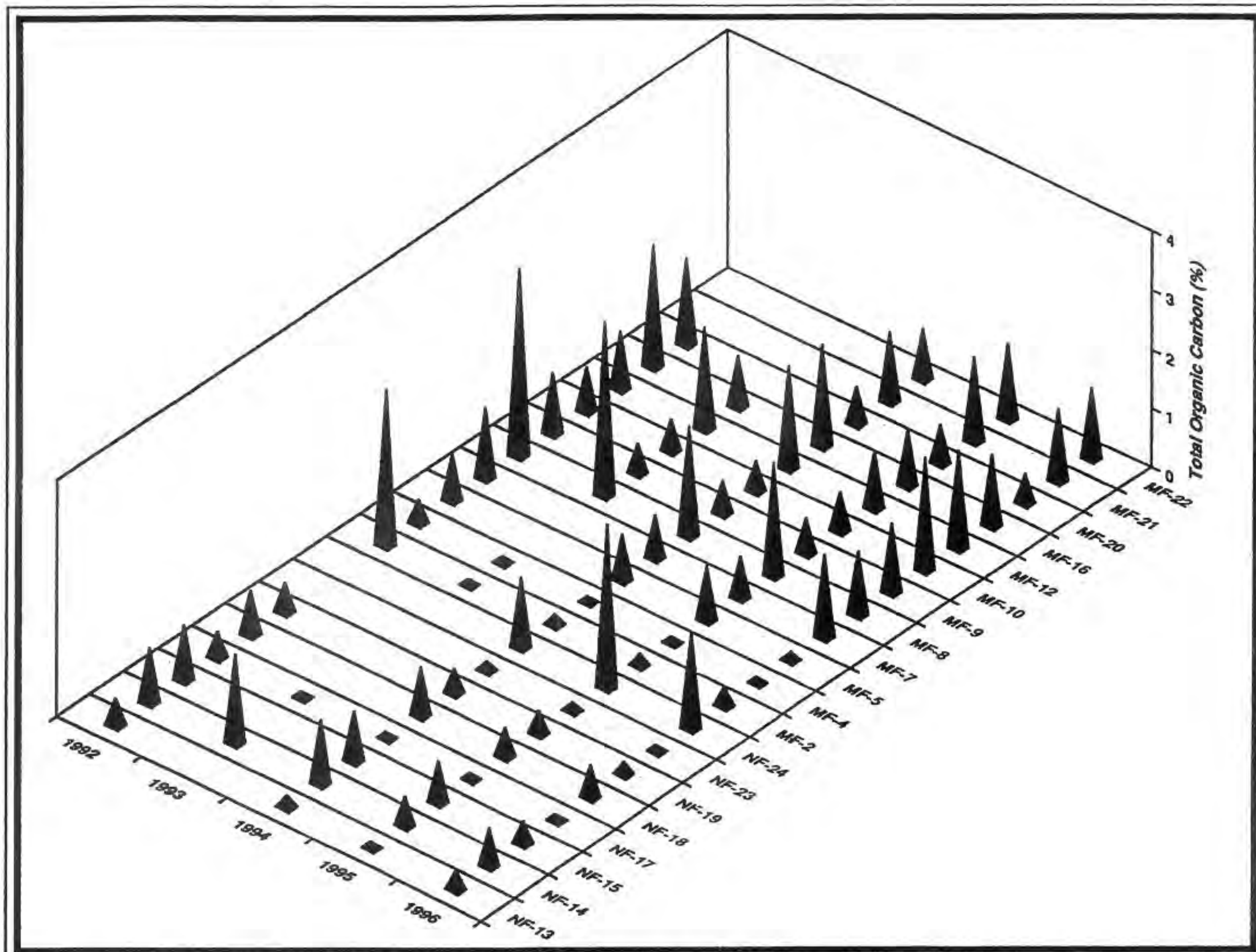


Figure 42. Total organic carbon concentrations at the nearfield and midfield stations for the period 1992-1996.

Implications for sediment thresholds

- No expectation of substantial change.
- Change, if any, should be small, possibly not localized to the immediate vicinity of the outfall.
- Schedule leaves little or no time for detailed interpretation of the data prior to reporting on thresholds.
- Strong push from regulators & oversight committee for a KISS approach to threshold testing that's nonetheless ecologically and statistically valid.

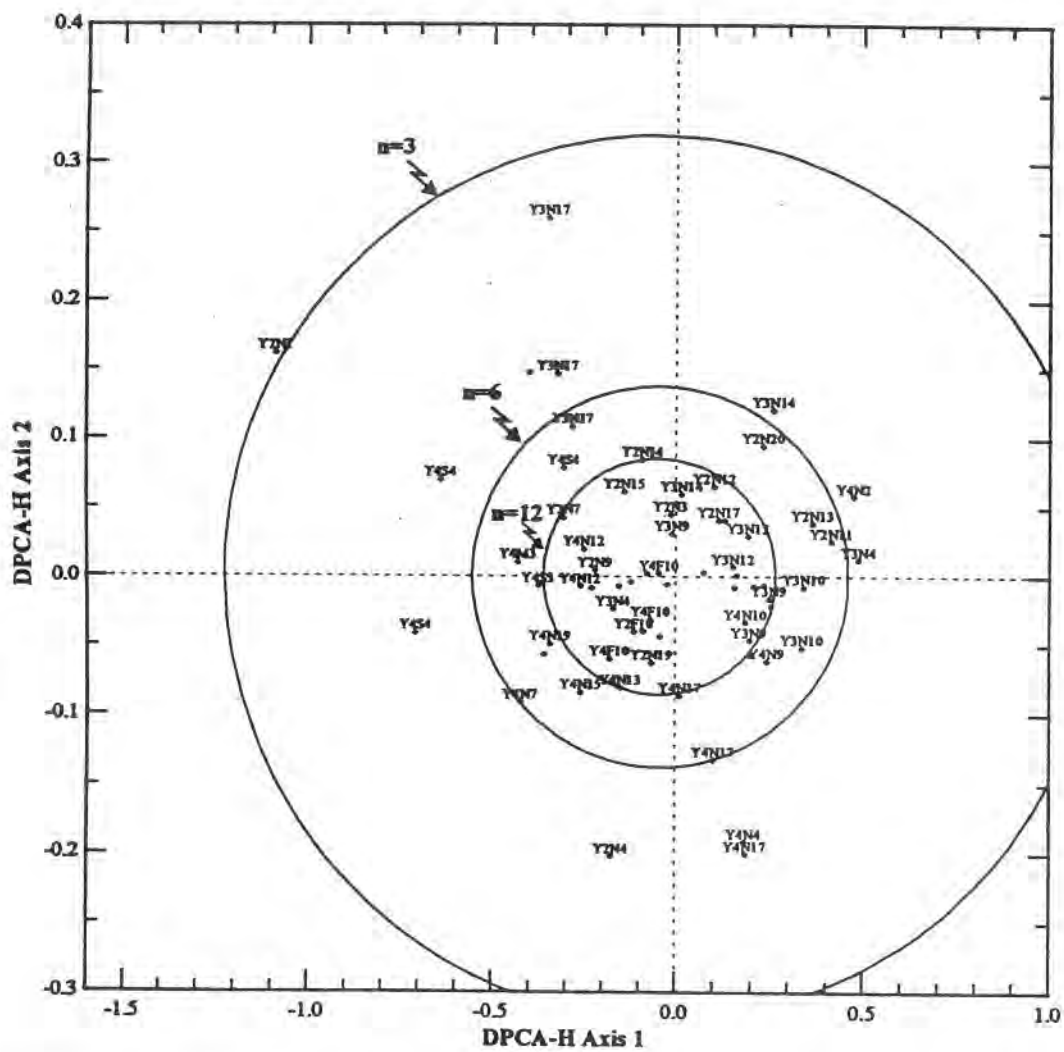
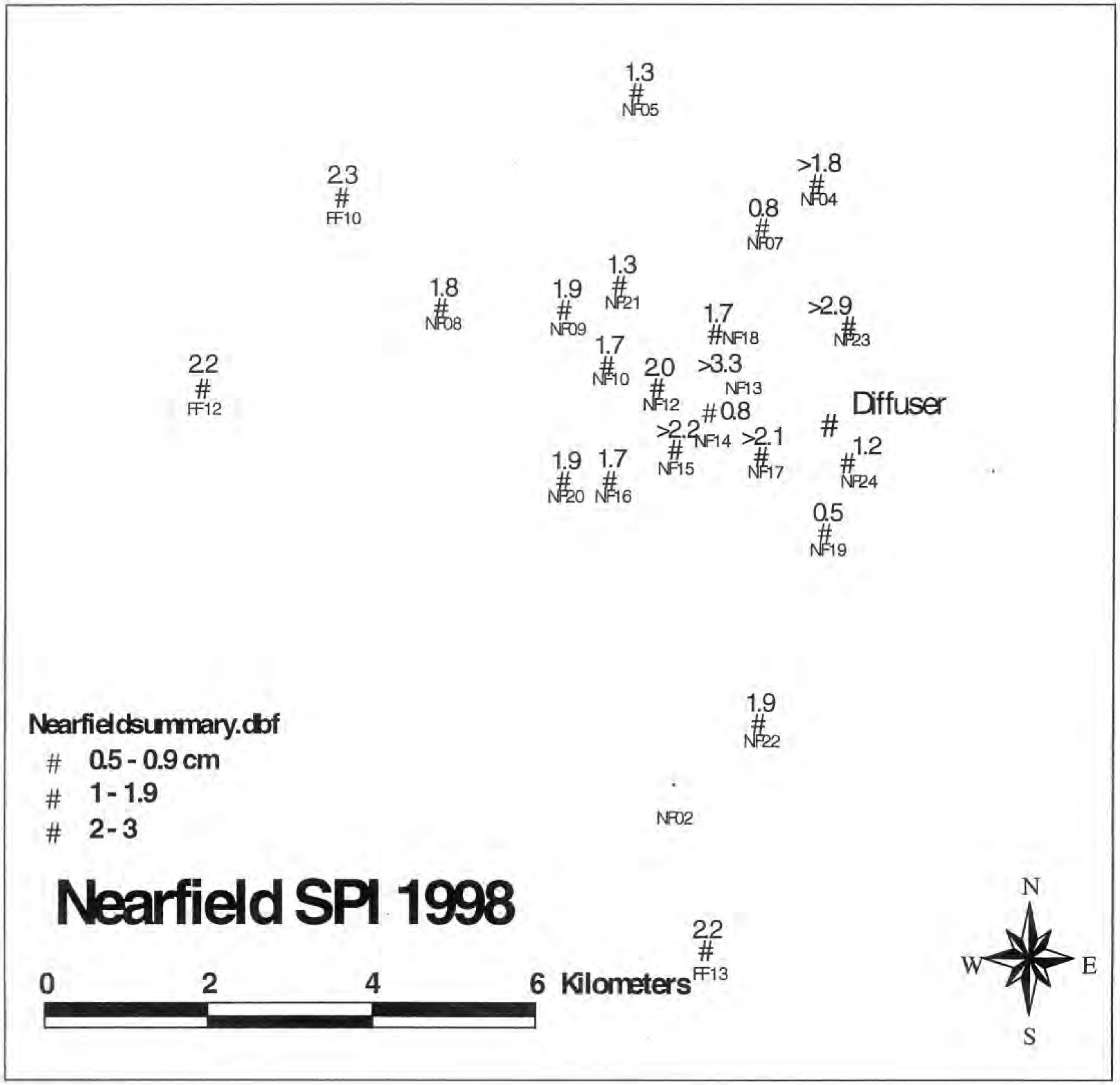


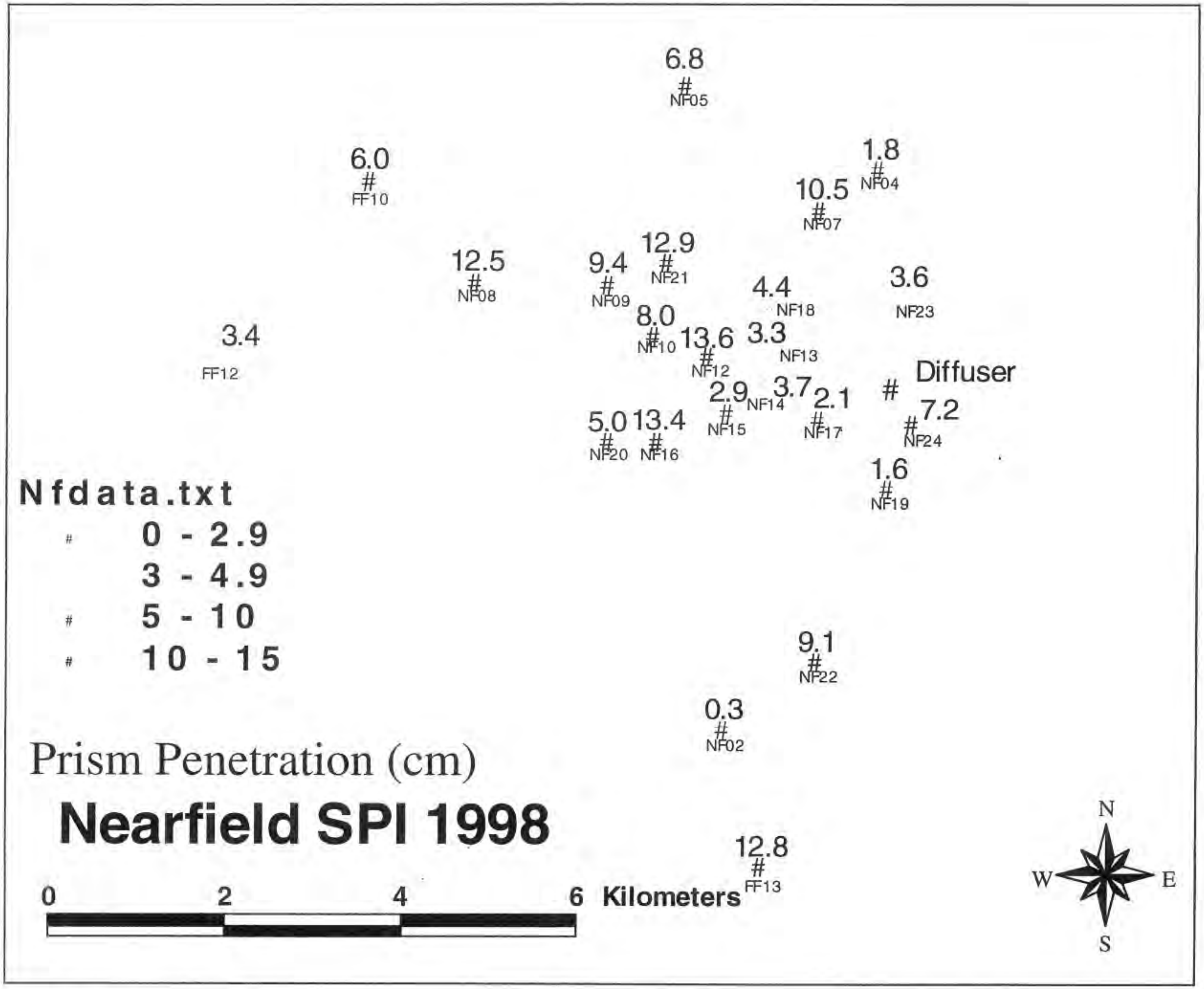
Figure 20. Adjusted DPCA-H coordinates. Equivalent to the residuals from the regression shown in Figures 18 and 19. The three ellipses delineate regions within which new mean values, computed with one of three sample sizes (*n*), would not be significantly different from that of the baseline sentinel stations at $\alpha = 0.05$ and $\beta = 0.5$. Replicate labeling is as described in Figure 12.

Benthic Monitoring

1998 Sediment Profile Imaging *(Dr. Robert Diaz, VIMS)*

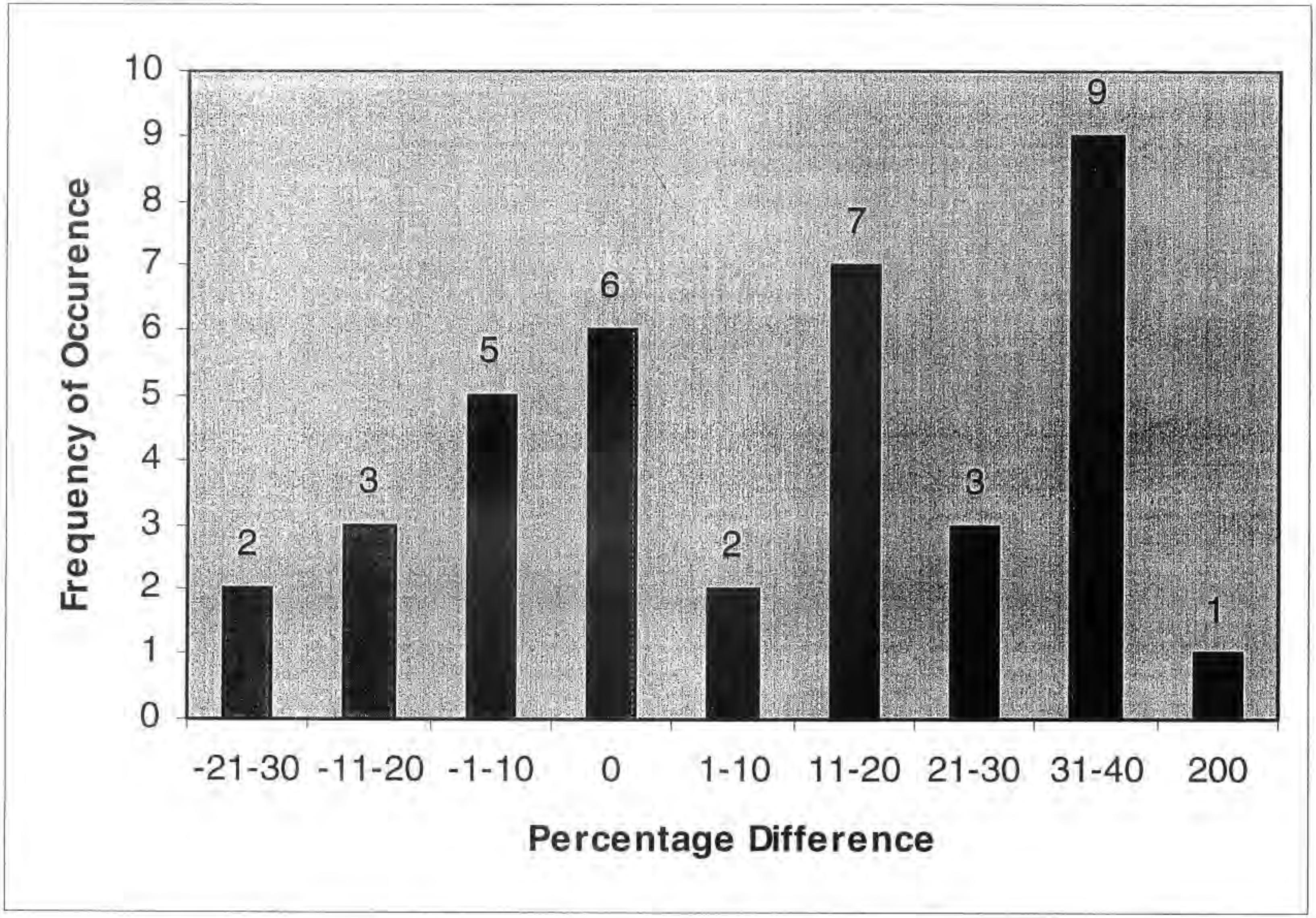


Nearfield SPI 1998
Nearfieldsummary.dbf
0.5 - 0.9 cm
1 - 1.9
2 - 3
0 2 4 6 Kilometers
N
S
E
W
Diffuser
1.3 NF05
2.3 FF10
>1.8 NF04
0.8 NF07
1.3 NF21
1.8 NF08
1.9 NF09
1.7 NF18
>2.9 NF23
2.2 FF12
1.7 NF10
2.0 NF12
>3.3 NF13
0.8 NF14
>2.2 NF15
>2.1 NF17
1.2 NF24
1.9 NF20
1.7 NF16
0.5 NF19
1.9 NF22
NF02
2.2 FF13


6.8 NF05
6.0 FF10
1.8 NF04
10.5 NF07
12.9 NF21
12.5 NF08
9.4 NF09
4.4 NF18
3.6 NF23
8.0 NF10
13.6 NF12
3.3 NF13
3.4 FF12
Diffuser
2.9 NF15
NF14 3.7
2.1 NF17
7.2 NF24
5.0 NF20
13.4 NF16
1.6 NF19
Nfdata.txt
0 - 2.9
3 - 4.9
5 - 10
10 - 15
9.1 NF22
0.3 NF02
Prism Penetration (cm)
Nearfield SPI 1998
12.8 FF13
0
2
4
6 Kilometers
N
W
E
S

Sediment Textures

- Dominated by broad-scale physical processes.
- Surface sediments were dominated by biological processes (bioturbation) .



RPD Measurments: QL - Detailed as %

- 38 station-replicate images that had measured RPD depths only one exceeded a difference of 50% (NF14-3).
- Indicates that Quick Look analysis has sufficient resolution to estimate RPD depths given the 50% change criteria.

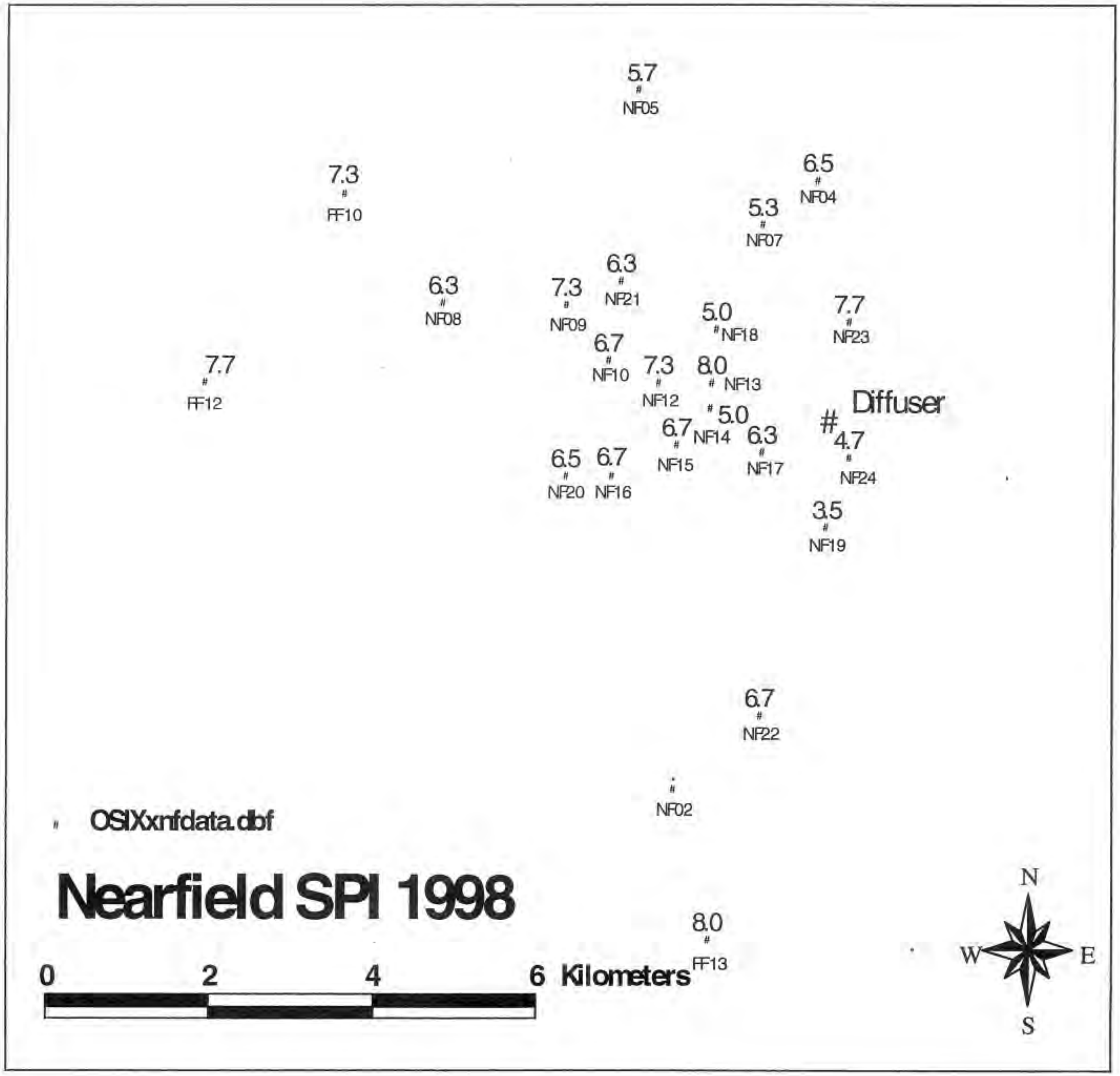
- Test sensitivity of the Quick Look analysis for estimating RPD depths within 50% of the actual RPD value
- Quick Look value was expressed as a percentage of the computer analysis value

For 3 station-replicates that had >1 cm differnece in RPD:

- Quick Look analysis values were ≥3 cm.
- Detailed analyses were 0.9, 1.0, and 1.8 cm for NF14-2, NF14-3, and NF18-3.
- Overestimated RPD depth related to light color and low contrast of sediment.
- Subsequently accounted for in the computer image analysis.

Quick Look vs. Detailed Analyses

- Correspondence was very good.
- Prism penetration 1in 69 station-replicates (NF23-1) differed by >1 cm.
- Surface relief 4 in 69 differed by >1 cm.
- RPD depth 3 in 69 differed by>1cm

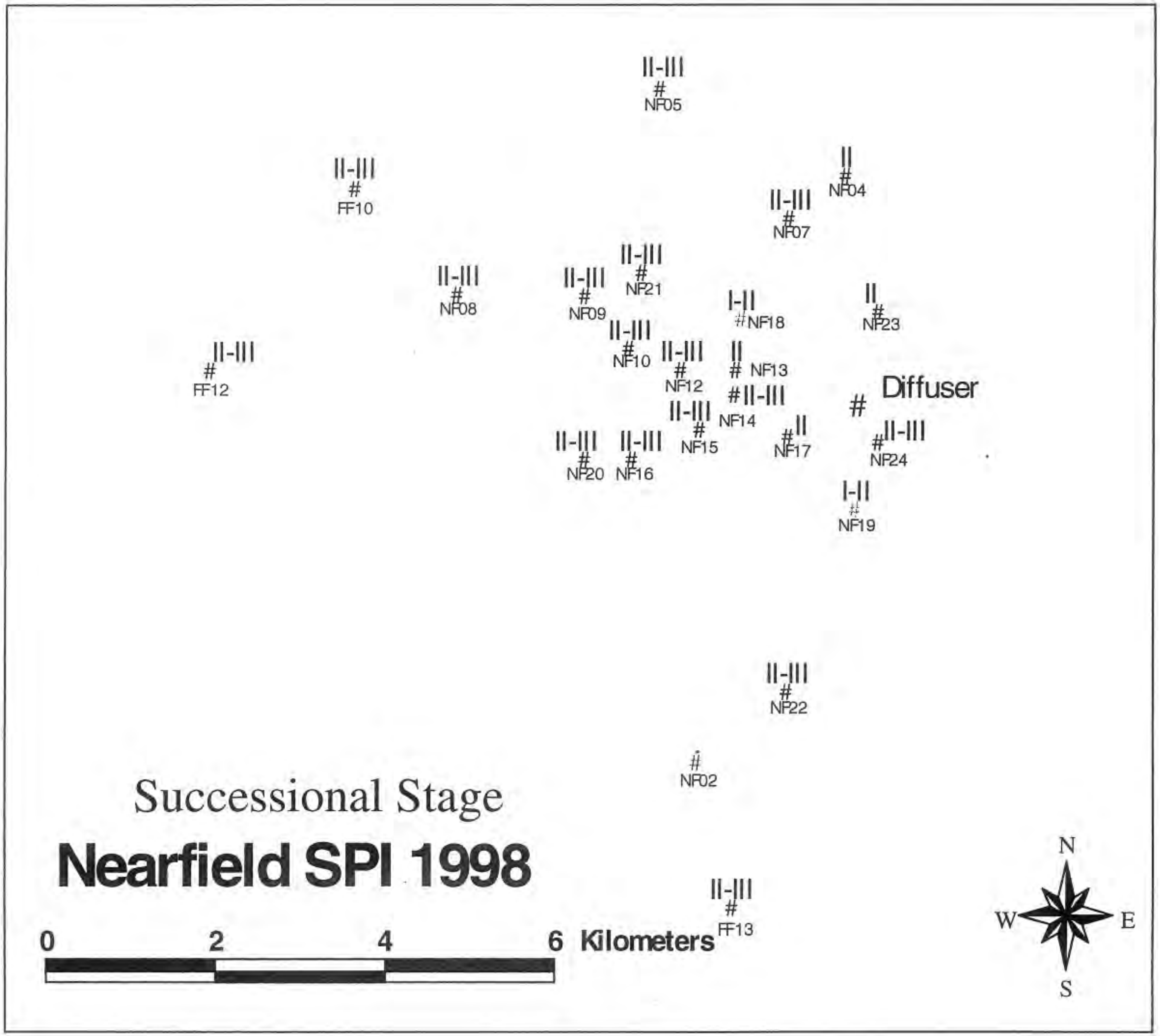

5.7
NF05
7.3
FF10
6.5
NF04
5.3
NF07
6.3
NF08
7.3
NF09
6.3
NF21
5.0
NF18
7.7
NF23
7.7
FF12
6.7
NF10
7.3
NF12
8.0
NF13
Diffuser
5.0
NF14
6.7
NF15
6.3
NF17
4.7
NF24
6.5
NF20
6.7
NF16
3.5
NF19
6.7
NF22
NF02
OSIXxnfdata.dbf
Nearfield SPI 1998
8.0
FF13
0
2
4
6
Kilometers
N
W
E
S

OSI (Rhoads and Germano 1986)

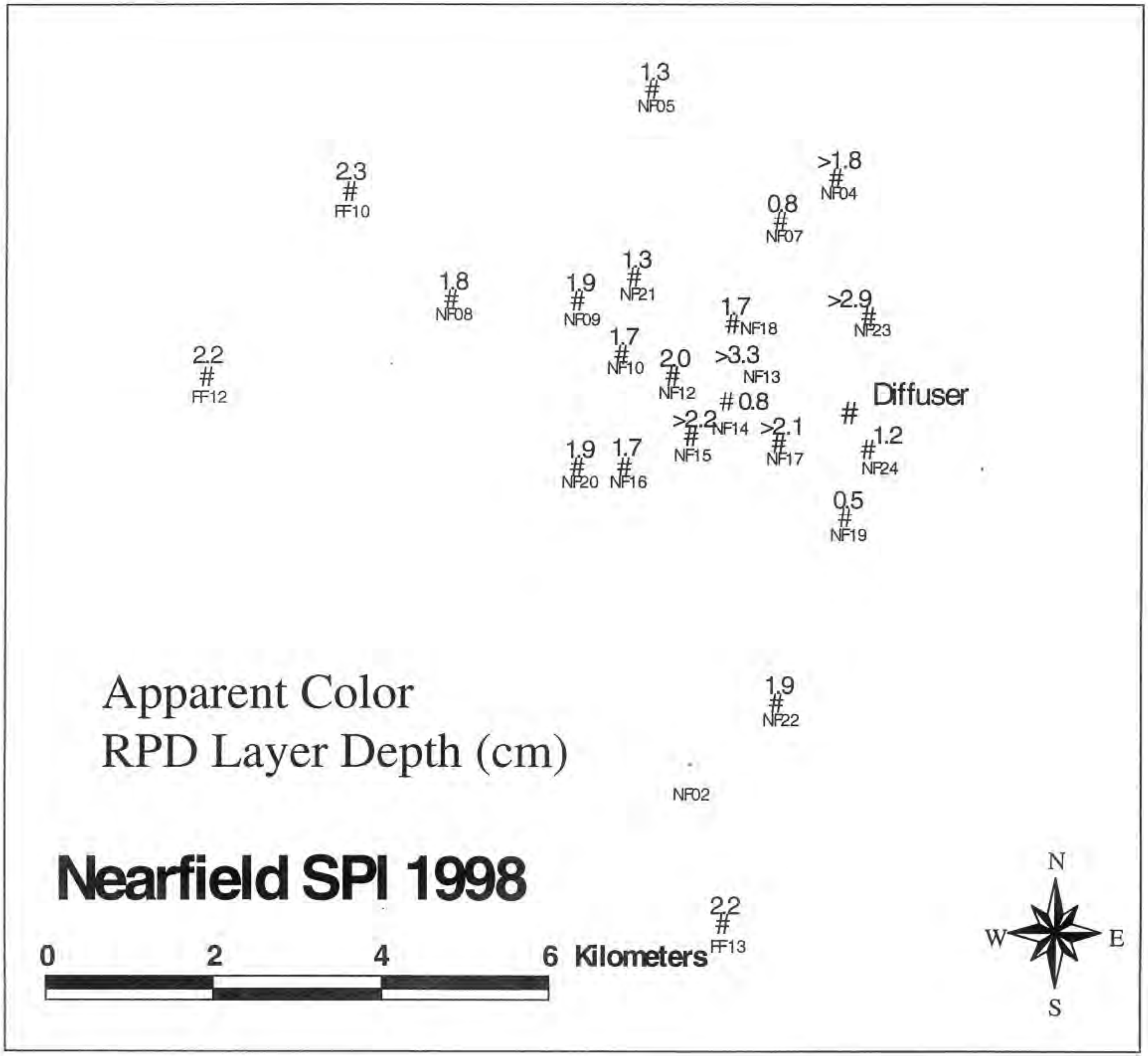
Depth of RPD:		Successional stage:	
0 cm 0		Azoic	-4
>0-0.75	1	I	1
0.76-1.50	2	I-II	2
1.51-2.25	3	II	3
2.26-3.00	4	II-III	4
3.01-3.75	5	III	5
>3.75	6	I on III	5
		II on III	5

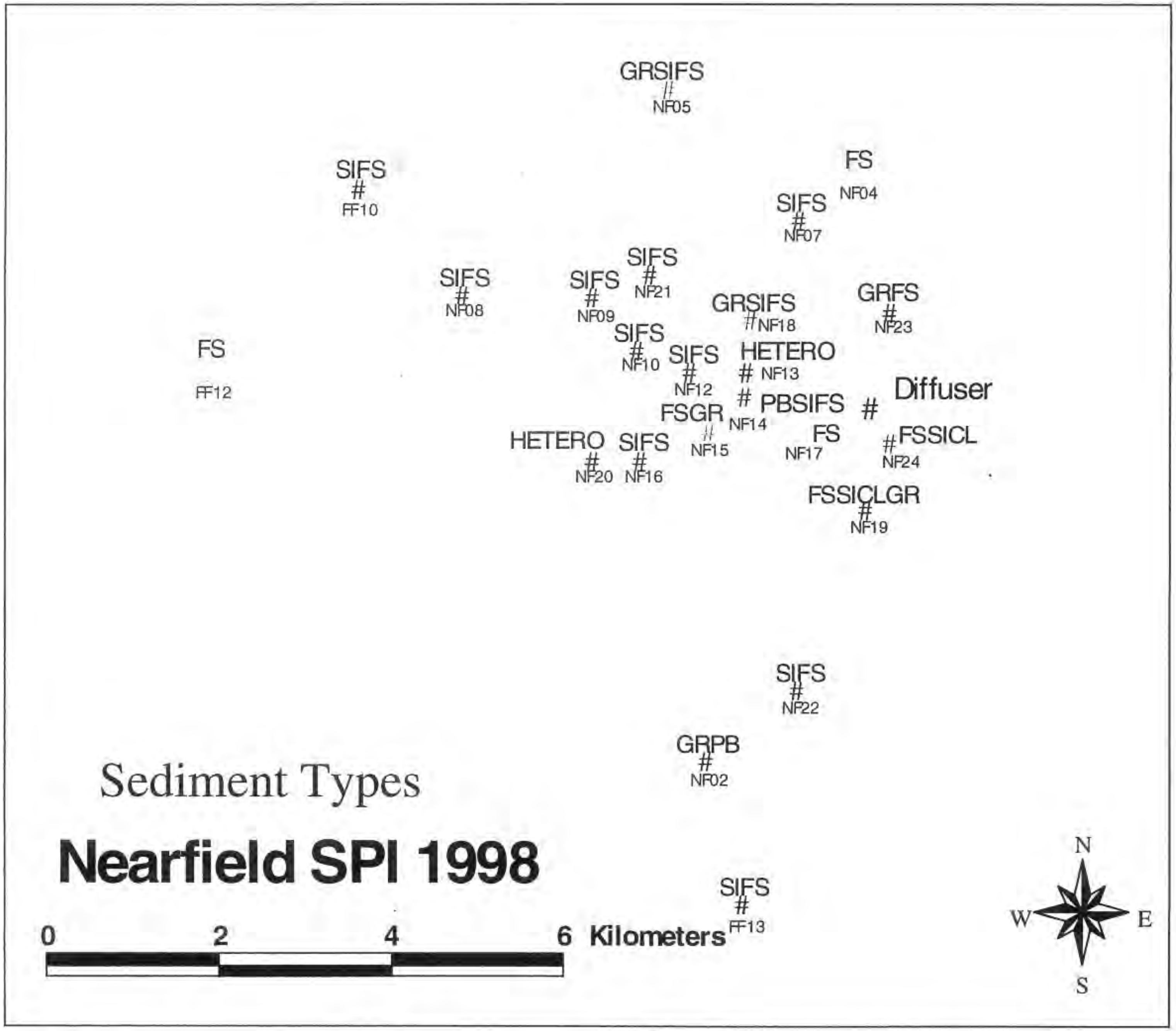
Other:

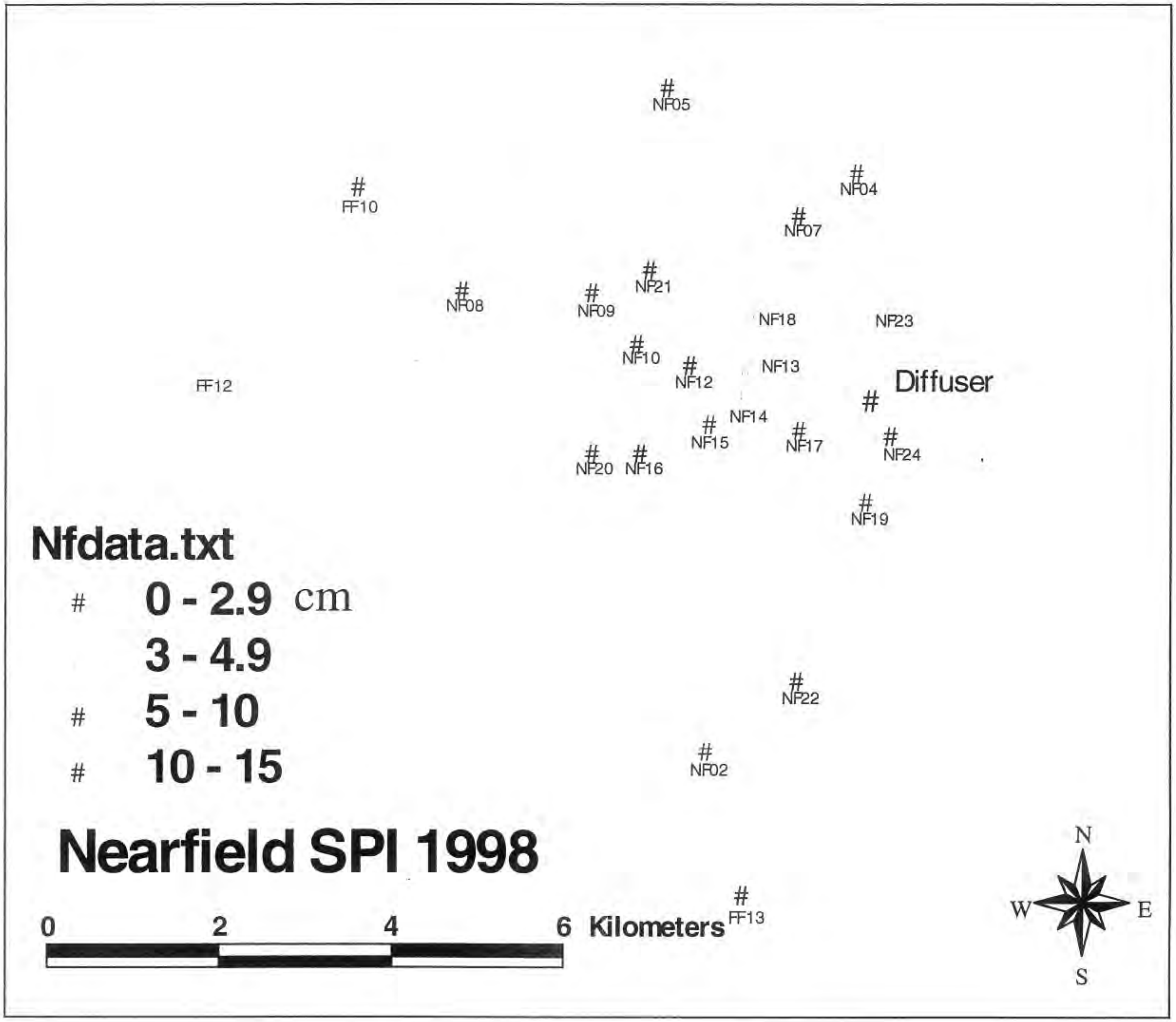
Methane voids present	-2
No/Low DO	-4


II-III NF05
II-III FF10
II NF04
II-III NF07
II-III NF21
II-III NF08
II-III NF09
I-II NF18
II NF23
II-III FF12
II-III NF10
II-III NF12
II NF13
II-III NF14
Diffuser
II-III NF15
II NF17
II-III NF24
II-III NF20
II-III NF16
I-II NF19
II-III NF22
NF02
Successional Stage
Nearfield SPI 1998
II-III FF13
0
2
4
6 Kilometers
N
W
E
S

Parameter	Succesional Stage I	II	III
Average RPD (cm)	<1	1-3	>2
Max depth RPD (cm)	<2	>2	>4
Small Tubes	+++	++	+
Large Tubes	-	++	+++
Burrows	-	++	+++
Feeding Voids	-	+	+++
Small Infauna	+++	++	+
Large Infauna	-	+	++
Epifauna	+	++	++

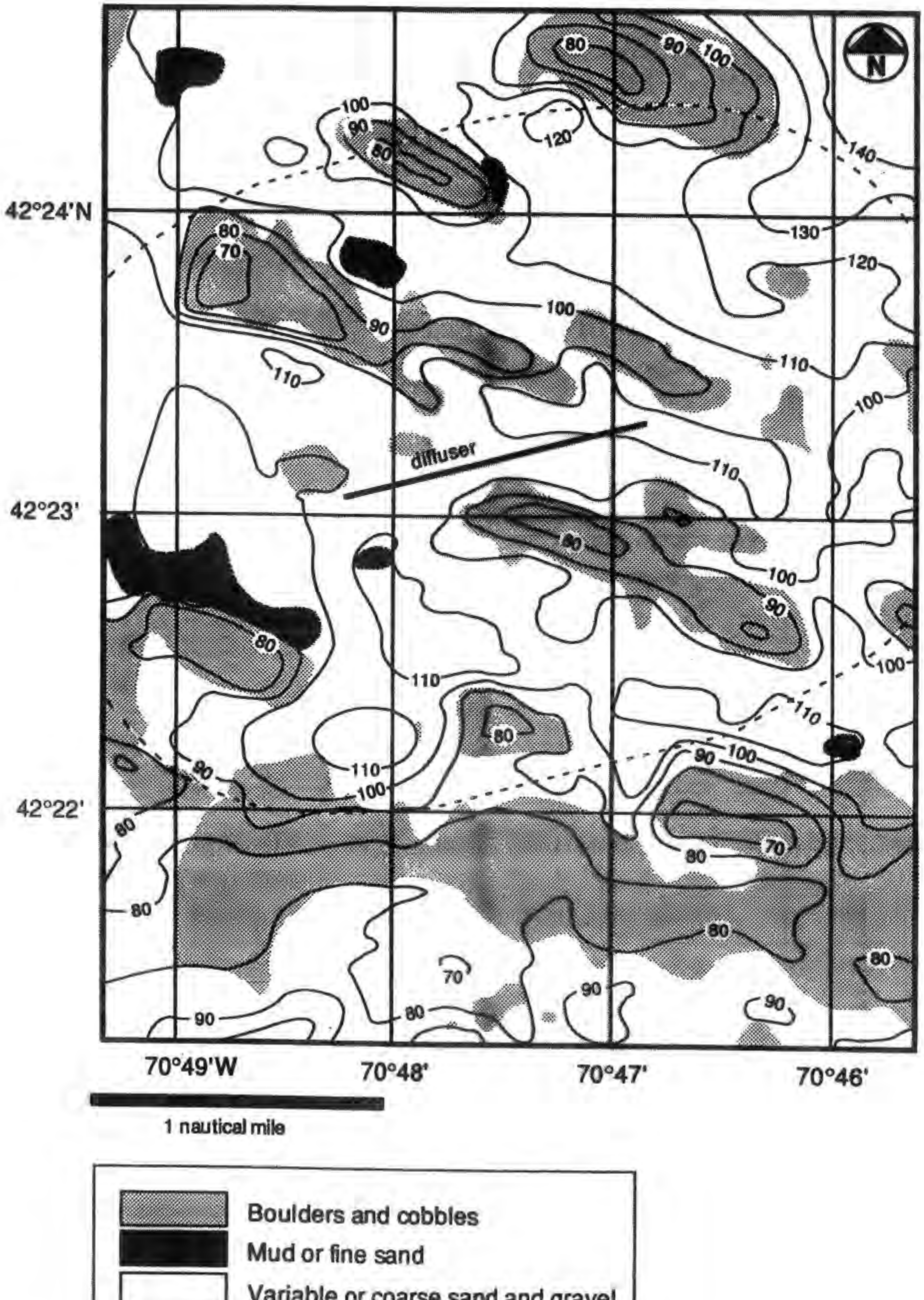

1.3
NF05
2.3
FF10
>1.8
NF04
0.8
NF07
1.3
NF21
1.8
NF08
1.9
NF09
1.7
NF18
>2.9
NF23
2.2
FF12
1.7
NF10
2.0
NF12
>3.3
NF13
0.8
NF14
Diffuser
>2.2
NF15
>2.1
NF17
1.2
NF24
1.9
NF20
1.7
NF16
0.5
NF19
1.9
NF22
NF02
2.2
FF13
Apparent Color
RPD Layer Depth (cm)
Nearfield SPI 1998
0
2
4
6 Kilometers
N
W
E
S


GRSIFS
NF05
SIFS
FF10
FS
NF04
SIFS
NF07
SIFS
NF21
SIFS
NF08
SIFS
NF09
GRSIFS
NF18
GRFS
NF23
FS
FF12
SIFS
NF10
SIFS
NF12
HETERO
NF13
PBSIFS
NF14
Diffuser
FSGR
NF15
FS
NF17
FSSICL
NF24
HETERO
NF20
SIFS
NF16
FSSICLGR
NF19
SIFS
NF22
GRPB
NF02
Sediment Types
Nearfield SPI 1998
SIFS
FF13
0
2
4
6 Kilometers
N
W
E
S

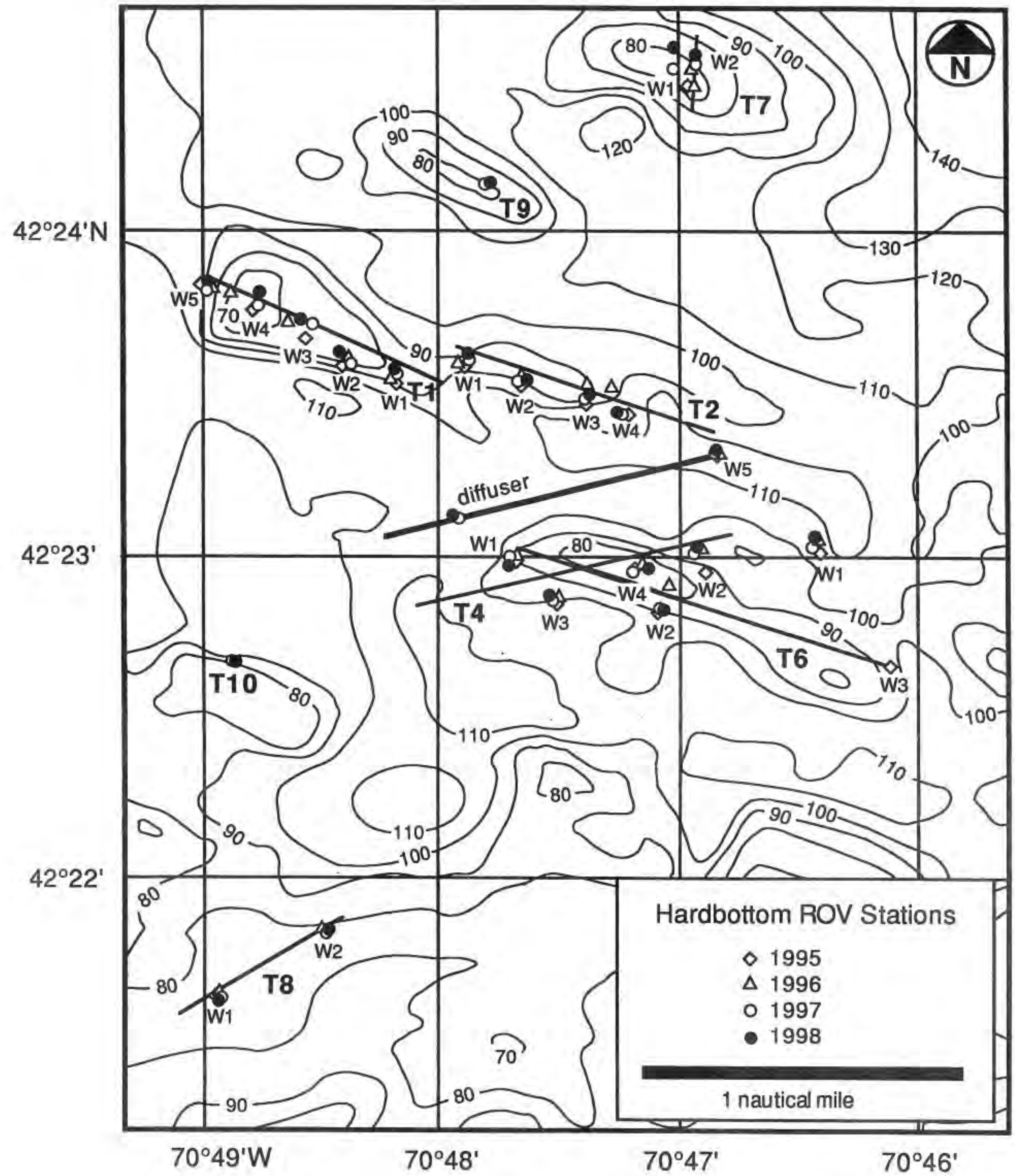

NF05
FF10
NF04
NF07
NF21
NF08
NF09
NF18
NF23
NF10
NF12
NF13
FF12
Diffuser
NF14
NF15
NF17
NF24
NF20
NF16
NF19
Nfdata.txt
0 - 2.9 cm
3 - 4.9
5 - 10
10 - 15
NF22
NF02
Nearfield SPI 1998
FF13
0
2
4
6 Kilometers
N
W
E
S

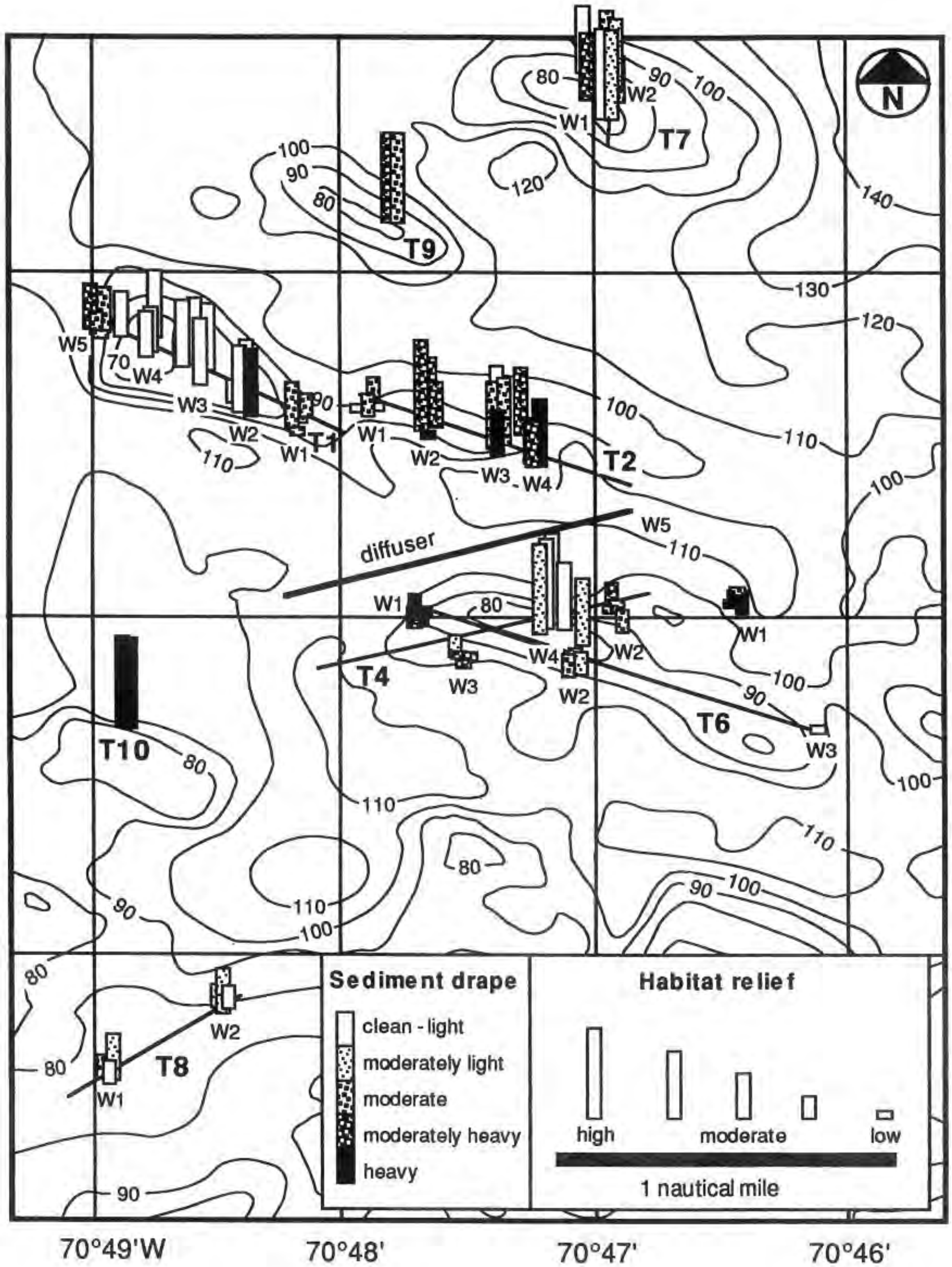
Benthic Monitoring

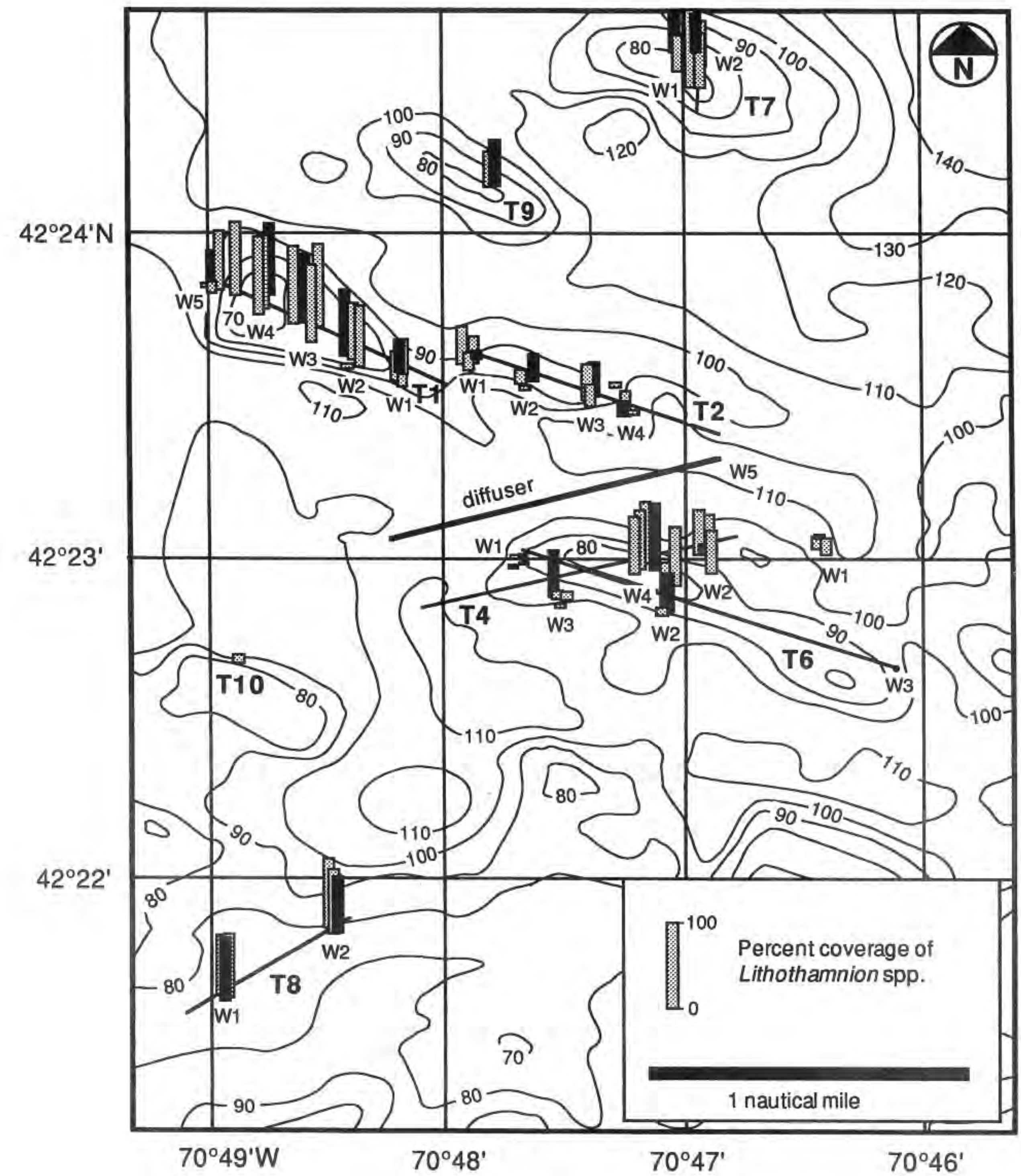
1998 Hardbottom Community *(Dr. Barbara Hecker, Hecker Environmental)*

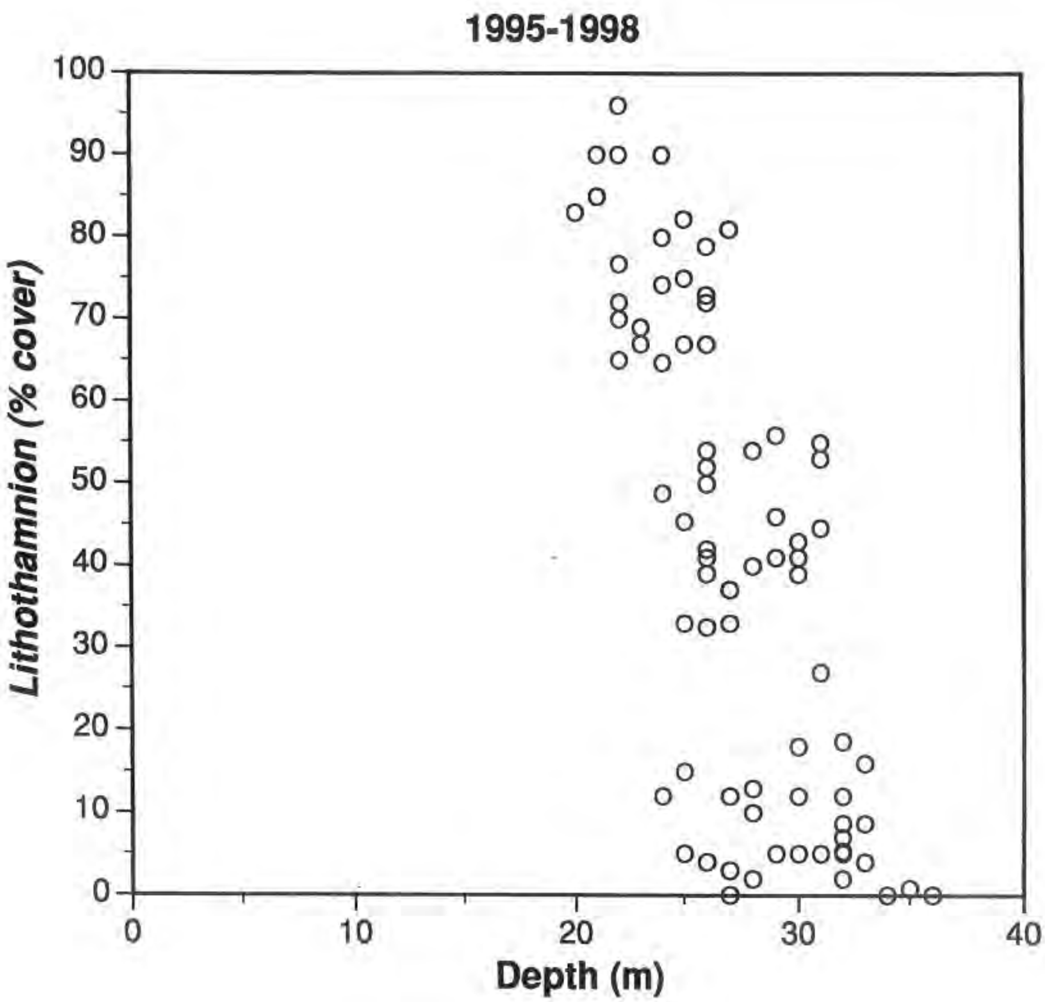


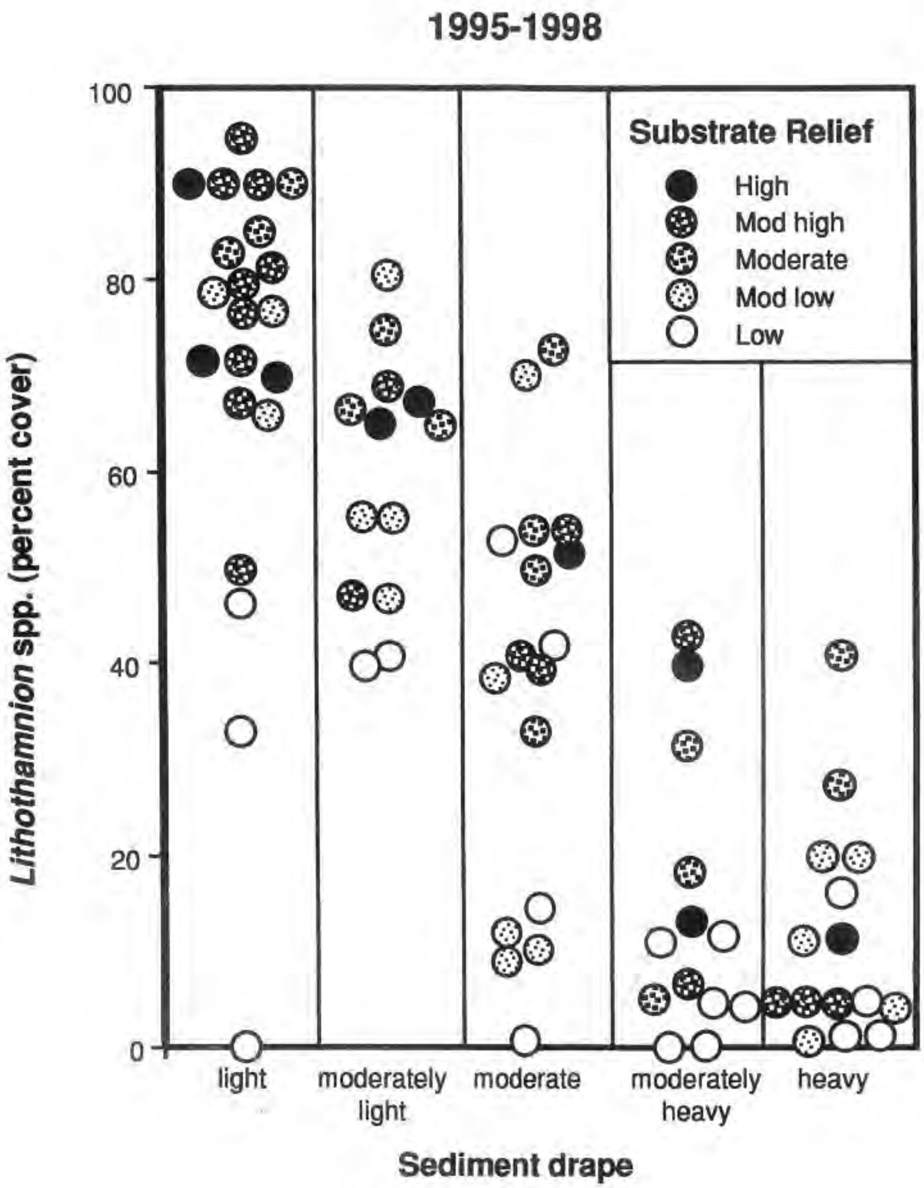
From Butman et al., 1992


42°24'N
42°23'
42°22'
70°49'W
70°48'
70°47'
70°46'
N
T1
T2
T4
T6
T7
T8
T9
T10
W1
W2
W3
W4
W5
diffuser
Hardbottom ROV Stations
1995
1996
1997
1998
1 nautical mile

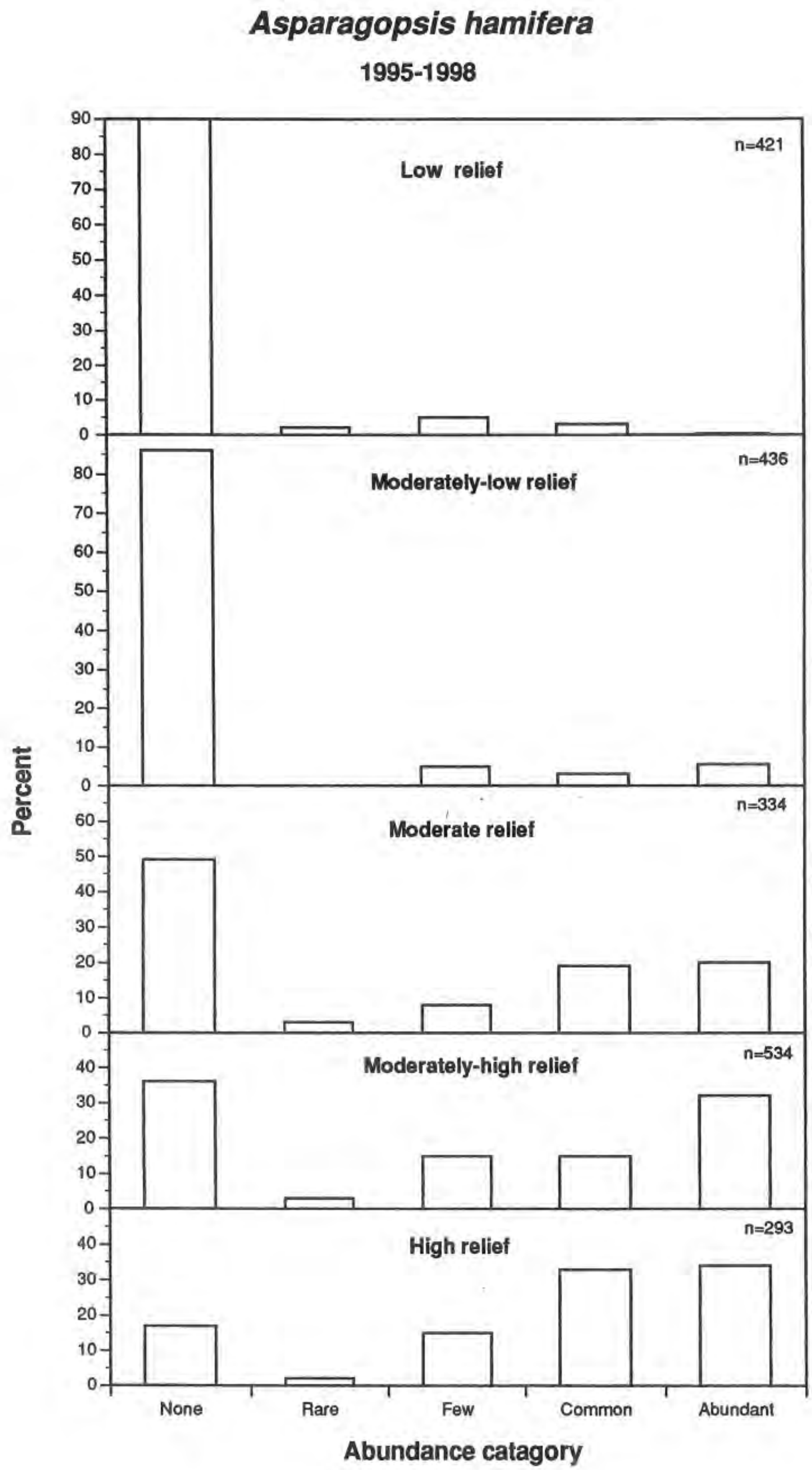

N
42°24'N
42°23'
42°22'
70°49'W
70°48'
70°47'
70°46'
T1
T2
T4
T6
T7
T8
T9
T10
W1
W2
W3
W4
W5
diffuser
80
90
100
110
120
130
140
70
Sediment drape
clean - light
moderately light
moderate
moderately heavy
heavy
Habitat relief
high
moderate
low
1 nautical mile


42°24'N
42°23'
42°22'
70°49'W
70°48'
70°47'
70°46'
N
T1
T2
T4
T6
T7
T8
T9
T10
W1
W2
W3
W4
W5
diffuser
Percent coverage of *Lithothamnion* spp.
100
0
1 nautical mile

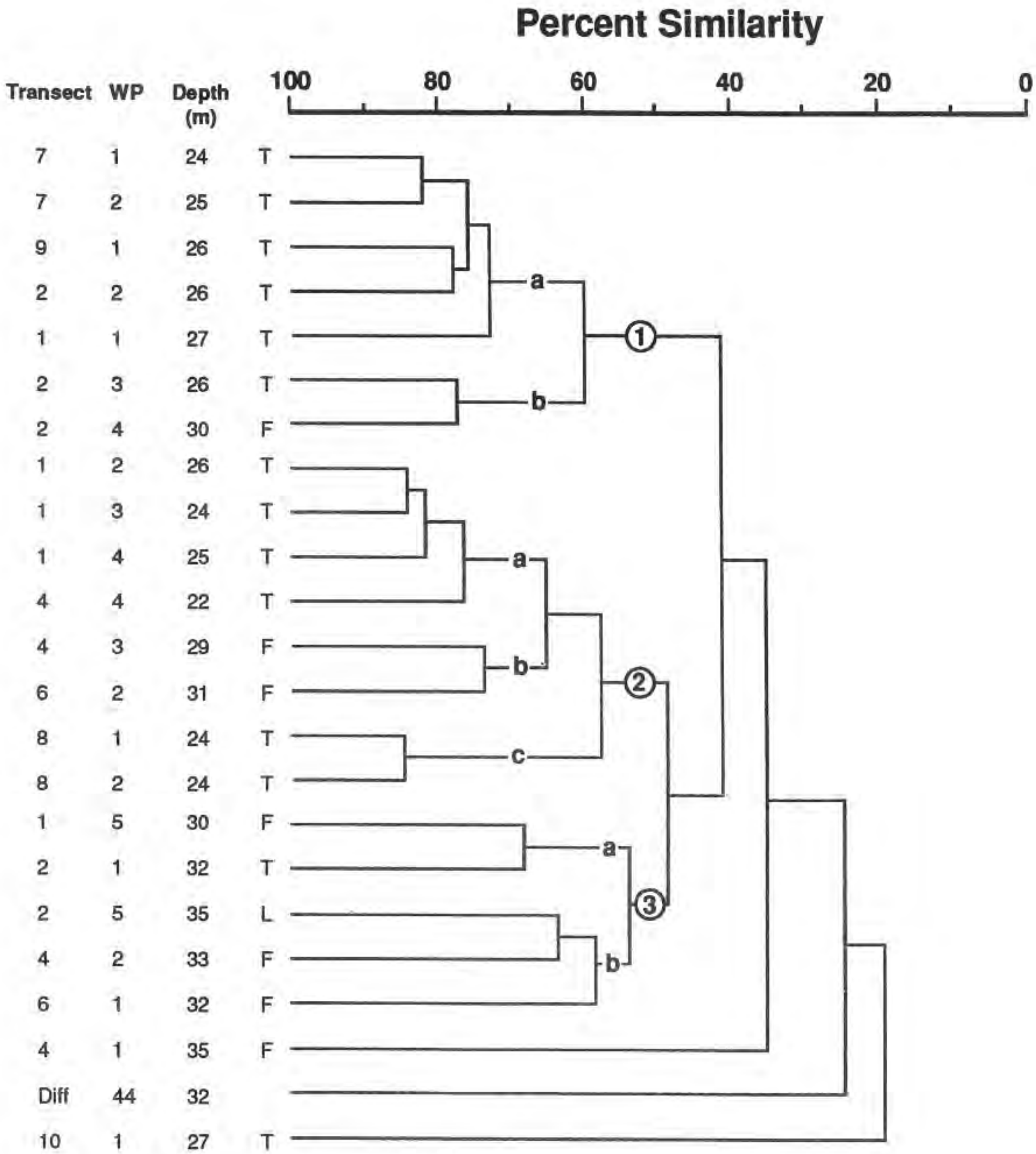

1995-1998
Lithothamnion (% cover)
Depth (m)
0
10
20
30
40
50
60
70
80
90
100



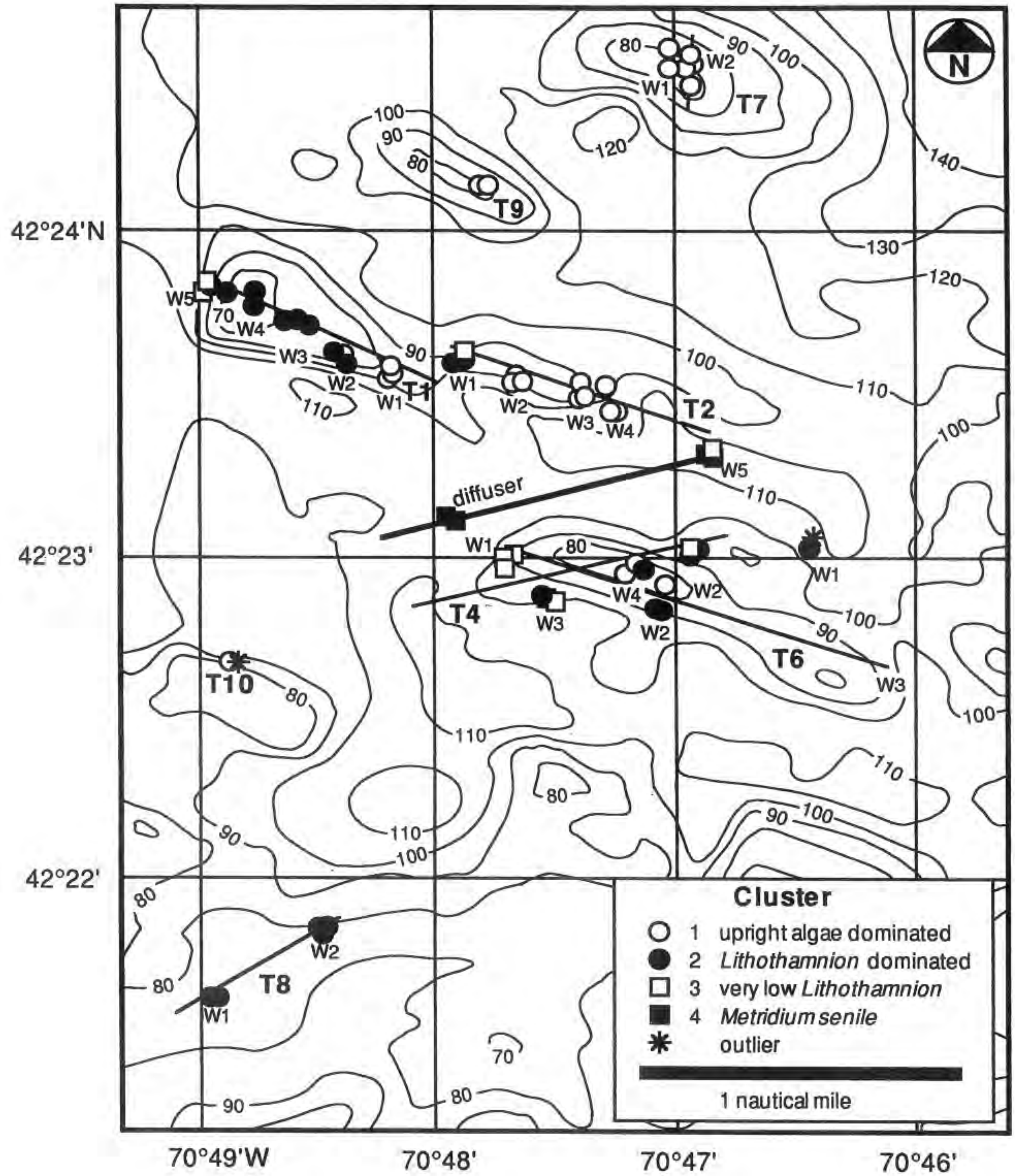
1995-1998
Substrate Relief
High
Mod high
Moderate
Mod low
Low
100
80
60
40
20
0
Lithothamnion spp. (percent cover)
light
moderately light
moderate
moderately heavy
heavy
Sediment drape



Asparagopsis hamifera
1995-1998
Percent
Low relief
n=421
Moderately-low relief
n=436
Moderate relief
n=334
Moderately-high relief
n=534
High relief
n=293
None
Rare
Few
Common
Abundant
Abundance catagory



Percent Similarity
100
80
60
40
20
0
Transcect WP Depth (m)
7 1 24 T
7 2 25 T
9 1 26 T
2 2 26 T
1 1 27 T
2 3 26 T
2 4 30 F
1 2 26 T
1 3 24 T
1 4 25 T
4 4 22 T
4 3 29 F
6 2 31 F
8 1 24 T
8 2 24 T
1 5 30 F
2 1 32 T
2 5 35 L
4 2 33 F
6 1 32 F
4 1 35 F
Diff 44 32
10 1 27 T
a
b
1
a
b
c
2
a
b
3


42°24'N
42°23'
42°22'
70°49'W
70°48'
70°47'
70°46'
N
T1
T2
T4
T6
T7
T8
T9
T10
diffuser
Cluster
1 upright algae dominated
2 *Lithothamnion* dominated
3 very low *Lithothamnion*
4 *Metridium senile*
outlier
1 nautical mile

Cluster group designations

1996-1998

Transect	Waypoint	1996	1997	1998
1	1	1a	1a	1a
	2	**1b**	2	2a
	3	2a	2a	2a
	4	2a	2a	2a
	5	**2c**	3	3
2	1	2b	2b	**3**
	2	1c	1b	1a
	3	1a	1a	1b
	4	1c	1b	1a
	5	4	4	**3**
4	1		2c	**outlier**
	2	2b	2c	**3**
	3	3	3	**2b**
	4	1b	1a	**2a**
6	1	3	3	3
	2	**1b**	2b	2b
7	1	1a	1a	1a
	2	1a	1a	1a
8	1		2b	2c
	2	2a	2b	2c
9	1		1	1a
10	1		1	**outlier**
Diff	44		4	4

1 dominated by upright algae

2 dominated by *Lithothamnion* spp.

3 very low *Lithothamnion* spp.

4 diffusers - *Metridium senile*

Lithothamnion spp. (percent cover)

1996-1998

Transect	Waypoint	1996	1997	1998
1	1	35	42	37
	2	71	72	79
	3	90	96	80
	4	87	83	82
	5	68	12	39
2	1	45	33	9
	2	5	13	33
	3	27	41	39
	4	7	27	18
	5	<1	<1	<1
4	1		16	≤1
	2	41	53	9
	3	12	12	56
	4	72	67	77
6	1	2	4	5
	2	69	55	45
7	1	65	43	49
	2	53	54	45
8	1		73	74
	2	82	75	65
9	1		40	54
10	1		12	≤1
Diff	44		<1	<1

Conclusions

structure of **benthic community** controlled by
location on drumlin - concurrent depth
substratum type
local relief
sediment drape

1) most areas appear to be **temporally stable**

2) but a number of areas are **spatially heterogeneous**

3) hard to dissect differences between temporal and spatial variance

4) some variability in data - **patchy** nature of hardbottoms

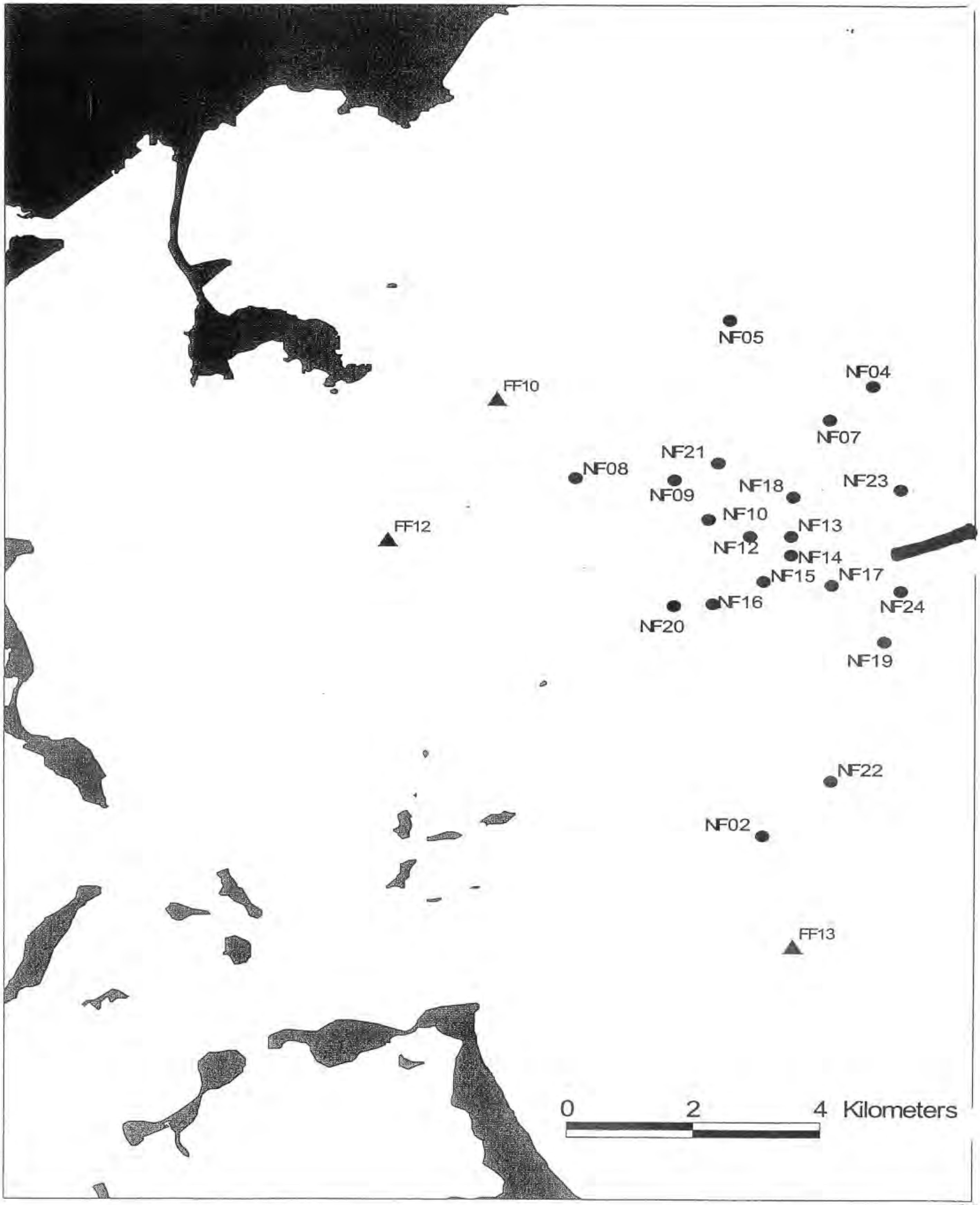
5) highly unlikely to be able to detect **small** shifts or changes in the composition of the hardbottom communities

6) probably the most likely "key-stone" species would be

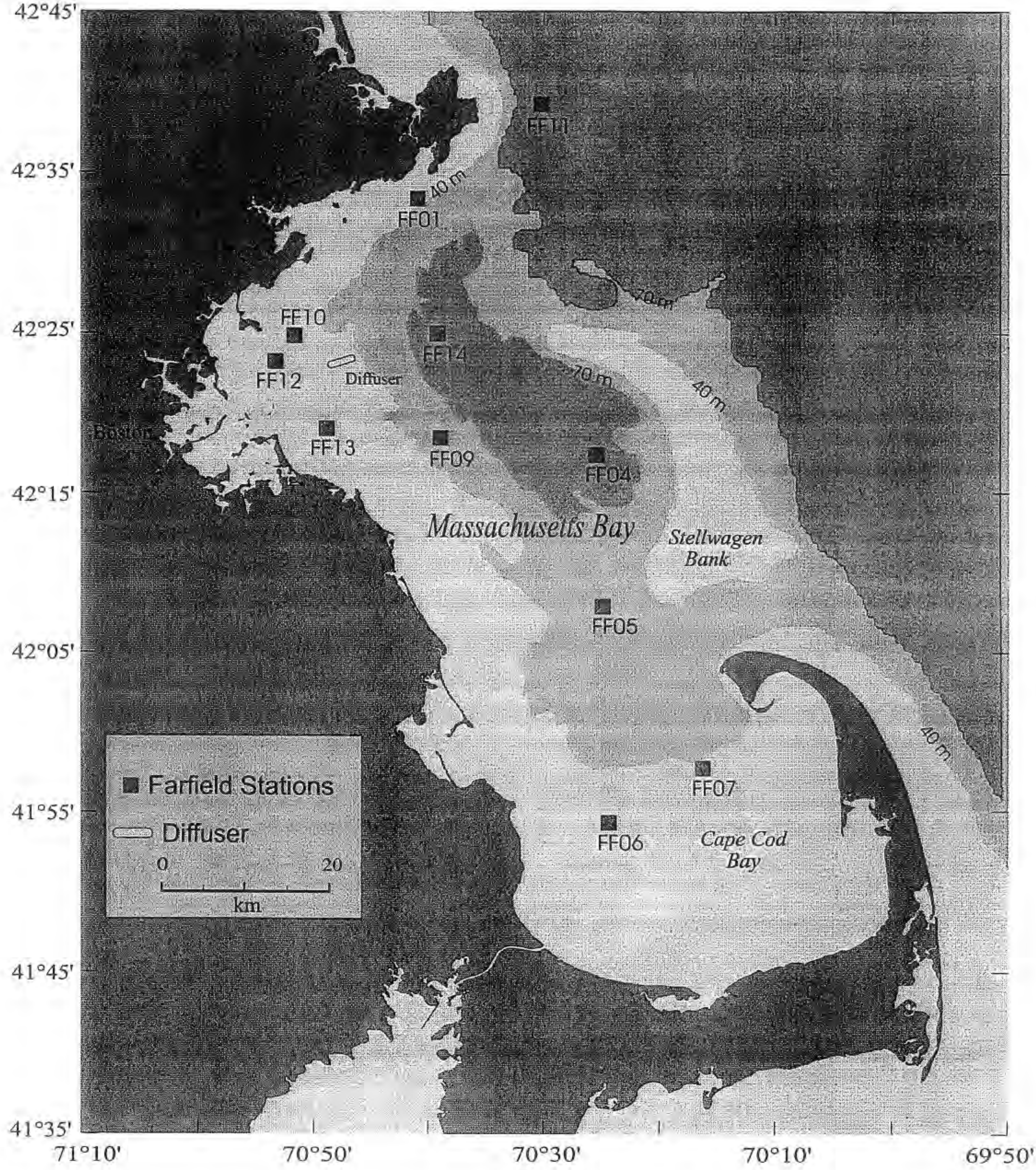
Lithothamnion
- **it is very abundant**
- **it is widely distributed**
- **less patchy than *Asparagopsis***
- **appears to be sensitive to sediment loading**

Benthic Monitoring
Infaunal Community Overview *(Dr. Roy Kropp, Battelle)*

Benthic Nearfield Stations



Benthic Farfield Stations



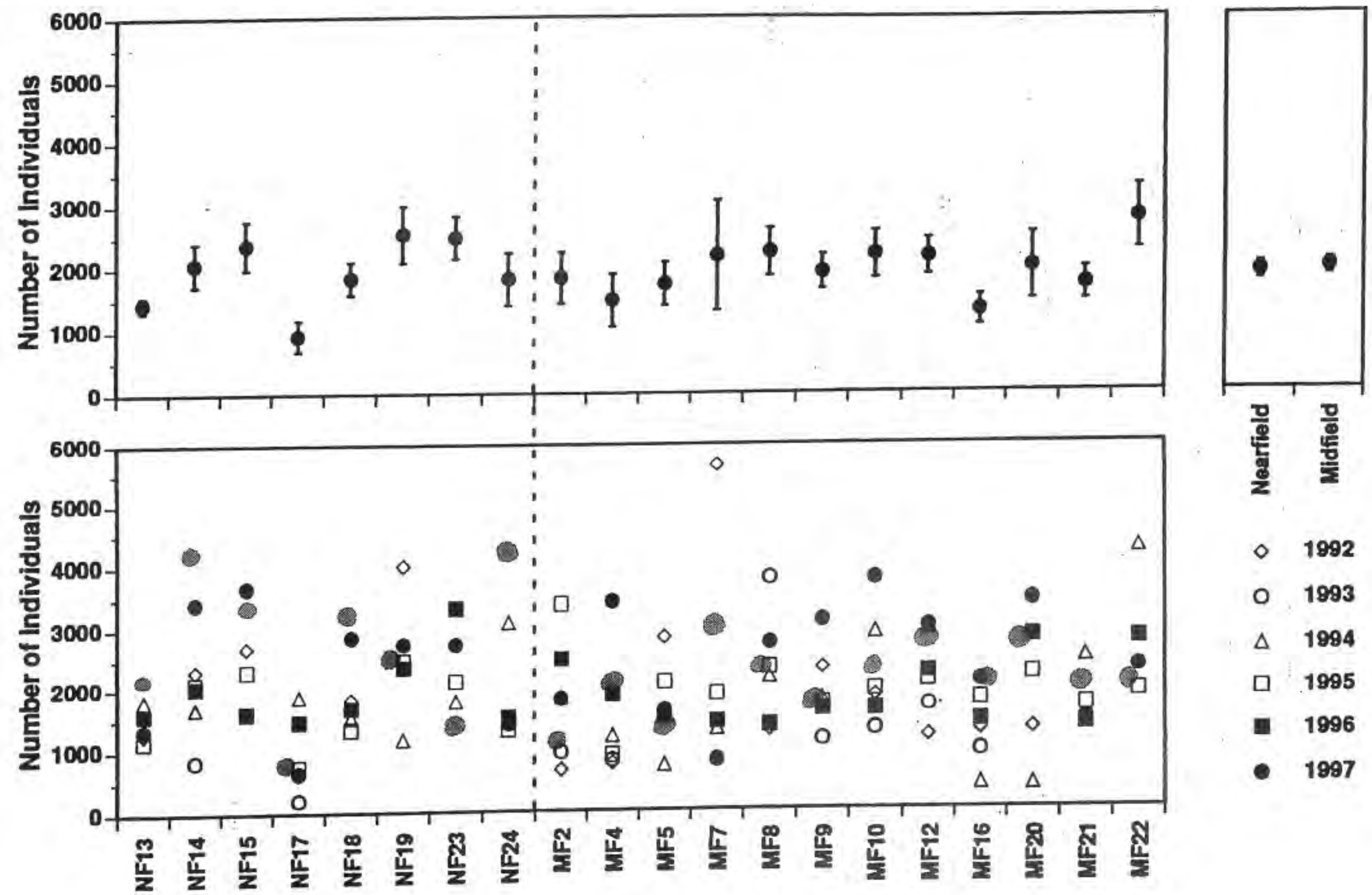


Figure 70. Infaunal densities at nearfield and midfield stations for the period 1992-1997. Top diagram shows the mean and standard error for each station; bottom diagram shows abundances for each year.

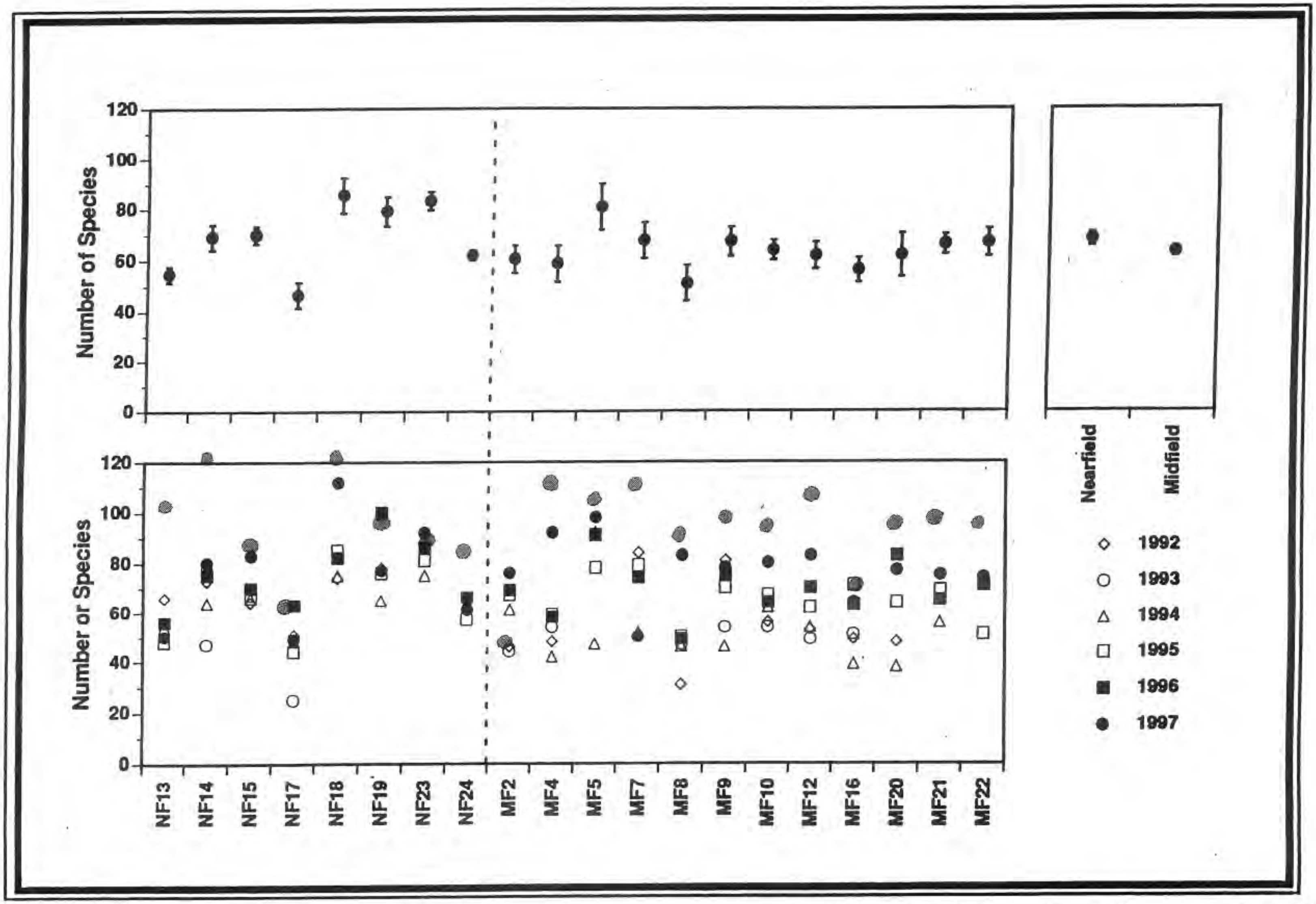


Figure 71. Number of species at nearfield and midfield stations for the period 1992-1997. Top diagram shows the mean and standard error for each station; bottom diagram shows values for each year.

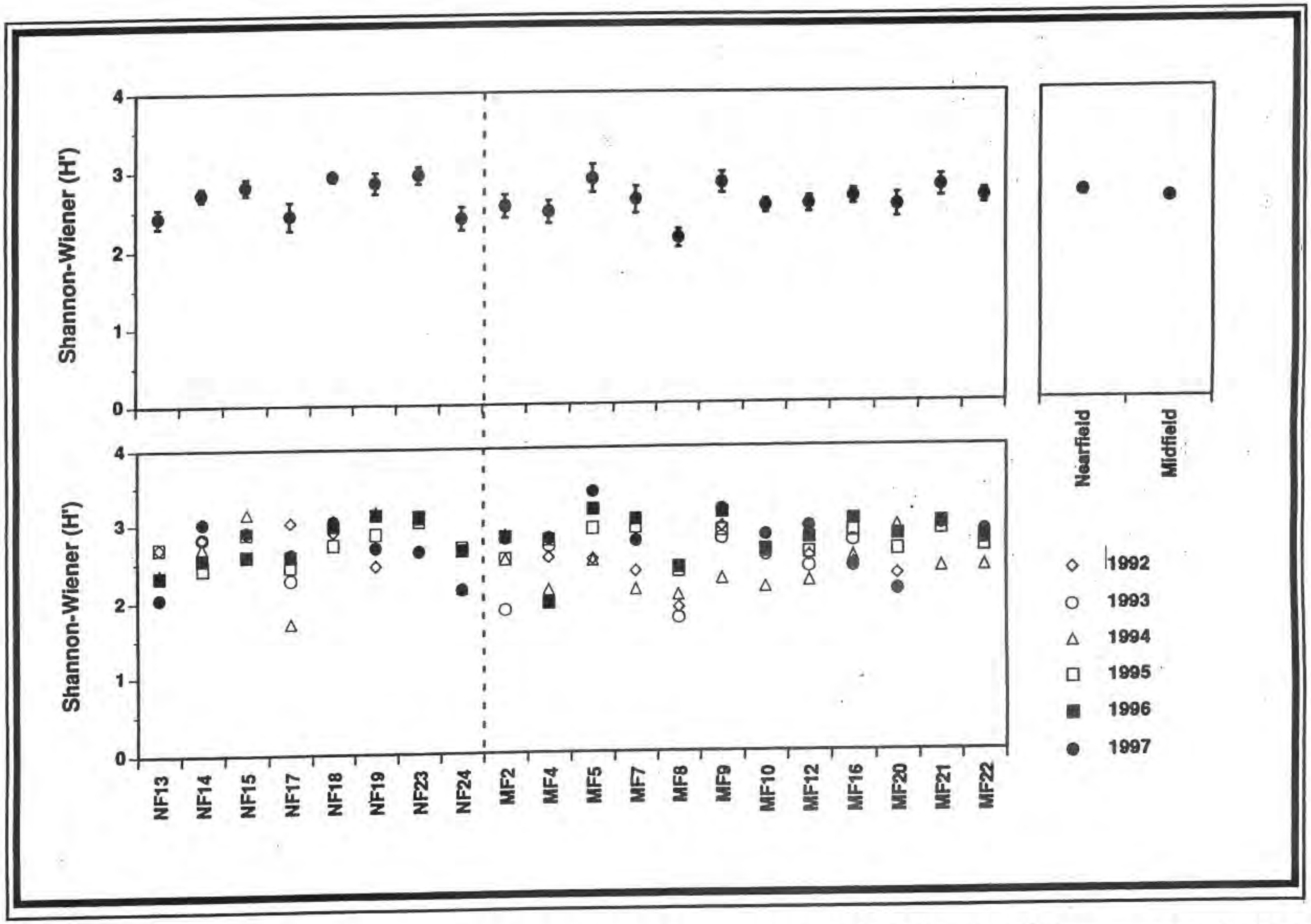
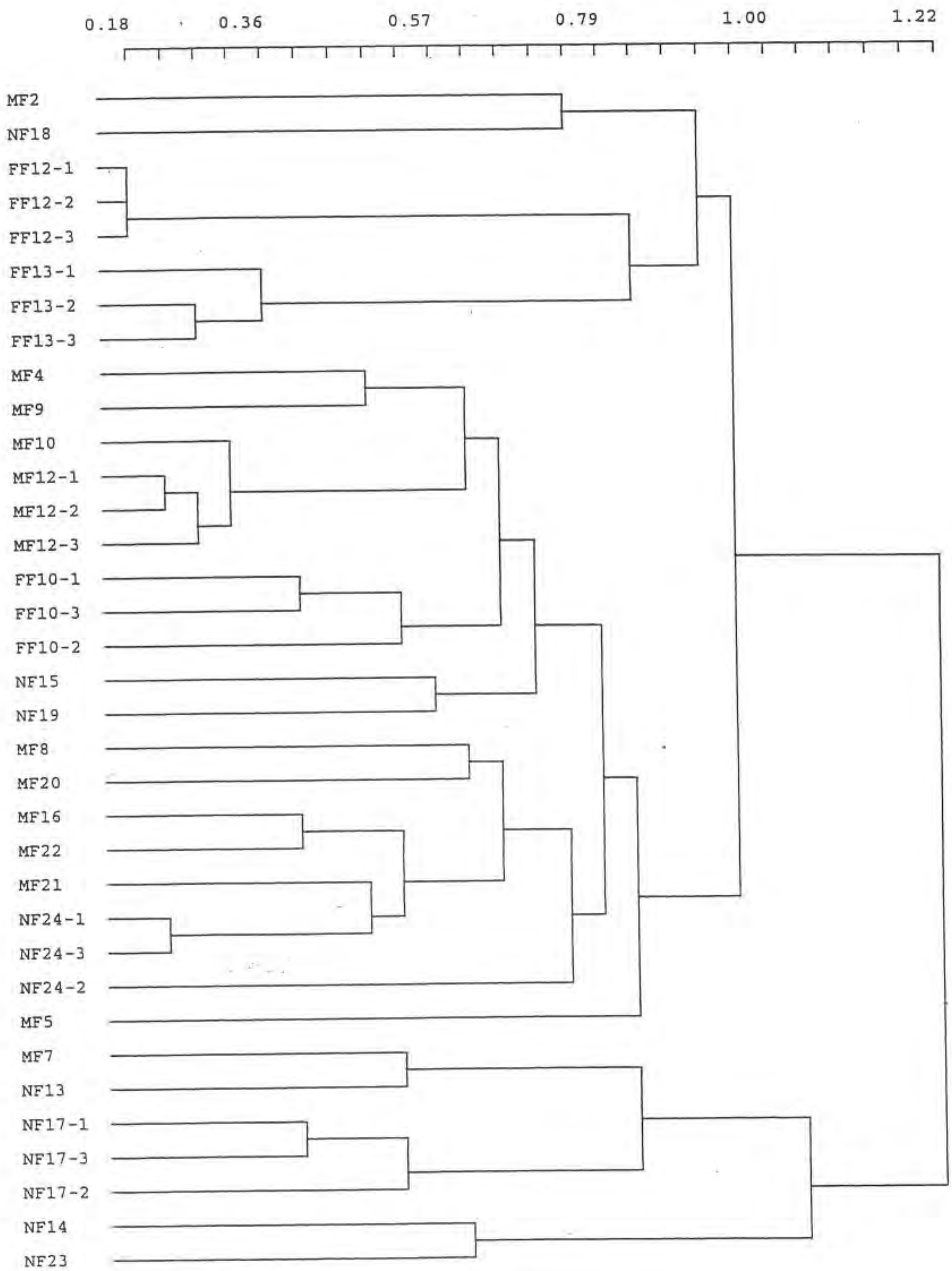
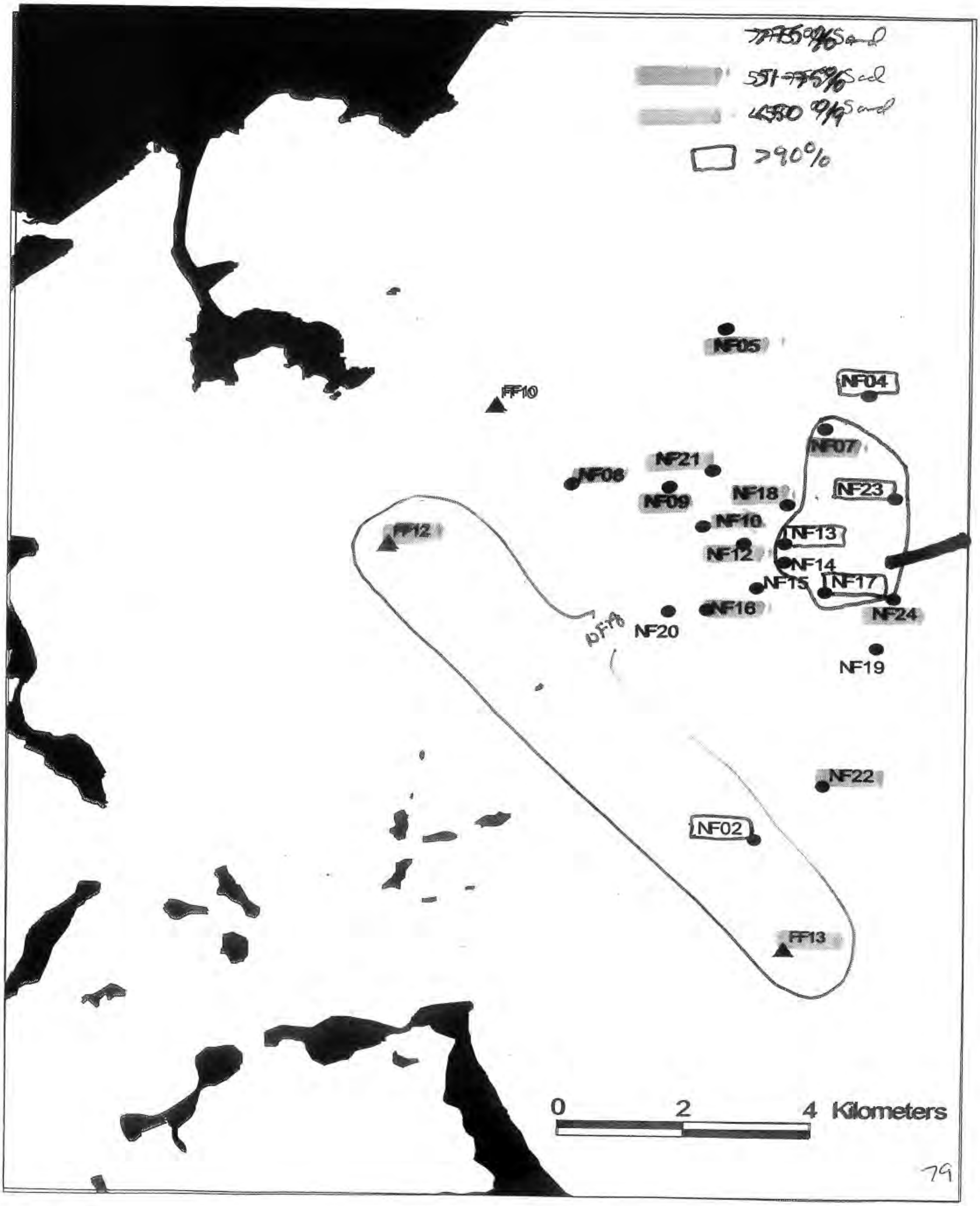


Figure 72. Shannon-Wiener diversity at nearfield and midfield stations for the period 1992-1997. Top diagram shows the mean and standard error for each station; bottom diagram shows H′ for each year.


0.18
0.36
0.57
0.79
1.00
1.22
MF2
NF18
FF12-1
FF12-2
FF12-3
FF13-1
FF13-2
FF13-3
MF4
MF9
MF10
MF12-1
MF12-2
MF12-3
FF10-1
FF10-3
FF10-2
NF15
NF19
MF8
MF20
MF16
MF22
MF21
NF24-1
NF24-3
NF24-2
MF5
MF7
NF13
NF17-1
NF17-3
NF17-2
NF14
NF23

Benthic Nearfield Stations

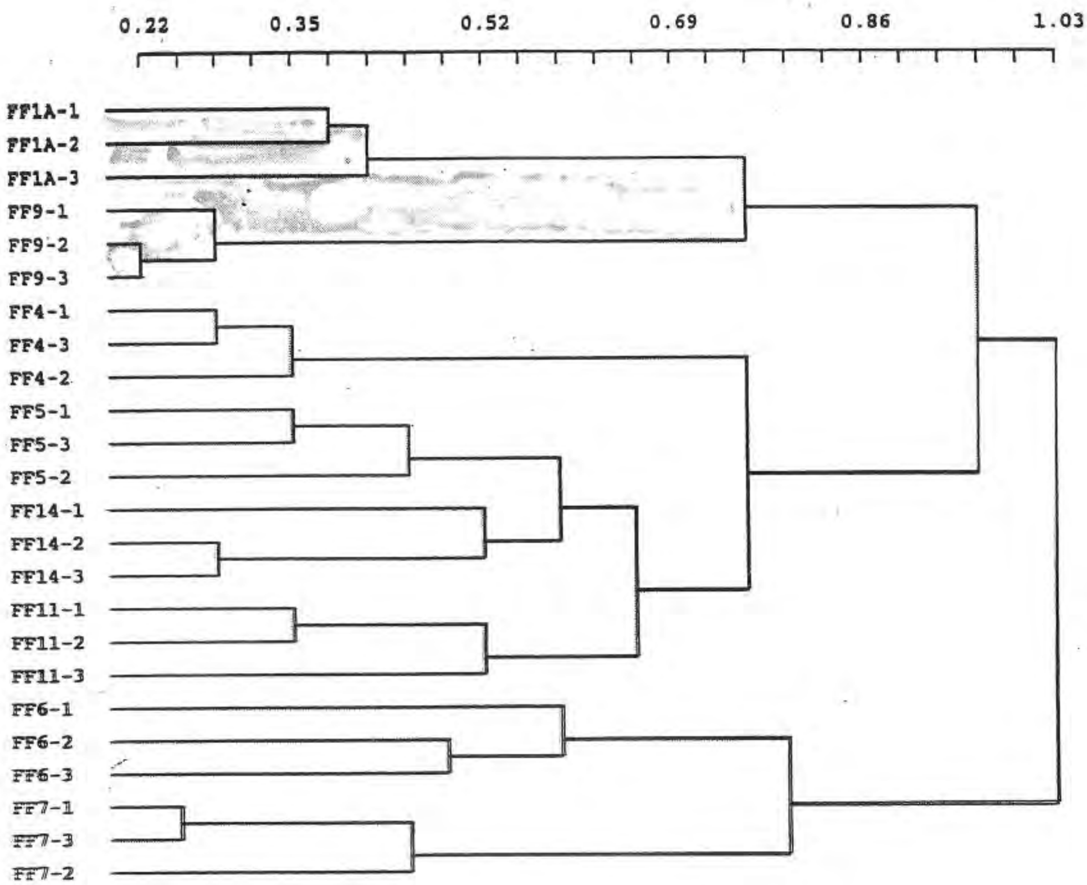
Benthic Nearfield Stations



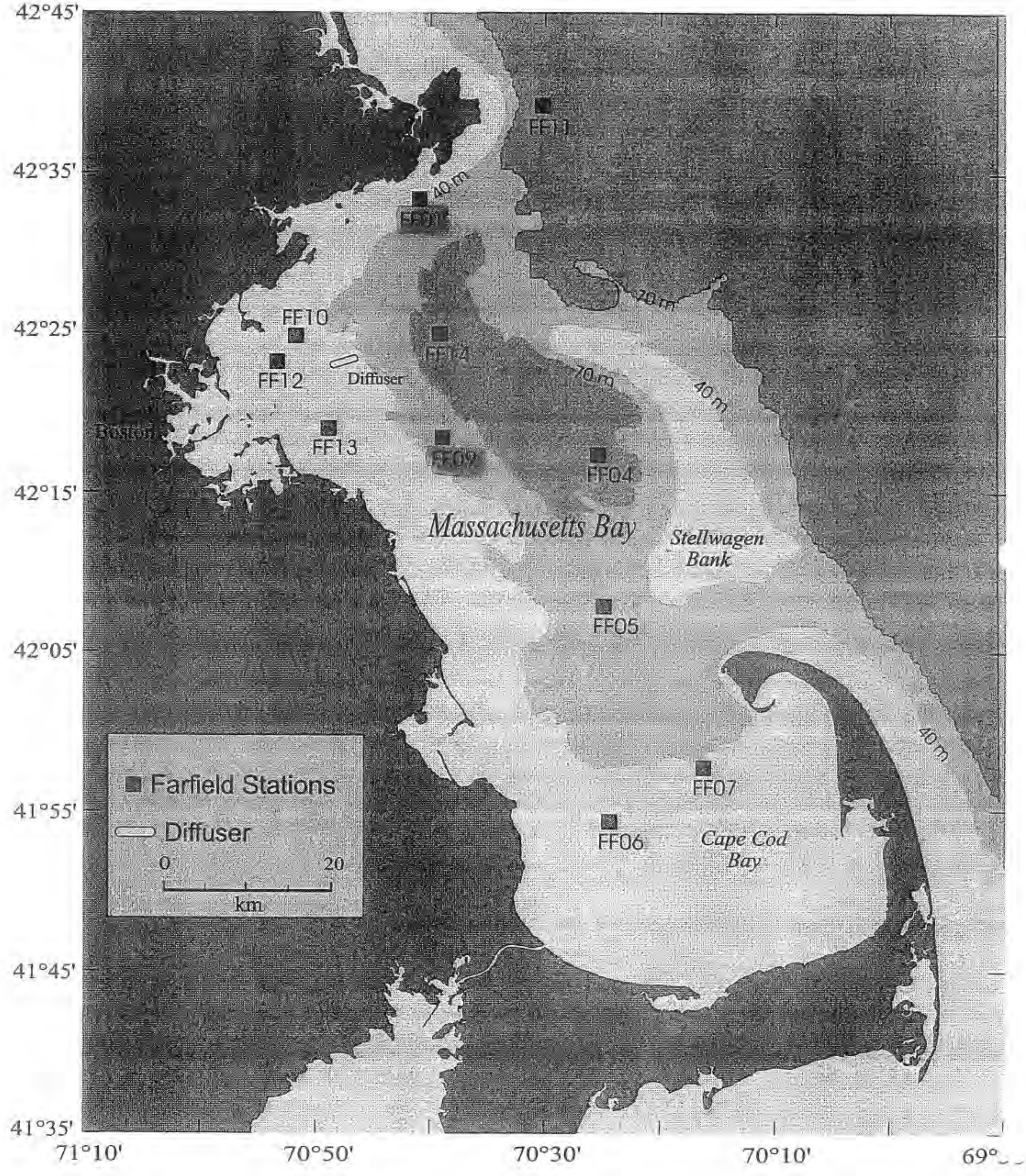
1998 Sed

Benthic Nearfield Stations

80


0.22
0.35
0.52
0.69
0.86
1.03
FF1A-1
FF1A-2
FF1A-3
FF9-1
FF9-2
FF9-3
FF4-1
FF4-3
FF4-2
FF5-1
FF5-3
FF5-2
FF14-1
FF14-2
FF14-3
FF11-1
FF11-2
FF11-3
FF6-1
FF6-2
FF6-3
FF7-1
FF7-3
FF7-2

Benthic Farfield Stations



82

Benthic Monitoring

Benthic Community Threshold Assessment *(Dr. Gene Gallagher, UMass – Boston)*

MA Bay Benthic Community Threshold Assessment

1999 MWRA Technical Workshop
Battelle New England
April 9, 1999

Eugene D. Gallagher
Jim Blake, ENSR
Peg Pelletier
UMASS/Boston

Methods for assessing change

Species & functional groups

- Changes in diversity
  - Log-series alpha
  - $E(S_{17})$
  - Pielou's J'
  - These diversity indices are sensitive to both species richness and species evenness
- Changes in functional group representation
  - MA Bay benthos has been classified into 8 functional groups
  - Chi-square tests
- Changes in indicator species

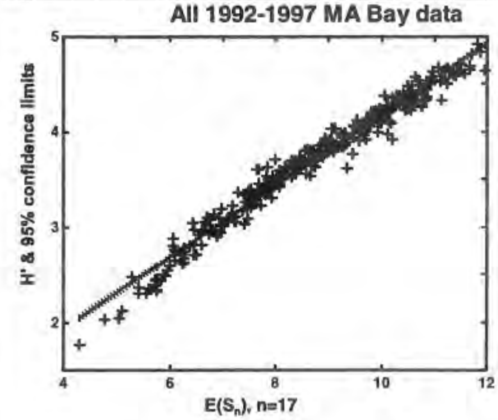
Benthic thresholds

Issues to be resolved

- The after effects will be determined using the 1992-1999 benthic baseline data
- What is the statistical population for Nearfield sites?
  - Are there significant differences among sand and silt-clay habitats in species richness or evenness
  - Do these groups need to be split for establishing a baseline
- So far, no major differences in sand vs. Mud in species diversity

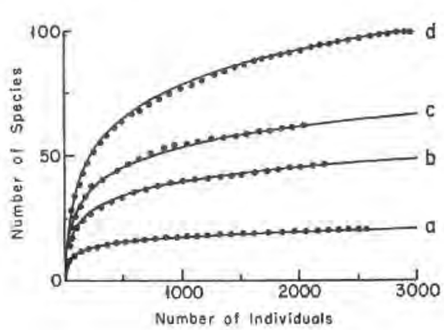
$E(S_{17})$ and H' are highly correlated

All 1992-1997 MA Bay data



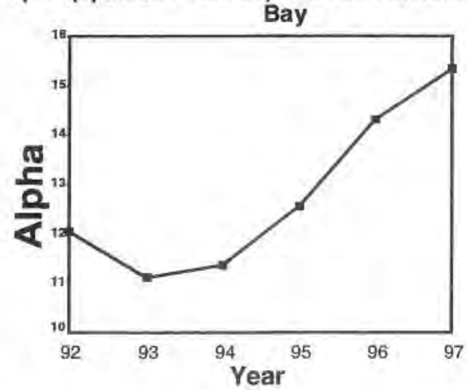
May's Log-series

May (1975): Log series fits Sanders' rarefaction curves



Log-series alpha

Alpha (species richness) has been increasing in MA Bay



Species diversity

Evenness may be more informative than richness

- Sanders-Hurlbert rarefaction curves reveal both richness & evenness
- Caswell (1972) used log series as a null model
- May (1975): Benthic communities tend to fit the log series
- Gray argued that benthic communities are not log-series, but were lognormally distributed
- Hughes & Lambshead showed that benthic communities are not log-normally distributed; Hughes modeled the dynamics

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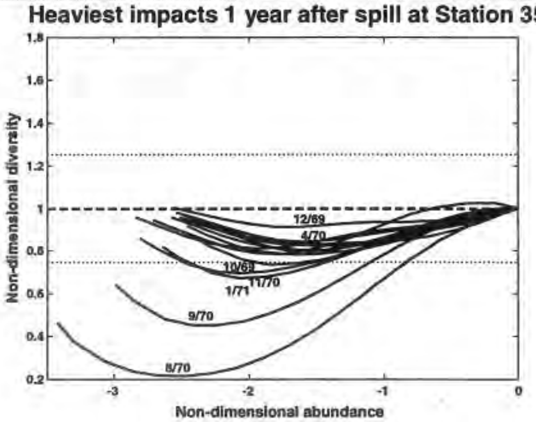
Non-dimensional diversity

Calculates evenness relative to a log-series null.

- Steps in analysis
  - Generate a rarefaction curve
  - Generate the log-series expectation
  - Divide the observed diversity by the log-series expectation
  - Non-dimensionalize by dividing numbers by the species total and expected species by observed total species
- A deeply dipping curve indicates less evenness than log series.

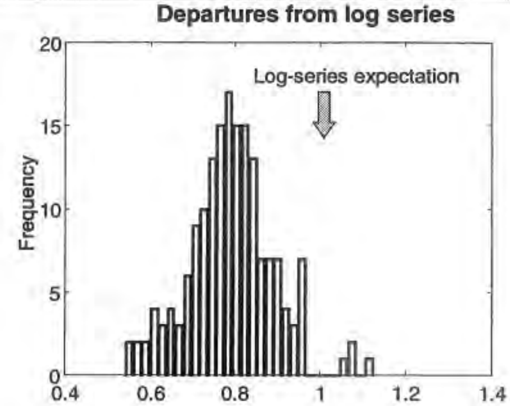
West Falmouth Oilspill

Heaviest impacts 1 year after spill at Station 35



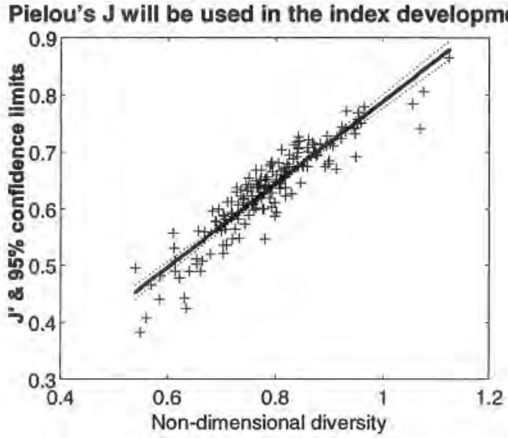
1992-1996 MA Bay

Departures from log series



Pielou's J' correlated with ND-Div

Pielou's J will be used in the index development



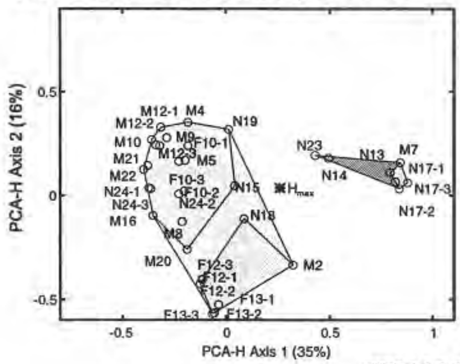
PCA-H analysis

Ordination based on CNESS

- Steps in analysis
  - Convert species data to probabilities
  - Cluster samples and species
  - Order samples and species in space
- Results
  - Cluster analysis
    - Two major species & sample groups
    - Sand assemblage: *Corophium*
    - Three mud assemblages
  - Ordination analysis
    - Sand vs. mud the key environmental gradient
    - Interannual variability less important than space

MA Bay benthos

1997 Nearfield Community structure



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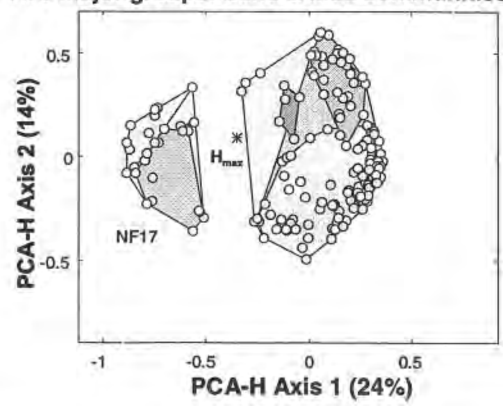
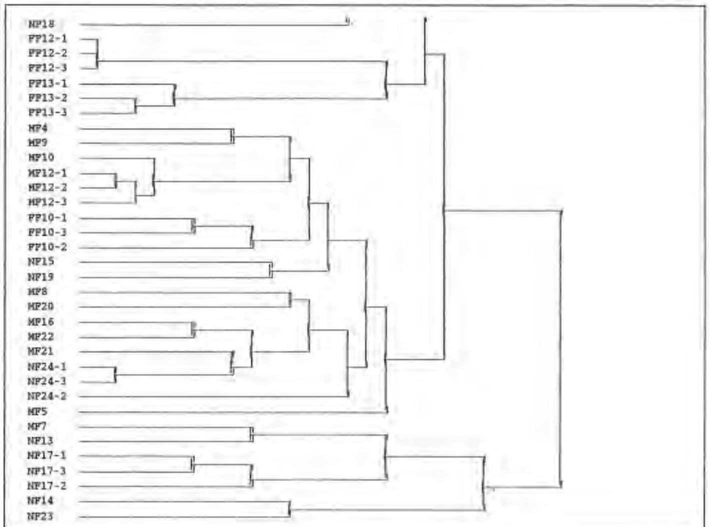
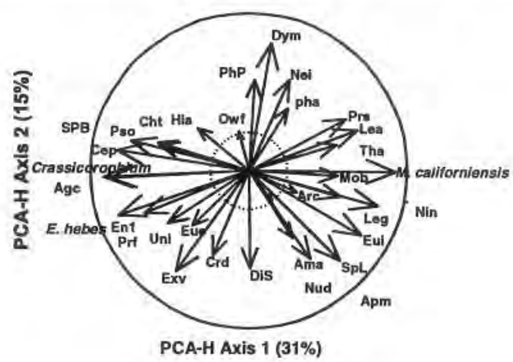
MA Bay 1992-1997 Nearfield

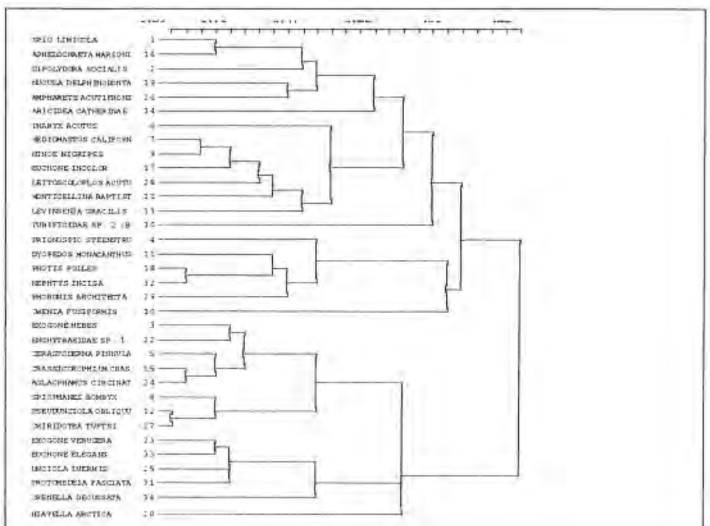
Two major groups: Sand & Mud communities



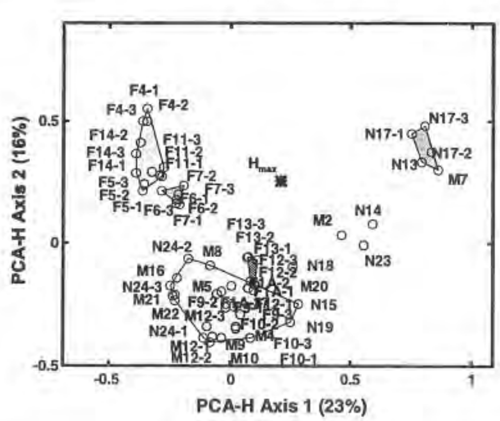


Species groups in MA Bay

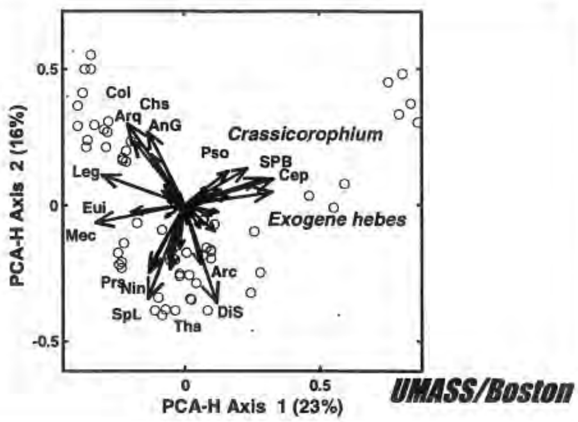


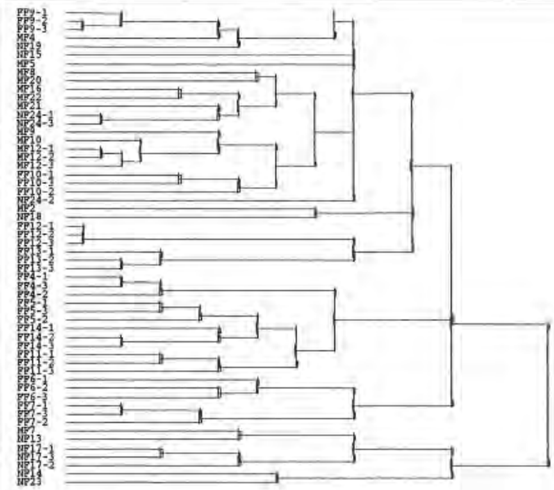


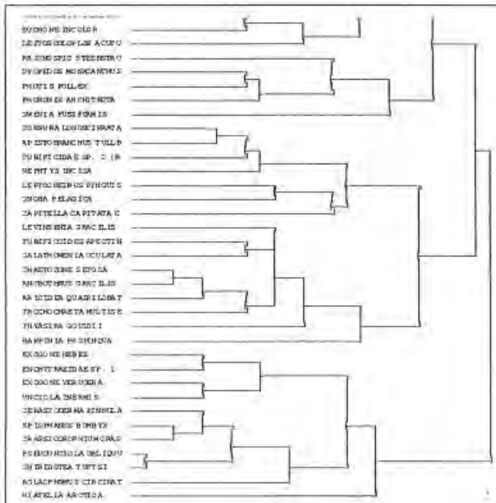
1997 Near and Farfield

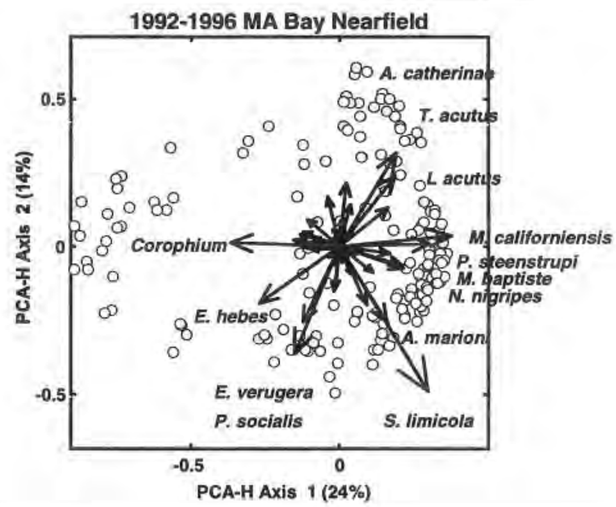


All 1997 benthos

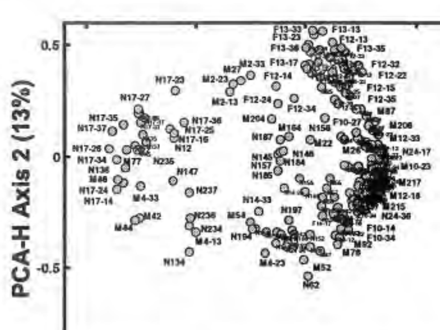






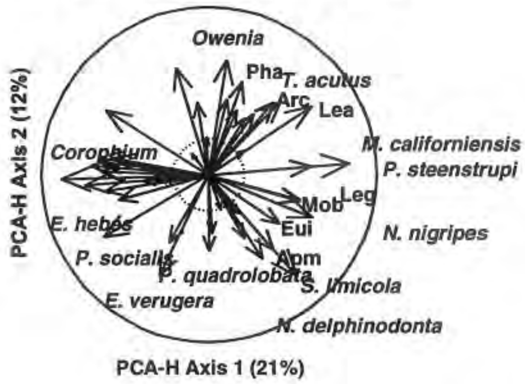


All 1992-1997 Nearfield



MA Bay Species groups

4 species groups: 1 sand & 3 mud



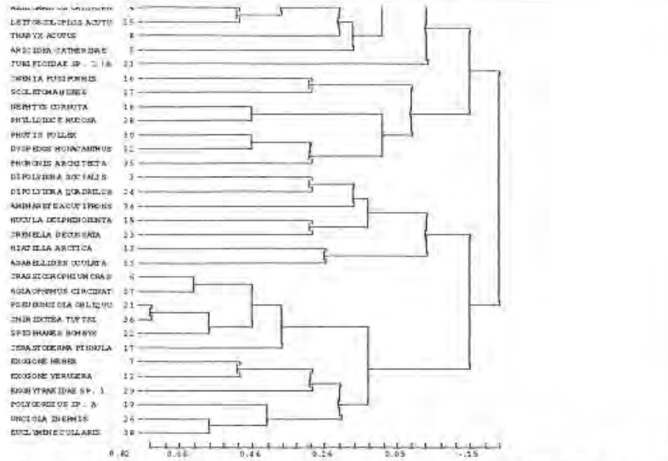
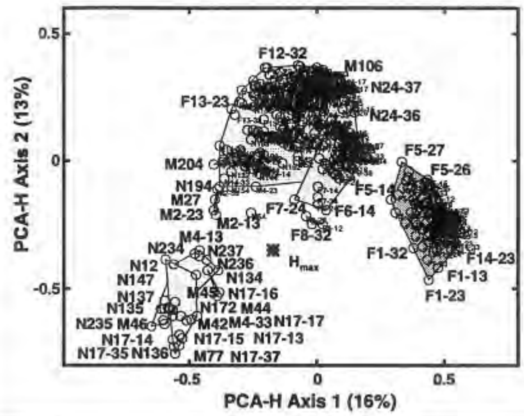
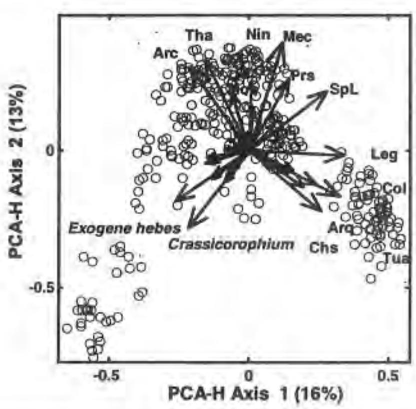


Figure 1. R-mode (species) cluster analysis for the species that contribut **UMASS/Boston** CNESS (NESSm=17) distances among samples for all 1992-1997 MA Bay Nearfield stations.

All 1992-1997 Near and Farfield



1992-1997 Near and Far



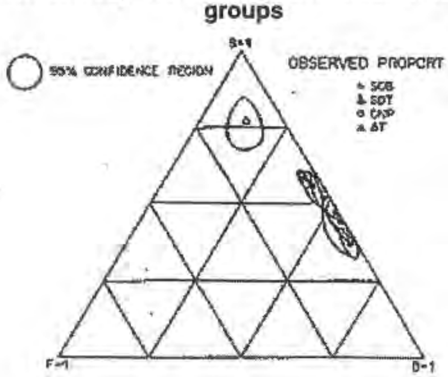
Functional groups

A dynamic explanation for the Hughes-type series

- Warwick, Clarke, Gray & Underwood argue that species id's not necessary
  - Major changes in community structure evident at phyla, class & family level
  - Tested on European pollution gradients
  - Not an explanations of dynamics
- Dynamic explanation
  - It is the diversity of functional groups that counts!
  - Seems to apply from deep sea to shallow water

Diversity of functional groups

Even the deep-sea has high evenness of feeding groups



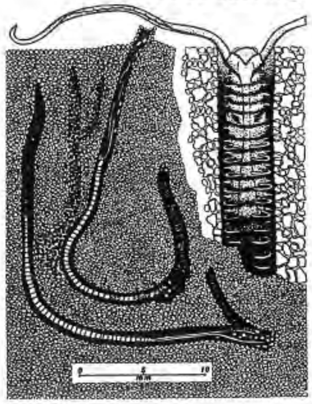
Functional groups

50 most abundant species classified

- Suspension feeders
- Interface feeders
- Surface deposit feeders
- Reverse conveyor-belt feeders
- Subsurface deposit feeders
- Top-down conveyor-belt species
- Omnivores/scavengers
- Predators

Reverse conveyor-belt feeding

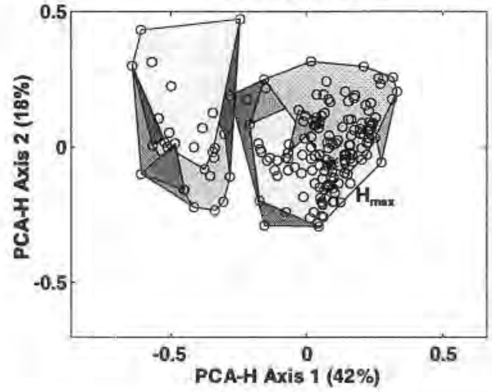
Food caching



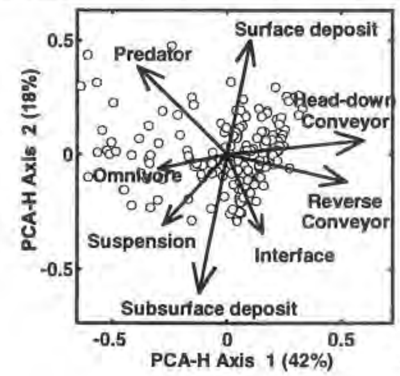
UMASS/Boston

Ordination of functional groups

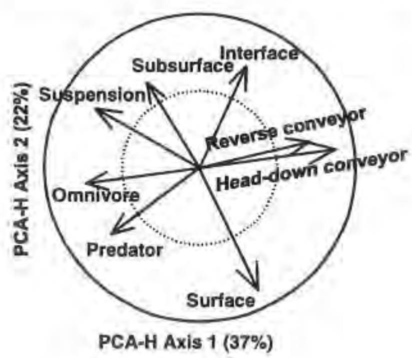
1992-1996 data



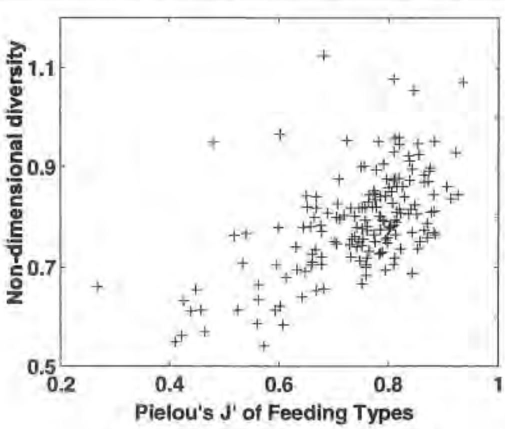
Ordination based on functional groups



Associations of functional groups



Species vs. Functional Evenness



Conclusions

At the levels of communities and functional groups

- Thresholds will be based on significant changes in a "pooled" population of nearfield stations with respect to:
  - Species diversity (richness and evenness)
  - Change in indicator species
  - Change in frequency of functional groups
- This threshold assessment can be made quickly (approximately 1 week)
- At the end of each year, a full assessment of change in species composition will be made. This requires a longer QA/QC process for species composition

Benthic Monitoring
1998 Sediment Chemistry *(Dr. Carlton Hunt, Battelle)*

Sediment Contaminant Special Studies - 1998

MWRA Benthic Science Review Meeting

April 9, 1999

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Sampling rationale

- Goal: Collect additional sediment collections and testing to address possible short-term transport and impact
  - Focus on high TOC/depositional areas
- Four locations were chosen based on the following criteria:
  - Historical fine grained material (>50% sand/silt);
  - Relatively stable area (grain size composition >50% sand/silt over the period monitored)
  - High TOC, relative to other locations nearby (at least 1% TOC)
  - Within the zone of particle deposition from the BEM
  - Expand areas sampled quarterly by USGS (avoid samples from near USGS stations (NF12 and NF17)

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Sampling rationale

- Recommended sites: FF10, NF8, NF24, and NF 22.
  - The first three stations lie on a line extending to the northwest from the west end of the diffuser and provide spatial gradient extending from the diffuser. This gradient extends towards the high deposition area predicted by the model.
- NF 22 lies to the southwest of the west end of the diffuser and is along the projected long-term transport path from the diffuser.
- FF10 was selected over NF12 because it
  - .Extends the area of impact sampled under the contaminant special studies Task
  - .Represents a Farfield location near the center of the high deposition location predicted by the BEM model
- It is also a slightly more sandy location.

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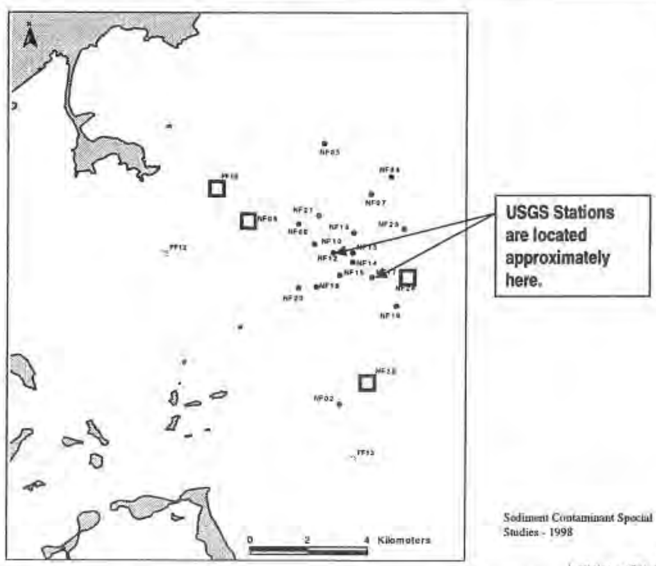
Sampling rationale



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Results - FF10

FF10	Units	1992	1993	1994	1995	1998	1998	ER-M
N		2	2	2	1	3	Stdev	
Total PAH	ng/g	1,698	1,654	3,509	11,328	2,122	135	44,782
Total PCB	ng/g	4.54	9.07	10.22	11.53	5.88	1.87	180
Total DDT	ng/g	2.27	1.75	3.59	1.51	2.22	1.90	46.1
Total CHLOR	ng/g	ND	0.17	0.85	ND	0.10	0.09	6
Total PEST	ng/g	0.40	1.62	4.96	ND	0.01	0.01	NA
Total LAB	ng/g	53.0	ND	92.3	19.5	79.2	12.6	NR
CLAY	PCT	3.70	2.62	6.05	4.30	10.96	3.87	NR
SILT	PCT	27.3	30.6	40.4	26.8	39.0	17.3	NR
% fines	PCT	31.0	33.2	46.5	31.1	49.9	21.2	NR
SAND	PCT	68.0	66.4	51.9	62.6	49.0	19.8	NR
GRAVEL	PCT	1.00	0.37	1.60	6.20	1.02	1.36	NR
TOC	PCT	1.52	1.03	1.30	0.99	0.99	0.18	NR
CPERF	/GDW	1,680	1,810	2,285	2,167	1,627	180	NR
DIELDRIN	ng/g	0.24	0.66	ND	ND	ND	ND	8
ALUMINUM	PCT	4.96	4.91	5.50	5.54	5.32	0.02	NR
CADMIUM	ug/g	0.13	0.16	0.16	0.12	0.06	0.06	9.6
CHROMIUM	ug/g	78.1	72.6	99.0	56.9	70.1	8.3	370
COPPER	ug/g	12.9	11.8	17.5	8.7	15.1	2.9	270
IRON	PCT	1.89	1.79	1.89	1.68	1.83	0.11	NR
LEAD	ug/g	32.9	34.6	34.0	30.8	31.4	1.5	218
MERCURY	ug/g	0.09	0.09	0.12	0.07	0.27	0.26	0.71
NICKEL	ug/g	14.9	13.5	17.5	11.6	15.0	1.7	51.6
SILVER	ug/g	0.35	0.19	0.35	0.29	0.30	0.01	3.7
ZINC	ug/g	51.5	40.9	47.5	42.4	43.8	2.0	410

Reasonably stable GS, TOC, and contaminants

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Sediment Contaminant Special Studies - 1998

Results - NF08

NF08.	Units	1992	1993	1994	1995	1998	1988	ER-M
N		1	2	1	1	3	Stdev	
Total PAH	ng/g	19,876	26,158	7,485	12,621	6,763	2,349	44,782
Total PCB	ng/g	77.1	129.2	43.1	40.2	26.9	7.1	180
Total DDT	ng/g	17.37	18.12	12.81	4.53	11.03	10.73	46.1
Total CHLOR	ng/g	ND	2.05	2.04	0.56	0.68	0.12	6
Total PEST	ng/g	10.64	2.63	8.09	0.64	0.74	0.24	NA
Total LAB	ng/g	2,037	1,774	833	191	290	53	NR
CLAY	PCT	22.9	12.3	22.7	14.0	11.1	2.9	NR
SILT	PCT	59.1	62.3	61.6	71.9	38.6	13.8	NR
% fines	PCT	82.0	74.6	84.3	85.9	49.8	16.7	NR
SAND	PCT	18.0	25.4	15.6	14.0	48.5	13.8	NR
GRAVEL	PCT	ND	ND	ND	ND	1.7	2.9	NR
TOC	PCT	6.33	5.89	3.80	3.84	2.62	0.55	NR
CPERF	#/GDW	8,100	8,835	9,060	320	4,590	361	NR
DIELDRIN	ng/g	2.61	2.50	ND	ND	0.33	0.06	8
ALUMINUM	PCT	6.35	5.76	6.00	6.15	5.86	0.26	NR
CADMIUM	ug/g	0.81	0.89	0.56	0.40	0.24	0.06	9.6
CHROMIUM	ug/g	282	206	169	120	119	14.8	370
COPPER	ug/g	108.0	60.5	44.0	35.2	32.4	3.7	270
IRON	PCT	3.82	3.33	2.92	2.27	2.78	0.16	NR
LEAD	ug/g	117.0	81.3	64.5	54.6	49.6	3.0	218
MERCURY	ug/g	1.36	0.60	0.32	0.36	0.34	0.05	0.71
NICKEL	ug/g	32.3	34.9	31.0	22.9	21.8	1.0	51.6
SILVER	ug/g	3.06	2.25	1.73	1.07	0.90	0.17	3.7
ZINC	ug/g	200.0	145.5	98.0	91.9	81.1	8.0	410

Shift in contmaint levels between 92/93 and 95/98

Likely grain size and TOC driven in 98 94 and 95 appear to be "real" sift

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Sediment Contaminant Special Studies - 1998

Results - NF22

NF22	Units	1994	1995	1998	1988	ER-M
N		1	1	3	Stdev	
Total PAH	ng/g	5,631	4,117	3,904	705	44,782
Total PCB	ng/g	21.0	20.7	11.1	2.7	180
Total DDT	ng/g	6.7	8.8	2.5	0.443	46.1
Total CHLOR	ng/g	1.28	0.38	0.27	0.06	6
Total PEST	ng/g	7.53	0.27	0.14	0.12	NA
Total LAB	ng/g	442	187	184	18.9	NR
CLAY	PCT	9.90	14.50	11.13	0.78	NR
SILT	PCT	58.1	55.2	34.6	5.18	NR
% fines	PCT	68.0	69.7	45.8	6.0	NR
SAND	PCT	31.9	30.2	51.8	1.28	NR
GRAVEL	PCT	0.10	0.10	2.50	4.07	NR
TOC	PCT	1.80	2.57	1.39	0.38	NR
CPERF	#/GDW	4,730	9,700	3,230	534	NR
DIELDRIN	ng/g	ND	ND	0.13	0.11	8
ALUMINUM	PCT	6.00	5.91	5.90	0.02	NR
CADMIUM	ug/g	0.21	0.24	0.11	0.02	9.6
CHROMIUM	ug/g	105.0	93.1	73.4	8.8	370
COPPER	ug/g	27.0	28.2	21.8	2.7	270
IRON	PCT	2.71	2.56	2.57	0.08	NR
LEAD	ug/g	50.0	51.7	40.0	2.9	218
MERCURY	ug/g	0.23	0.28	0.35	0.07	0.71
NICKEL	ug/g	26.0	21.9	19.8	3.1	51.6
SILVER	ug/g	0.97	0.91	0.59	0.10	3.7
ZINC	ug/g	69.0	83.5	63.4	3.4	410
	Coarsing of sediments in 98, TOC down a bit					
	Realtively state concentrations 1994 to 1998					

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Sediment Contaminant Special Studies - 1998

Results - NF24

NF24		1994	1995	1998	1998	ER-M
N	Units	2	1	3	Stdev	
Total PAH	ng/g	7,563	11,503	17,122	20,237 *	44,782
Total PCB	ng/g	19.1	52.9	20.7	9.8	180
Total DDT	ng/g	6.2	11.2	4.0	2.0	46.1
Total CHLOR	ng/g	0.80	1.09	0.27	0.27	6
Total PEST	ng/g	4.65	0.73	0.23	0.28	NA
Total LAB	ng/g	98.4	251.0	191.0	54.8	NR
CLAY	PCT	10.1	72.8	14.5	8.4	NR
SILT	PCT	58.8	17.2	46.1	28.9	NR
% fines	PCT	68.9	90.0	60.6	37.2	NR
SAND	PCT	31.1	10.0	38.7	34.7	NR
GRAVEL	PCT	ND	ND	0.67	0.83	NR
TOC	PCT	2.30	5.61	2.14	1.02	NR
CPERF	#/GDW	4,425	17,000	2,613	1,756	NR
DIELDRIN	ng/g	ND	ND	0.18	0.24	8
ALUMINUM	PCT	3.50	5.05	5.74	1.04	NR
CADMIUM	ug/g	0.15	0.46	0.11	0.07	9.6
CHROMIUM	ug/g	118	177	95.1	56.2	370
COPPER	ug/g	31.0	54.2	31.2	9.6	270
IRON	PCT	2.56	2.94	2.52	0.80	NR
LEAD	ug/g	59.4	92.8	55.4	23.5	218
MERCURY	ug/g	0.73	1.69	0.32	0.18	0.71
NICKEL	ug/g	22.5	31.7	19.9	7.8	51.6
SILVER	ug/g	0.50	1.10	0.70	0.43	3.7
ZINC	ug/g	74.0	131.5	72.3	28.4	410
*Note: one of the three 1998 samples had high pyrogenic PAH content						
		Finer; high TOC in '95				
		Contamaints similar levels 1994 and 1998				

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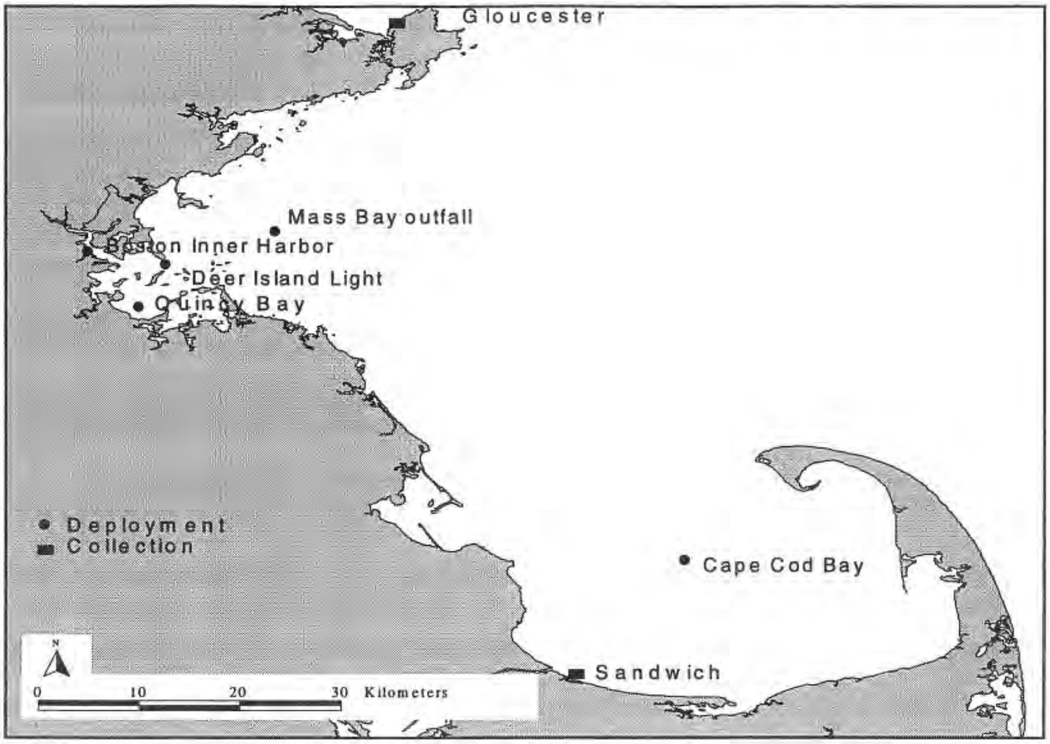
Sediment Contaminant Special Studies - 1998

Fish and Shellfish Monitoring
1998 Caged Mussel Studies *(Ms. Lisa Lefkovitz, Battelle)*

MUSSEL COLLECTION



Summary of Arrays Deployed and Recovered at 40- and 60-Days

Site	# Arrays Deployed (1)	40 Days # Arrays/Cages Recovered	60 Days # Arrays/Cages Recovered
Inner Harbor	**3**	**1 Array** **2 Gloucester** **1 Sandwich**	**1 Array** **2 Gloucester** **1 Sandwich**
Deer Island	**3**	**1 Array** **2 Gloucester** **1 Sandwich**	**0 Array** **0 Gloucester** **0 Sandwich**
Quincy Bay	**3**	**1/2 Array** **0 Gloucester** **1 Sandwich**	**1/2 Array** **0 Gloucester** **1 Sandwich**
Outfall	**4**	**1 Array** **2 Gloucester** **1 Sandwich**	**0 Array** **0 Gloucester** **0 Sandwich**
Cape Cod	**4**	**1 Array** **2 Gloucester** **1 Sandwich**	**1 Array** **2 Gloucester** **1 Sandwich**

(1) Each "Array" consisted of 2 Gloucester Cages and 1 Sandwich Cage

MUSSEL MEASUREMENTS

SUMMARY OF BIOLOGICAL CONDITION PARAMETERS

Parameter
Shell Length
Shell Volume
Shell Weight
Total Organism Weight
Total Soft Tissue Weight
Gonad-Mantle Weight
Non-Gonadal Tissue Weight

SUMMARY OF CHEMICAL PARAMTERS

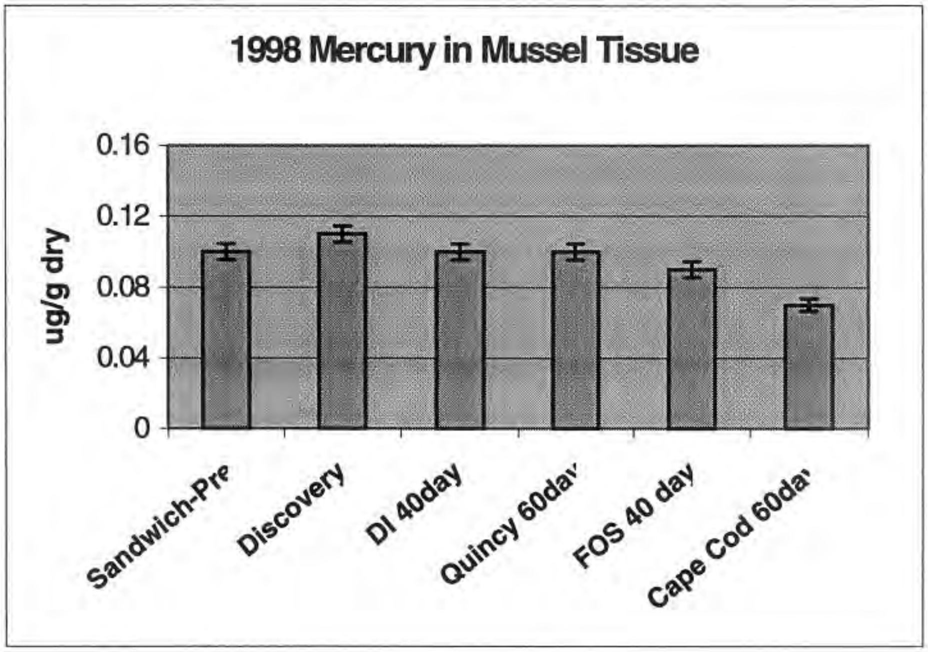
Sample Type	Number of Samples	Hg	Pb	PCBs	PAHs	Pests	Lipids
Gloucester	36			!	!	!	!
Sandwich	36	!	!	(1)	(1)	(1)	(1)

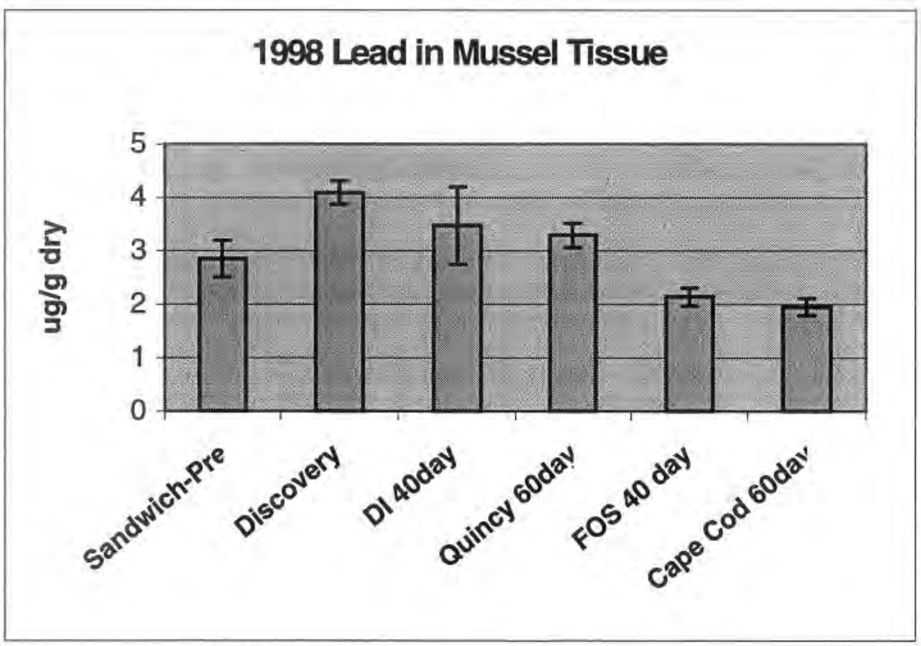
(1) Sandwich Predeployment mussels were analyzed for organics in order to compare to Quincy 60-day Sandwich mussels which were also analyzed for organics due to loss of Gloucester mussels.

MUSSEL GROWTH AND CONDITION

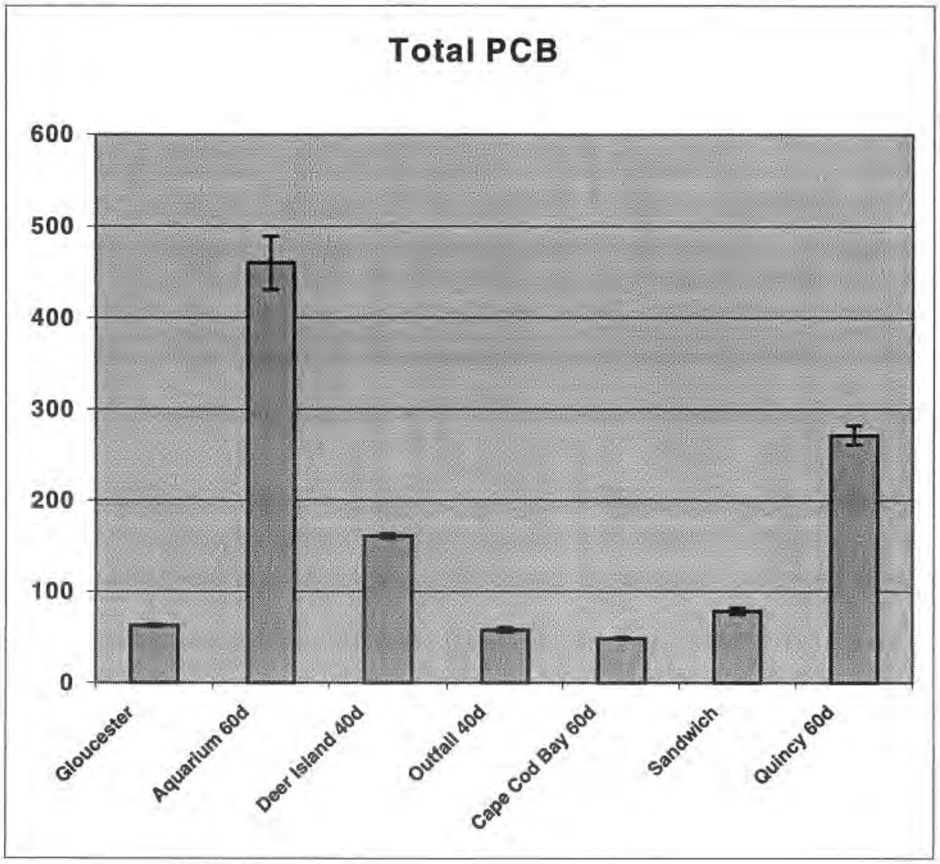
- No acute mortality of deployed mussels at any of the locations.
- Shell length, volume and biomass increased during Discovery deployment.
- Did not assess biological condition at other stations due to lack of 60-day recoveries.

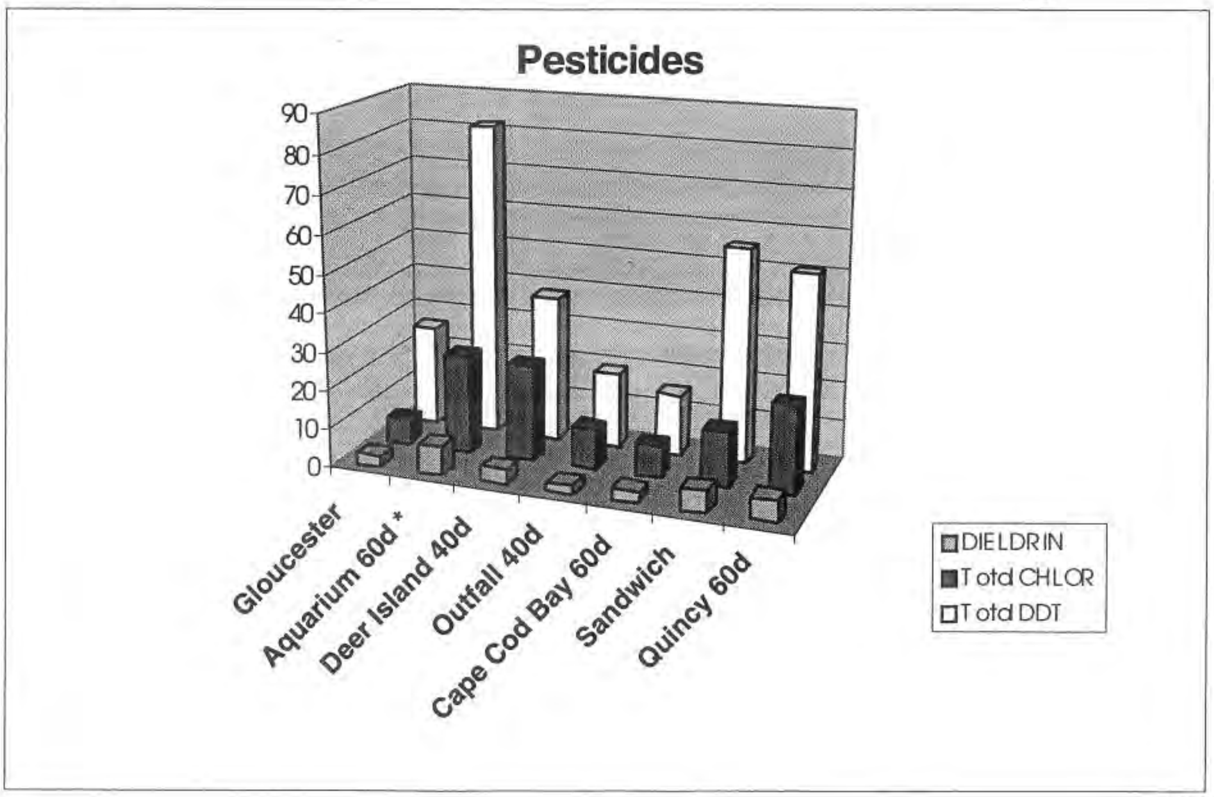
1998 MUSSEL RESULTS - METALS





1998 MUSSEL RESULTS – Chlorinated Organics
(ng/g dry weight)





SUMMARY OF PAH LISTS OF ANALYTES

1997/ 1998 Complete PAH List

Low Molecular Weight PAHs

1-METHYLNAPHTHALENE
1-METHYLPHENANTHRENE
2,3,5-TRIMETHYLNAPHTHALENE
2,6-DIMETHYLNAPHTHALENE
2-METHYLNAPHTHALENE
ACENAPHTHENE
ACENAPHTHYLENE
ANTHRACENE
BENZOTHIAZOLE
BIPHENYL
C1-DIBENZOTHIOPHENES
C1-FLUORENES
C1-NAPHTHALENES
C1-PHENANTHRENES/ANTHRACENES
C2-DIBENZOTHIOPHENES
C2-FLUORENES
C2-NAPHTHALENES
C2-PHENANTHRENES/ANTHRACENES
C3-DIBENZOTHIOPHENES
C3-FLUORENES
C3-NAPHTHALENES
C3-PHENANTHRENES/ANTHRACENES
C4-NAPHTHALENES
C4-PHENANTHRENES/ANTHRACENES
DIBENZOFURAN
DIBENZOTHIOPHENE
FLUORENE
NAPHTHALENE
PHENANTHRENE

High Molecular Weight PAHs

BENZ(A)ANTHRACENE
BENZO(A)PYRENE
BENZO(B)FLUORANTHENE
BENZO(E)PYRENE
BENZO(G,H,I)PERYLENE
BENZO(K)FLUORANTHENE
C1-CHRYSENES
C1-FLUORANTHRENES/PYRENES
C2-CHRYSENES
C2-FLUORANTHENES/PYRENES
C3-CHRYSENES
C3-FLUORANTHENES/PYRENES
C4-CHRYSENES
CHRYSENE
DIBENZO(A,H)ANTHRACENE
FLUORANTHENE
INDENO(1,2,3-C,D)PYRENE
PERYLENE
PYRENE

NOAA "Historic" PAH List

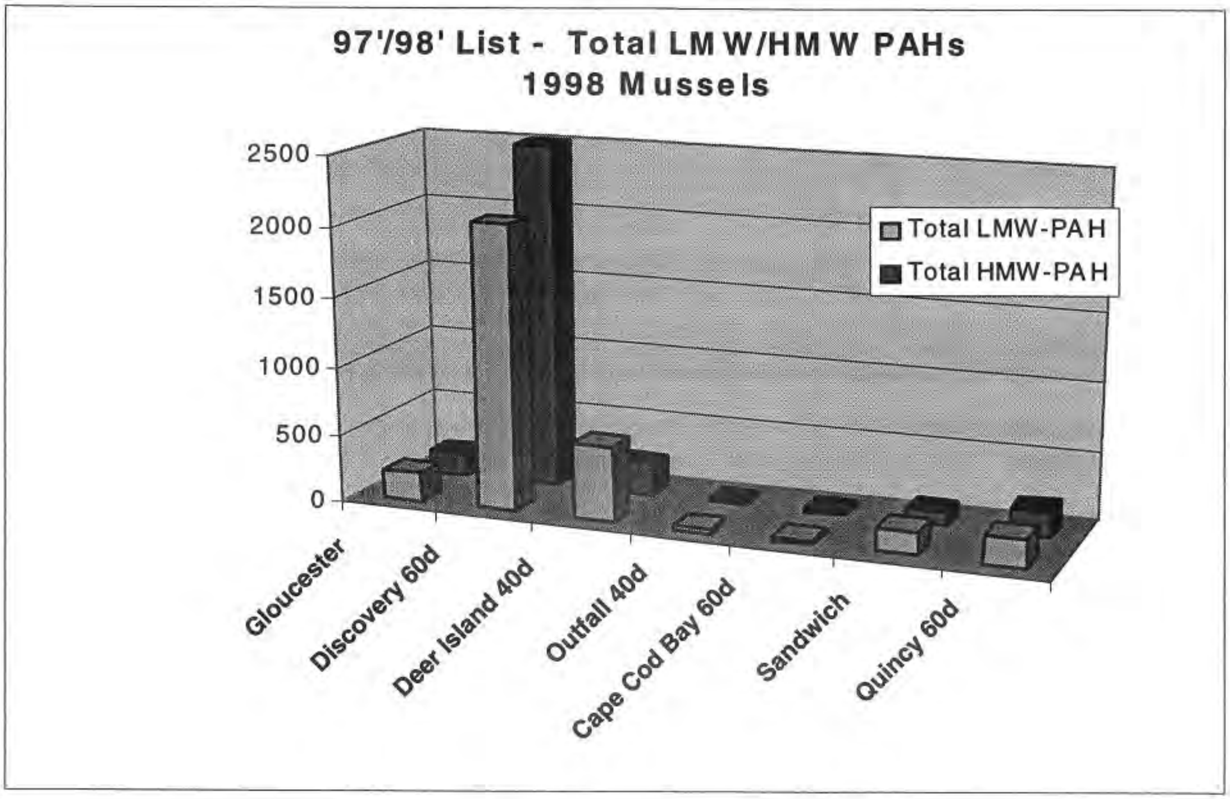
Low Molecular Weight PAHs

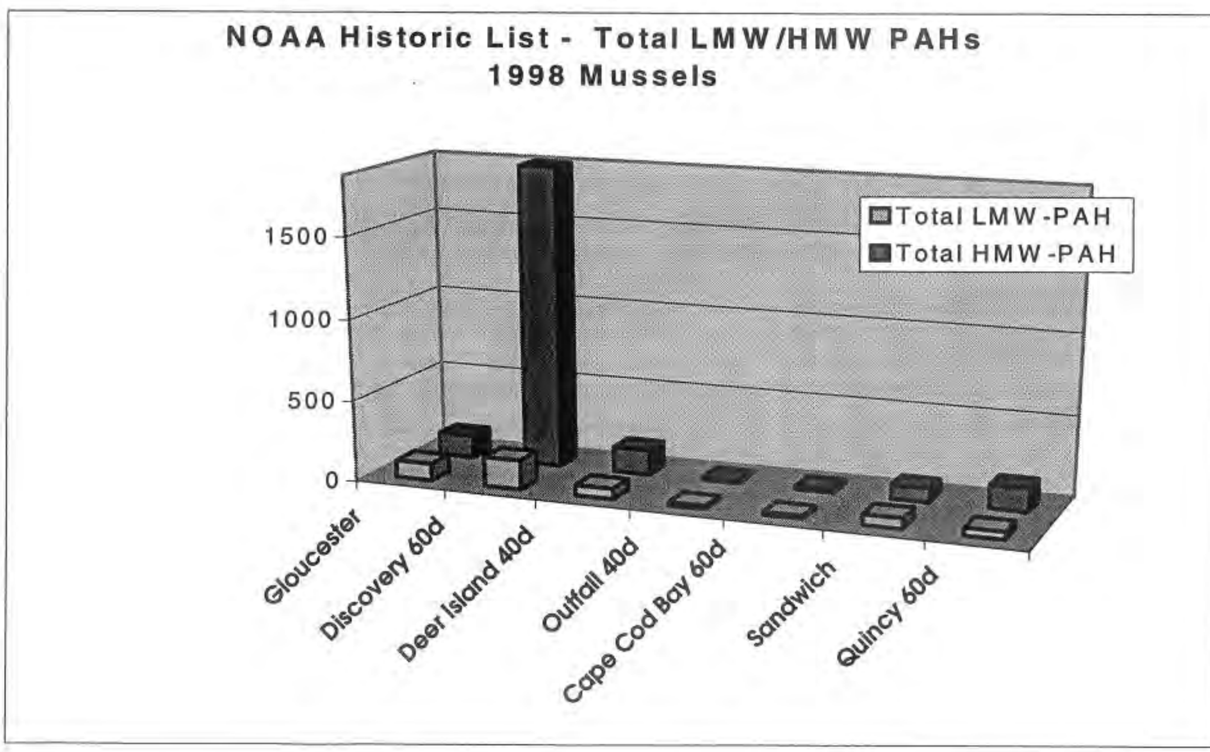
1-METHYLNAPHTHALENE
1-METHYLPHENANTHRENE
2,3,5-TRIMETHYLNAPHTHALENE
2,6-DIMETHYLNAPHTHALENE
2-METHYLNAPHTHALENE
ACENAPHTHENE
ACENAPHTHYLENE
ANTHRACENE
BENZOTHIAZOLE
BIPHENYL
DIBENZOFURAN
DIBENZOTHIOPHENE
FLUORENE
NAPHTHALENE
PHENANTHRENE

High Molecular Weight PAHs

BENZ(A)ANTHRACENE
BENZO(A)PYRENE
BENZO(B)FLUORANTHENE
BENZO(E)PYRENE
BENZO(G,H,I)PERYLENE
BENZO(K)FLUORANTHENE
CHRYSENE
DIBENZO(A,H)ANTHRACENE
FLUORANTHENE
INDENO(1,2,3-C,D)PYRENE
PERYLENE
PYRENE

1998 MUSSEL RESULTS- PAHs
(ng/g dry weight)





TEST FOR SIGNIFICANT DIFFERENCE FROM PRE-DEPLOYMENT CONCENTRATIONS
(using 2-tailed student t-test)

Parameter	Discovery	DI	FOS	Cape Cod Bay	Quincy
Mercury	No	No	No	Yes	No
Lead	Yes	No	No	Yes	No
Total PCBs	Yes	Yes	No	Yes	Yes
Total DDTs	Yes	Yes	Yes	Yes	No
Total Chlordanes	Yes	Yes	Yes	No	Yes
Dieldrin	Yes	Yes	Yes	No	No
Lindane	Yes	Yes	No	No	No
PAHs - 97'/98' List					
Total LMWPAH	Yes	Yes	Yes	Yes	No
Total HMWPAH	Yes	Yes	Yes	Yes	Yes
Total PAH	Yes	Yes	Yes	Yes	Yes

(1) Assume random sampling, normal distribution and equal variances

TEST FOR SIGNIFICANT DIFFERENCE FROM PRE-DEPLOYMENT CONCENTRATIONS
(using 2-tailed student t-test)

Parameter	Discovery	DI	FOS	Cape Cod Bay	Quincy
PAHs - 97'/98' List					
Total LMWPAH	Yes	Yes	Yes	Yes	No
Total HMWPAH	Yes	Yes	Yes	Yes	Yes
Total PAH	Yes	Yes	Yes	Yes	Yes
PAHS - NOAA Historic List					
Total LMWPAH	Yes	Yes	Yes	Yes	No
Total HMWPAH	Yes	No	Yes	Yes	Yes
Total PAH	Yes	No	Yes	Yes	Yes

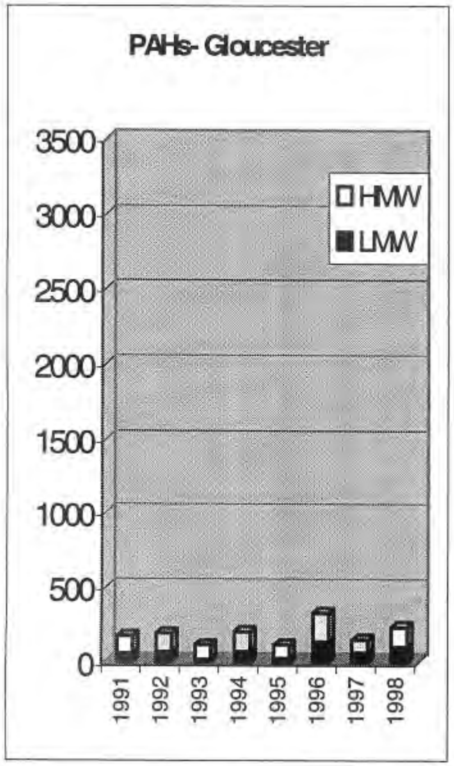
(1) Assume random sampling, normal distribution and equal variances

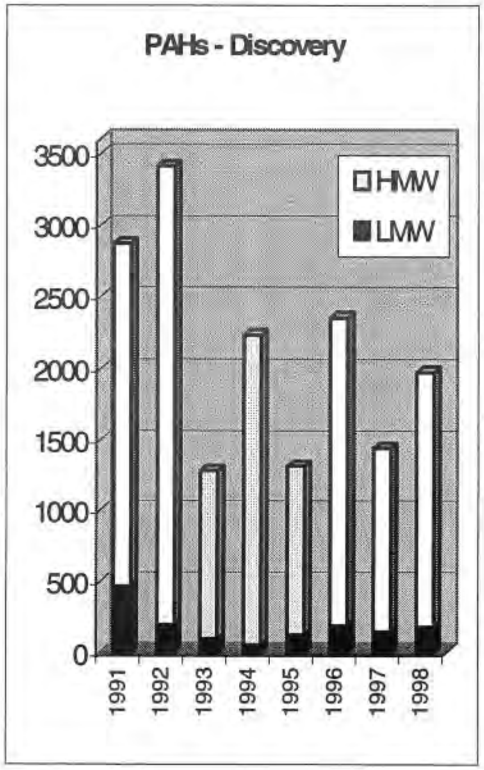
COMPARISON BETWEEN GLOUCESTER AND SANDWICH PREDEPLOYMENT MUSSELS

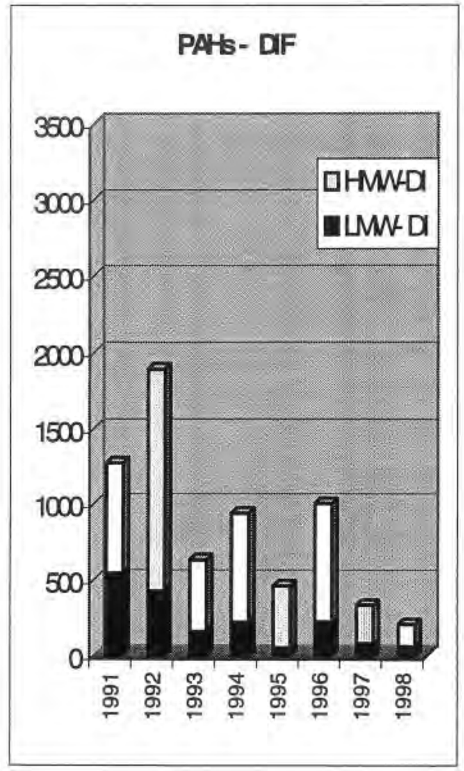
Parameter	SANDWICH		GLOUCESTER		Significantly Different (P=0.05)
	mean	*s.d.*	mean	*s.d.*	
Total PCB	**79.1**	*7.8*	63.2	*2.6*	YES
Total Chlordane	**14.2**	*1.4*	6.8	*0.5*	**YES**
Total DDT	**55.8**	*5.7*	34.1	*2.9*	**YES**
DIELDRIN	**5.7**	*0.5*	2.8	*0.3*	**YES**
97'/98' PAHs					
Total LMW PAH	146.0	*37.9*	207.3	*28.1*	**NO**
HMW PAH	65.1	*8.2*	166.3	*17.5*	**YES**
Total PAH	211.1	*22.8*	373.6	*39.7*	**YES**
NOAA Historic List PAHs					
Total LMW	65.8	*17.3*	104.3	*27.7*	**YES**
Total HMW	58.1	*8.3*	138.6	*14.4*	**YES**
TOTAL PAH	123.9	*21.7*	242.8	*33.4*	**YES**

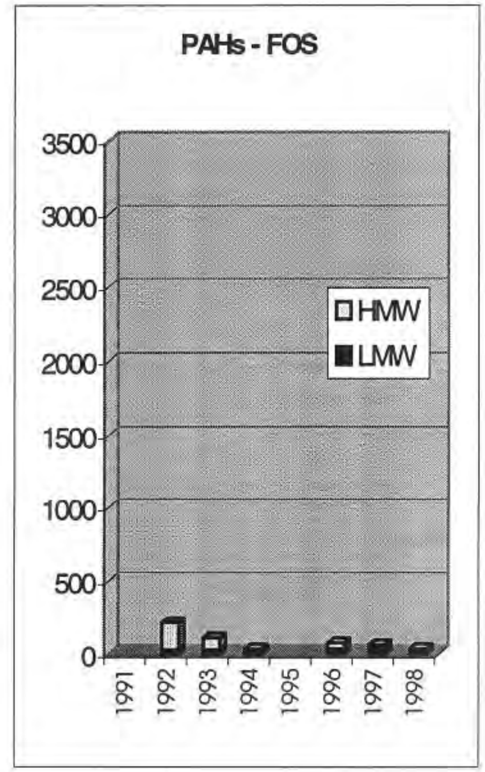
ANNUAL AVERAGE PAHS FOR 1992 – 1998 MUSSELS

(ng/g dry weight)



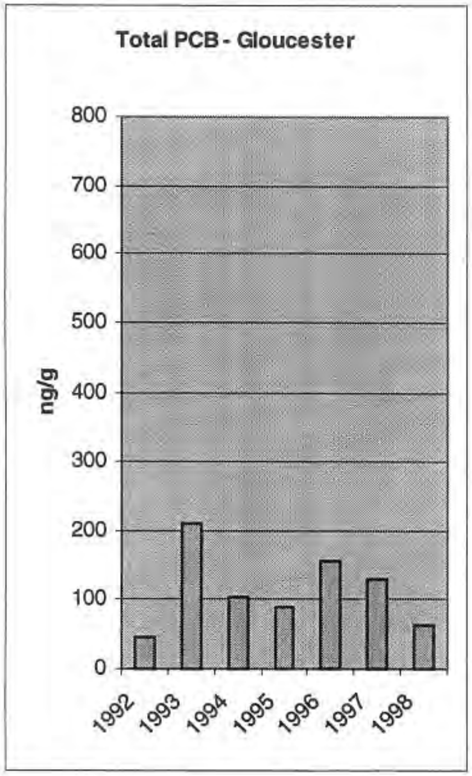


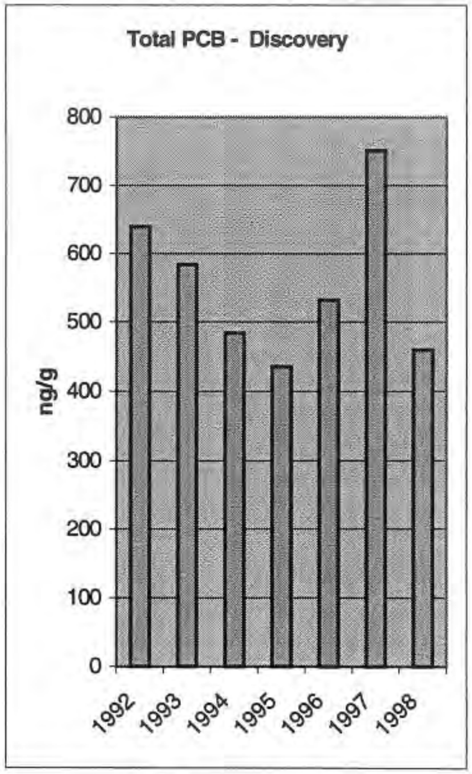


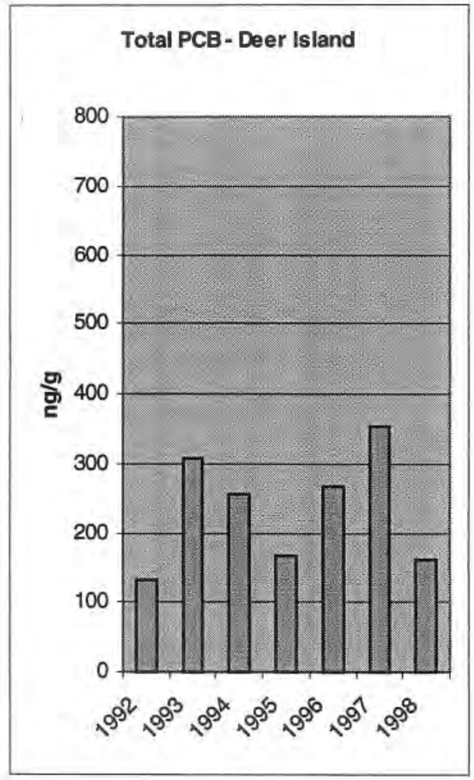


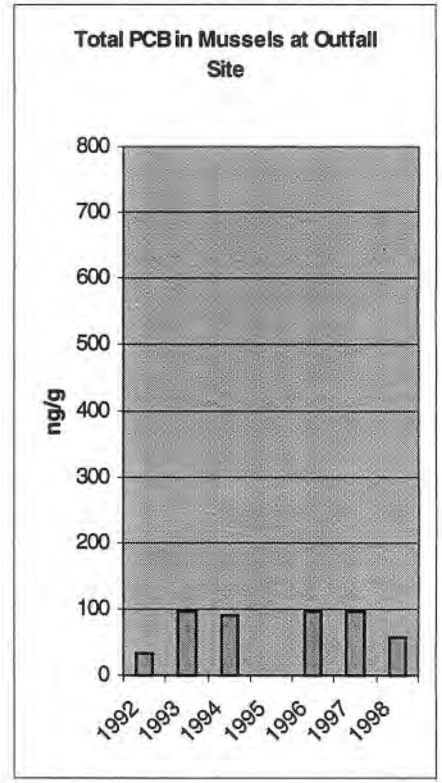
ANNUAL AVERAGE Total PCBs FOR 1992 – 1998 MUSSELS

(ng/g dry weight)



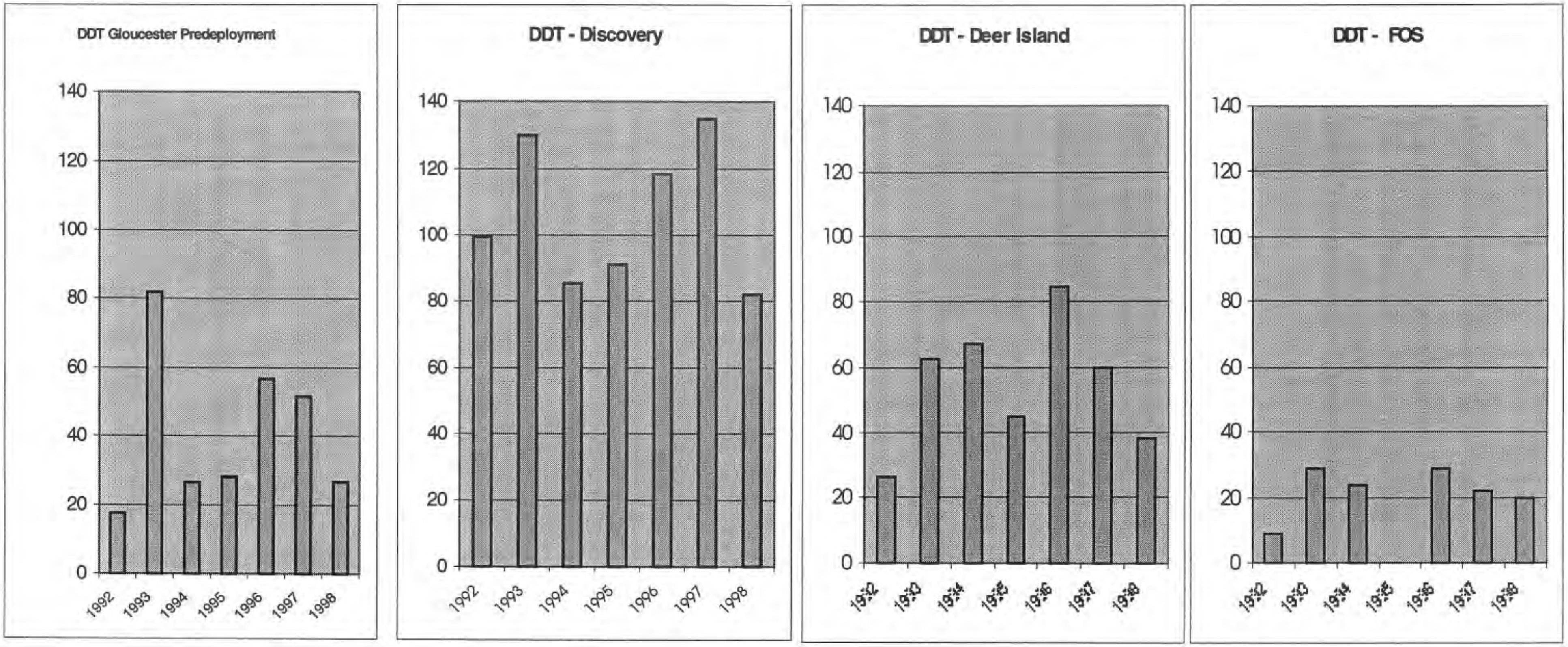




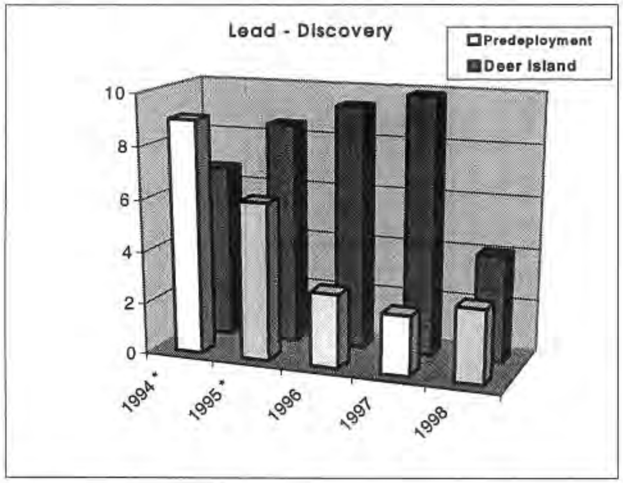


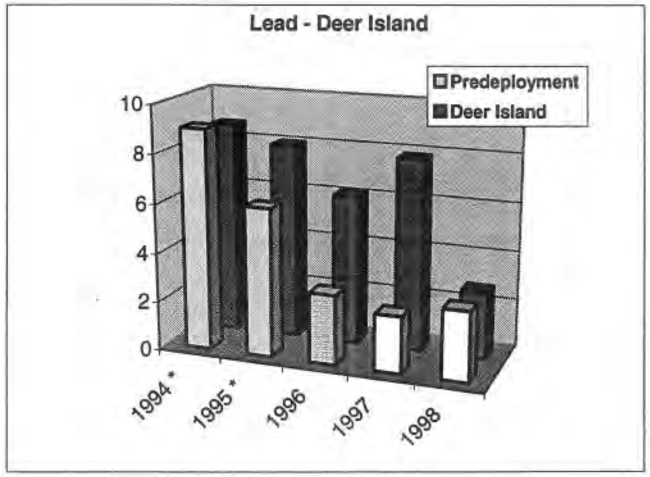
ANNUAL AVERAGE Total DDTs FOR 1992 – 1998 MUSSELS

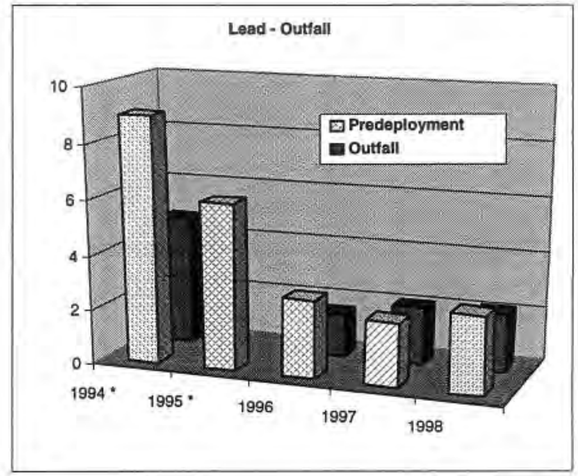
(ng/g dry weight)

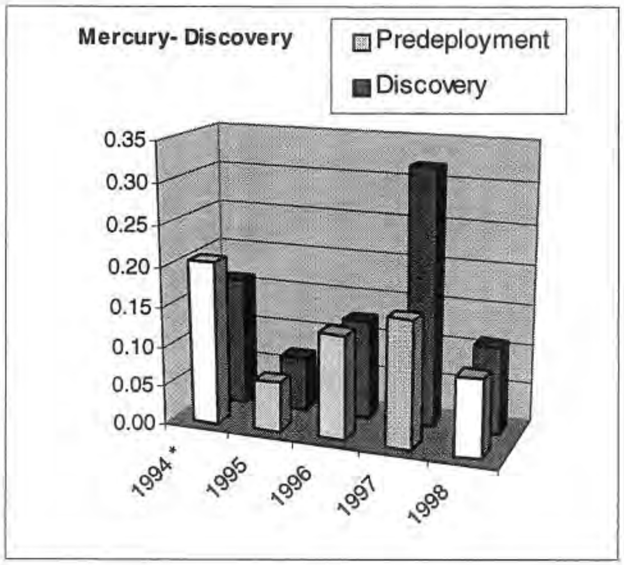


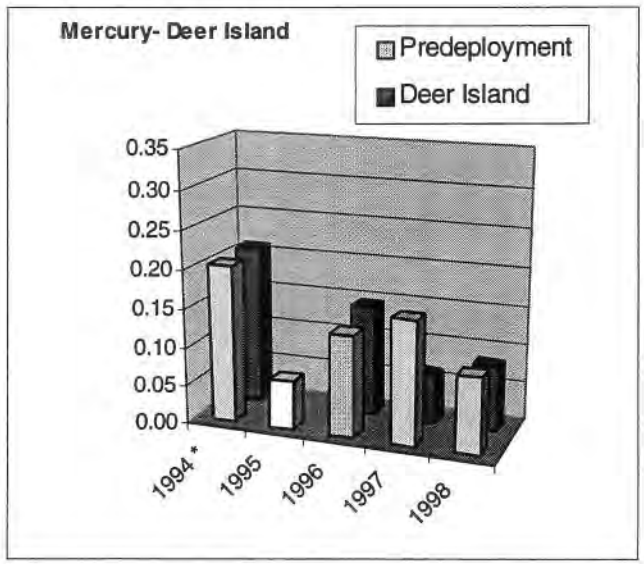
ANNUAL AVERAGE METALS FOR 1992 – 1998 MUSSELS

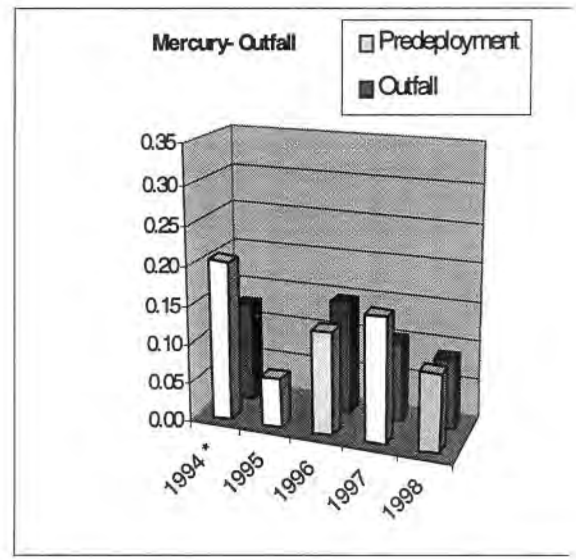












* Indicates pre-deployment mussels were collected from Gloucester. All other years used Sandwich Mussels

Comparison of 1998 Mussel Results with Thresholds

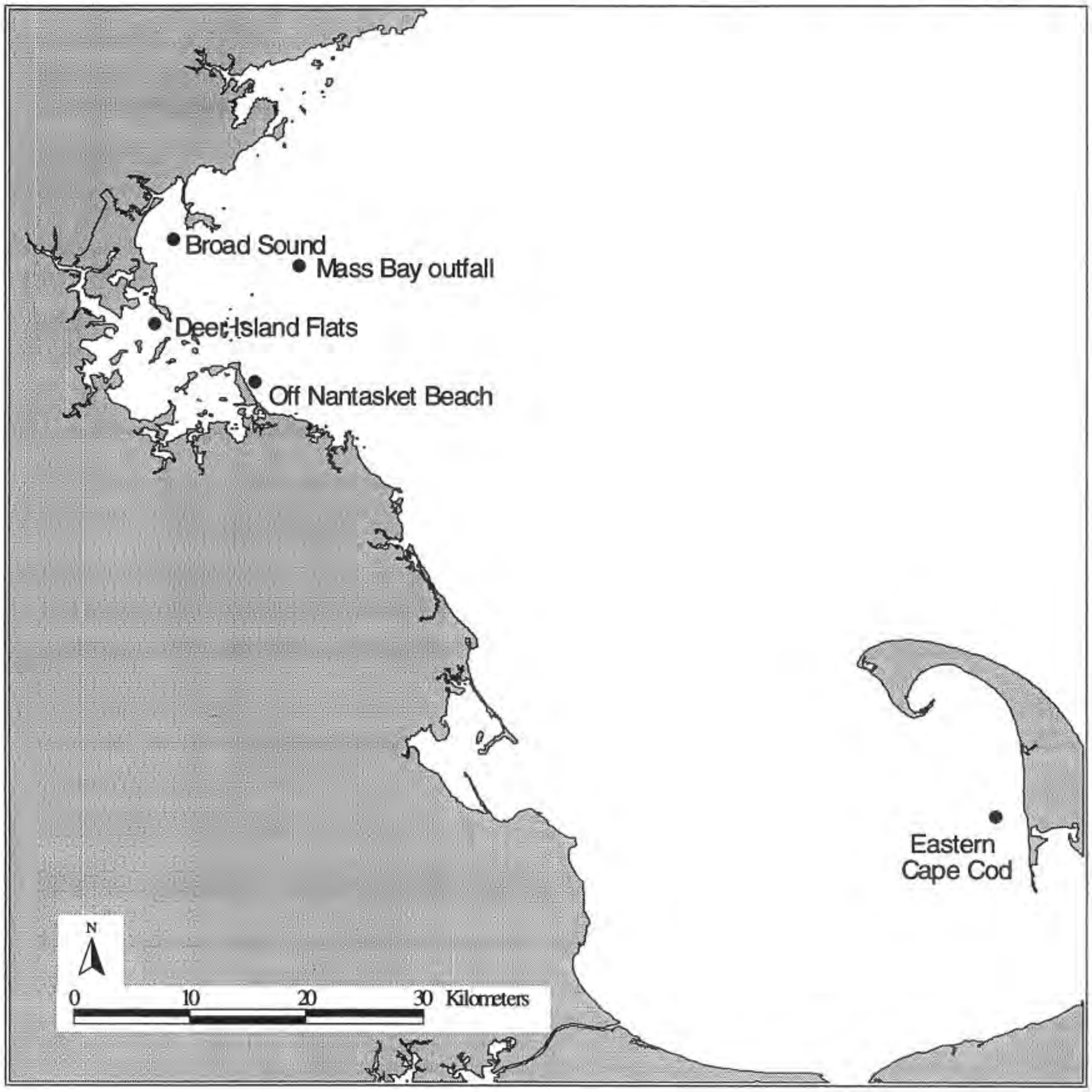
STATION	N	% Dry Wt.	Total PCB (ng/g wet wt.)		Total DDTs (ng/g DRY wt)		Total Chlordanes (ng/g wet wt.)		Total Dieldrin (ng/g wet wt.)		Total PAH (ng/g DRY wt.)		Mercury (Hg) (ug/g wet wt.)		Lead (Pb) (ug/g wet wt.)	
		Mean	Mean	*s.e.*	Mean	*s.e.*	Mean	*s.e.*	Mean	*s.e.*	Mean	*s.e.*	Mean	*s.e.*	Mean	*s.e.*
Deer Island(1)	5	14.75	23.7	*1.7*	38.0	*0.6*	3.7	*0.14*	0.60	*0.02*	217.7	*3.9*	0.016	*0.001*	0.57	*0.13*
Aquarium(6)	5	11.92	55.6	*6.9*	81.9	*5.1*	3.1	*0.40*	0.92	*0.10*	2047.0	*127.4*	0.016	*0.001*	0.58	*0.04*
Gloucester(7)	5	11.15	7.0	*0.3*	34.1	*1.3*	0.8	*0.04*	0.32	*0.02*	242.7	*14.9*	NA	*0.000*	NA	*0.00*
Sandwich(8)	5	13.29	78.7	*0.4*	55.8	*2.5*	14.2	*0.08*	5.67	*0.03*	150.4	*9.7*	0.015	*0.001*	0.44	*0.05*
Cape Cod (9)	8	18.32	8.9	*0.4*	15.8	*1.1*	1.5	*0.12*	0.52	*0.03*	37.1	*5.2*	0.014	*0.001*	0.40	*0.03*
Outfall(4)	8	15.77	9.2	*0.4*	19.8	*1.3*	1.6	*0.09*	0.35	*0.01*	38.1	*3.7*	0.015	*0.001*	0.36	*0.03*
Quincy(M7)	5	15.35	41.7	*1.5*	50.8	*2.2*	3.5	*0.12*	0.85	*0.03*	191.4	*8.9*	0.016	*0.001*	0.52	*0.03*
FDA Limit			2000		5000		300		300				1.000			
MWRA Caution Level (2 x Baseline 1992-1997)			28.4		45.3		2.4		0.57		258.8		0.044		1.1	
MWRA Warning Level (80% FDA)			1600										0.800			

Fish and Shellfish Monitoring
1998 Flounder and Lobster Chemistry Studies *(Ms. Lisa Lefkovitz, Battelle)*

FISH AND SHELLFISH 1998
FLOUNDER AND LOBSTER STUDY
CONCLUSIONS

- **1998 Results are consistent with previous study**
- **Organic contaminant concentrations are generally highest at Discovery (Boston Inner Harbor) and lowest at ECCB with DI levels somewhere in between.**
- **Concentrations of organic contaminants have generally decreased since 1992, especially at Discovery and DI locations.**
- **Metals concentrations are more variable and most concentrations have been relatively constant during the study period.**
- **Mercury concentrations in flounder livers appear to have decreased since 1992.**

FLOUNDER COLLECTION - 1998



FLOUNDER MEASUREMENTS

Physical/Biological Measurements

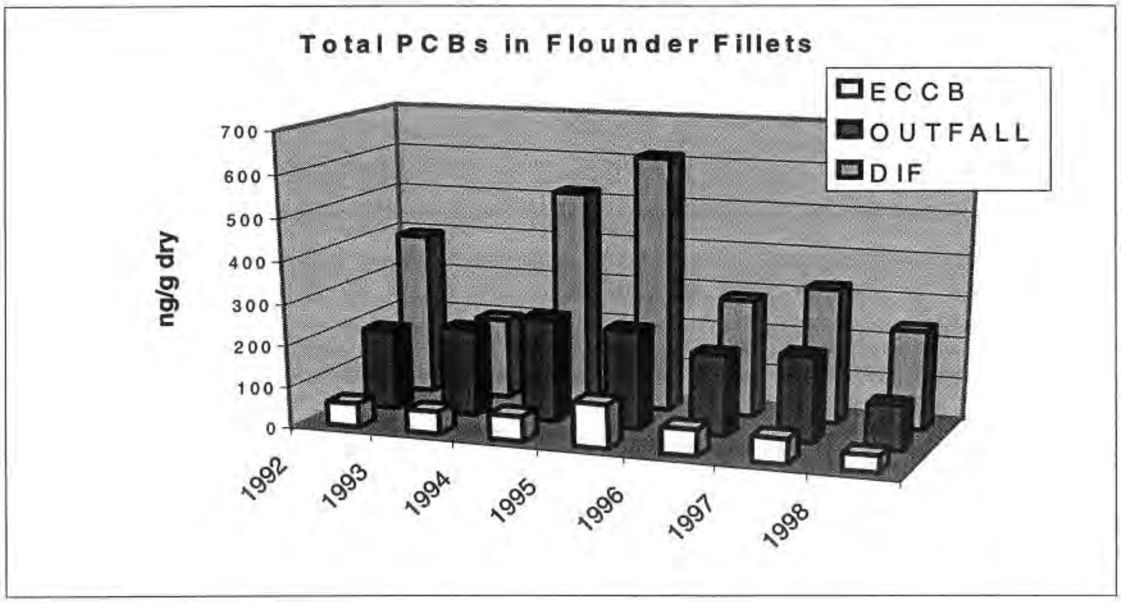
Morphological Measurements	Histological Measurements
Total Length (mm)	Neoplasm
Weight (g)	Focal HV
Age (yrs)	Tubular HV
Fin erosion	Centrotubular HV
Gross score/Lesions	Macrophage Aggregation
	Biliary proliferation

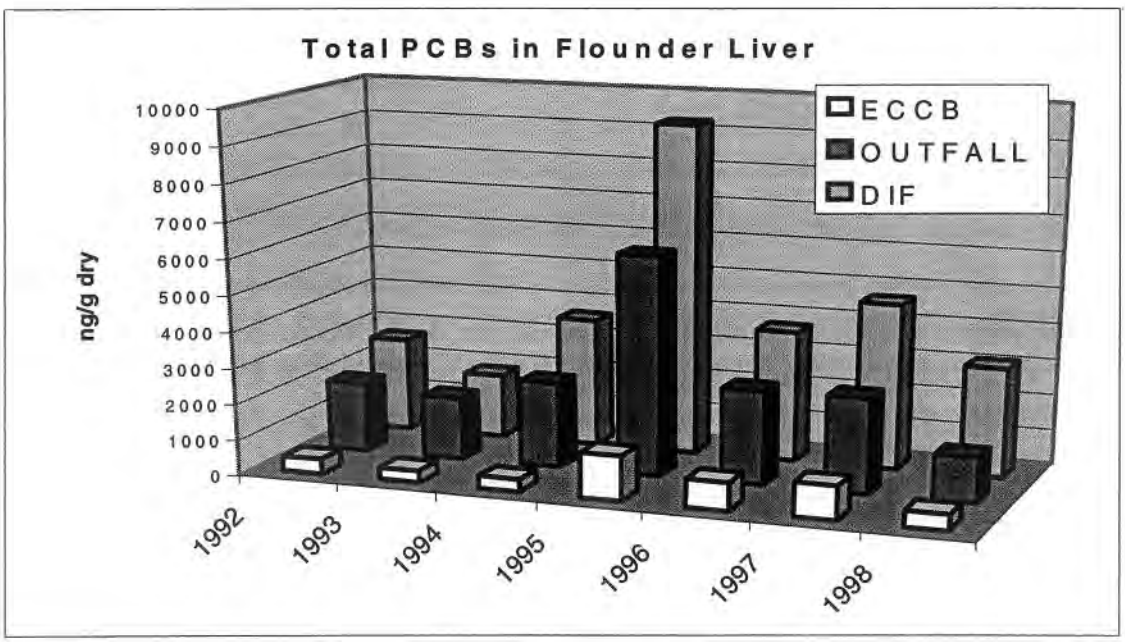
Chemical Measurements

Sample Type	Number of Samples	Metals (Ag, Cu, Cr, Cd, Pb, Ni, Zn)	Hg	Pb	PCBs	PAHs	Pests	Lipids
Flounder Meat	9*		!		!		!	!
Flounder Liver	9*	!	!	!	!	!	!	!

*** 1998 – 3 stations (3 composites each) analyzed for chemistry (DI, FOS, ECCB).**

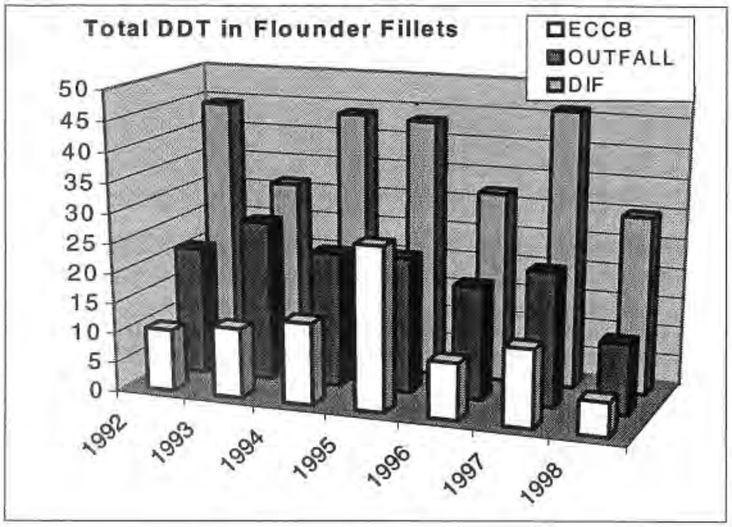
1992 - 1998 FLOUNDER RESULTS
TOTAL PCBs (ng/g dry weight)

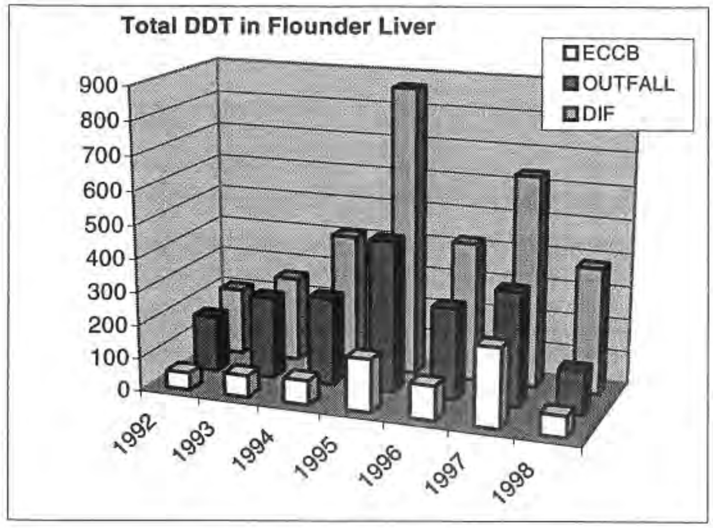


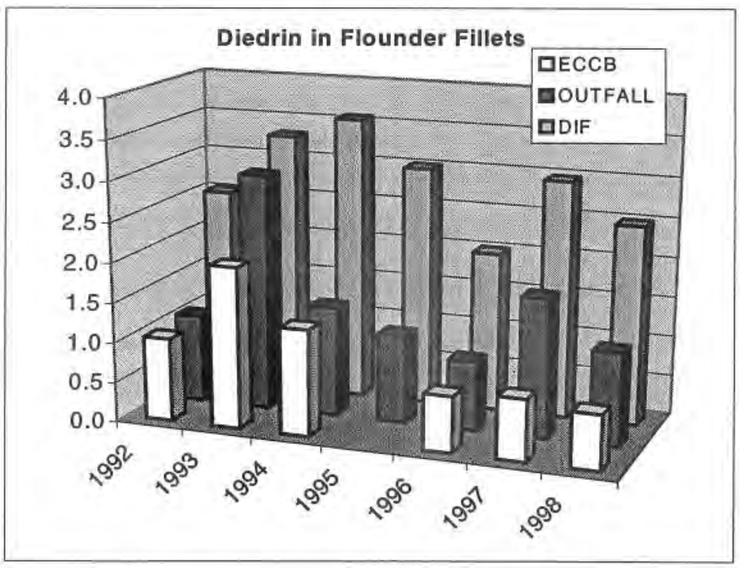


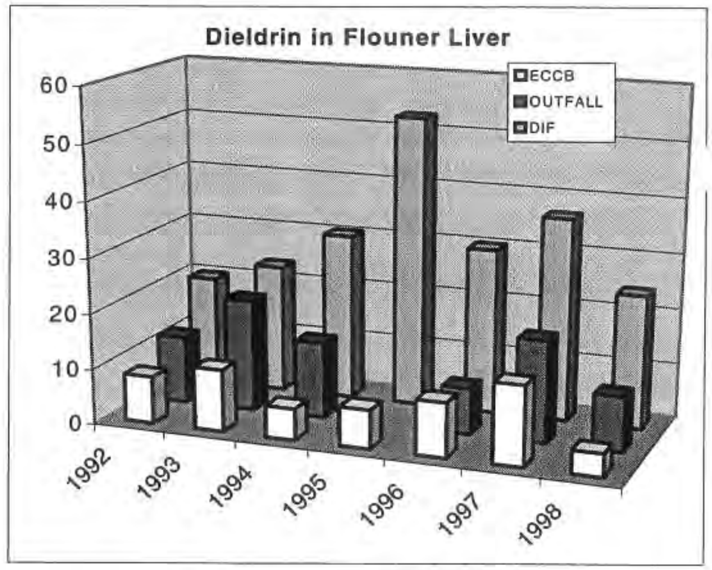
- **Total PCB concentrations in 1998 are lower than in recent years;**
- **The trend shows highest concentrations at DIF and lowest at ECCB, consistent with previous study years**

1992 - 1998 FLOUNDER RESULTS SELECTED PESTICIDES (ng/g dry weight)



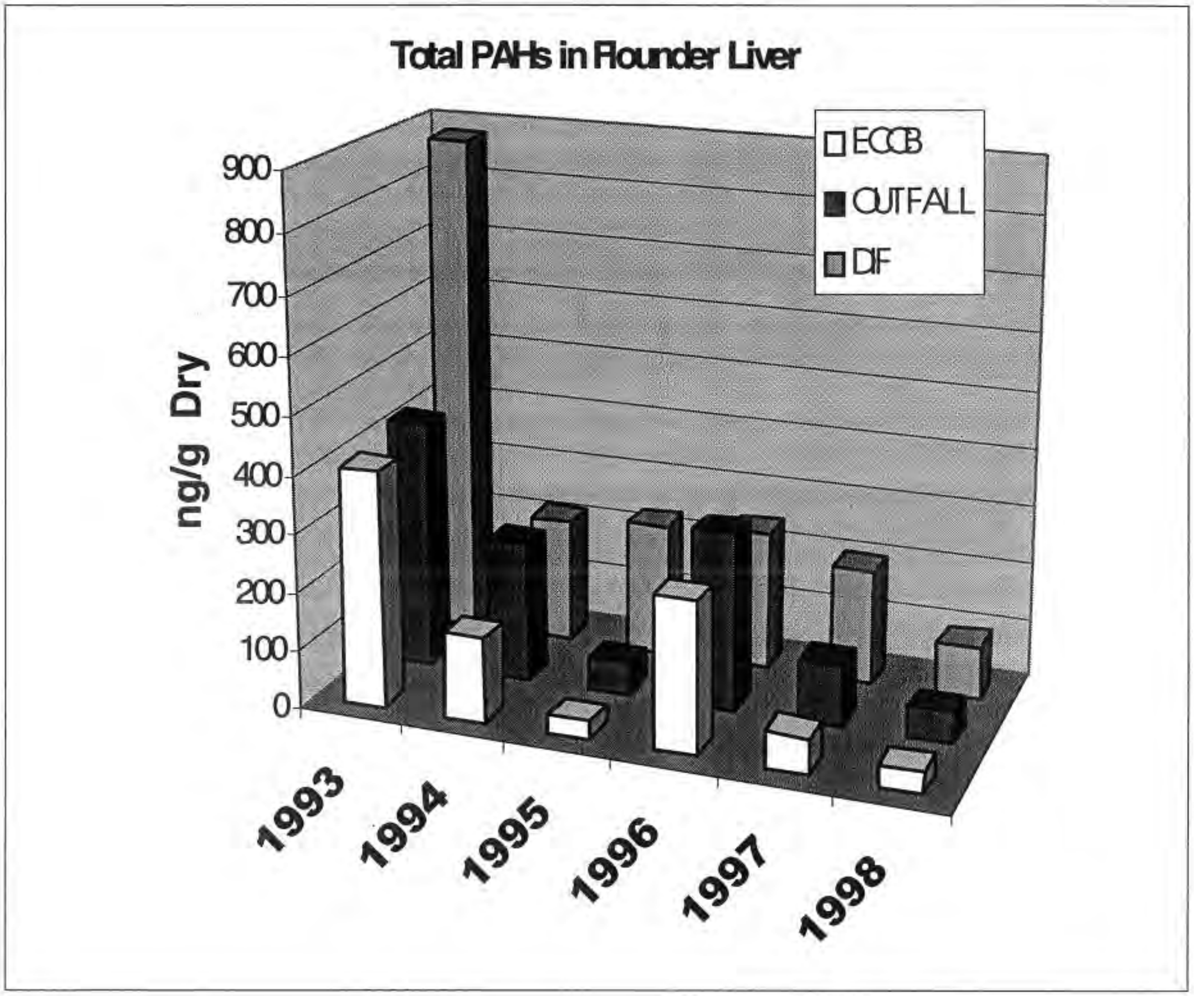






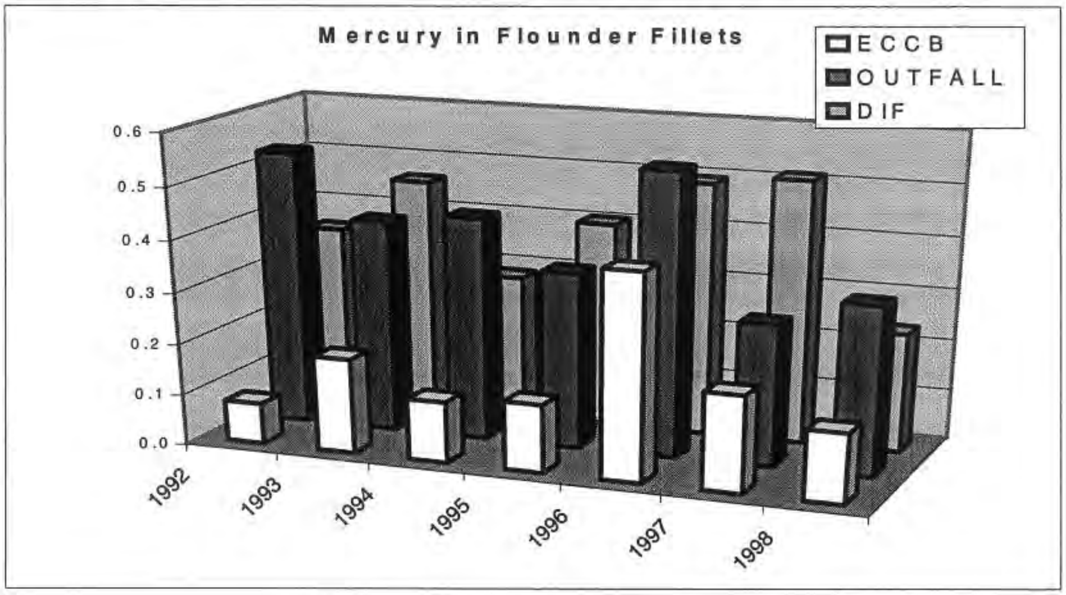
- **Pesticide concentrations in 1998 are within the range of previous years, t-DDTs are lowest since 1992 (except Mirex in livers)**
- **The trend shows highest concentrations at DIF and lowest at ECCB, consistent with previous study years**
- **No clear response to major infrastructure changes (91/92' DI sludge removal; 96 secondary treatment on-line)**

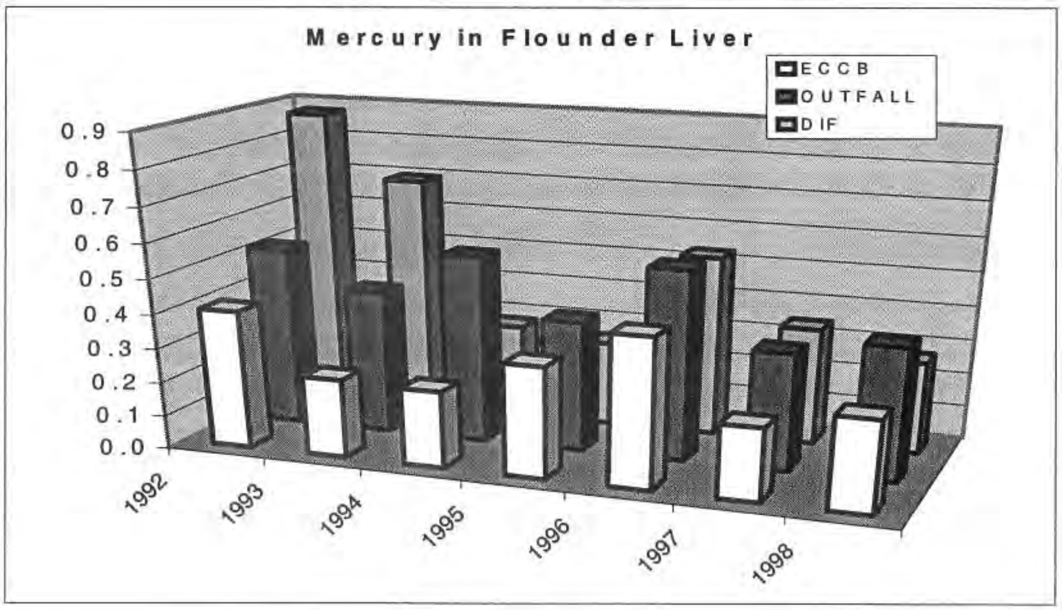
1992 - 1998 FLOUNDER RESULTS
TOTAL PAHS IN LIVER
(ng/g dry weight)



- **Total PAH concentrations in 1998 are among the lowest measured during study at all locations;**
- **The trend shows highest concentrations at DIF and lowest at ECCB, consistent with previous study years;**
- **Gradual decline in concentrations; corresponds to 1992 sludge removal at DI.**

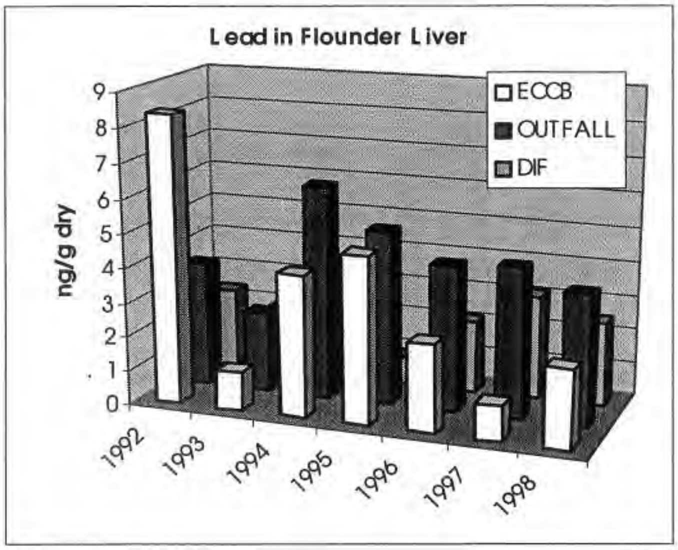
1992 - 1998 FLOUNDER RESULTS SELECTED METALS (ug/g dry weight)

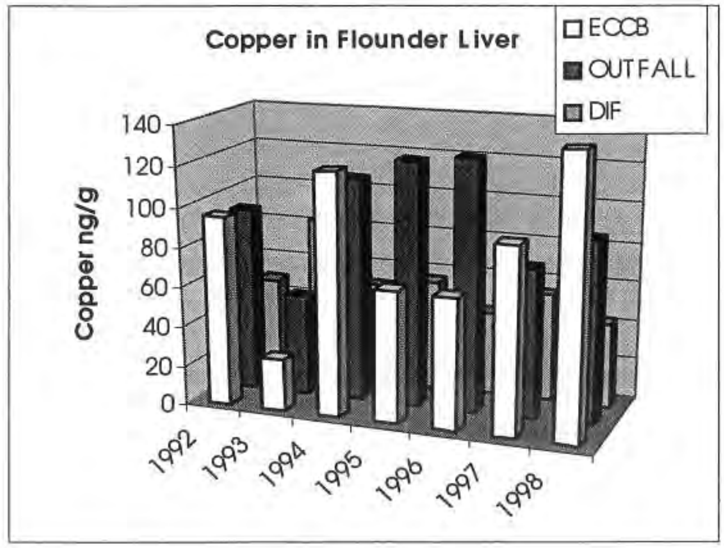


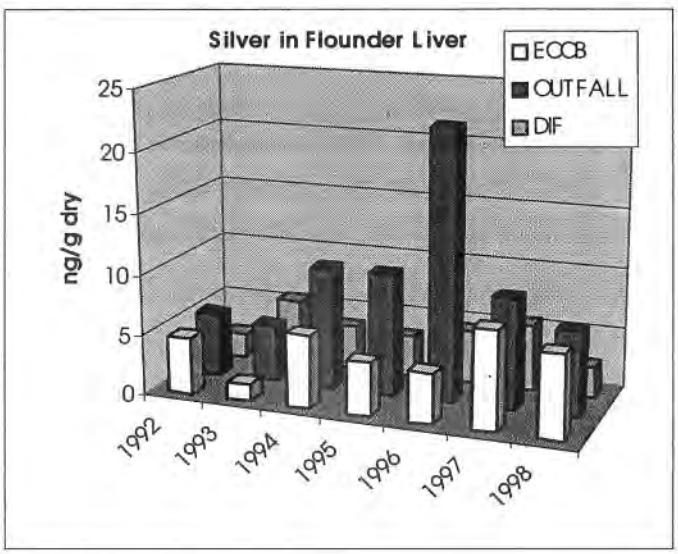


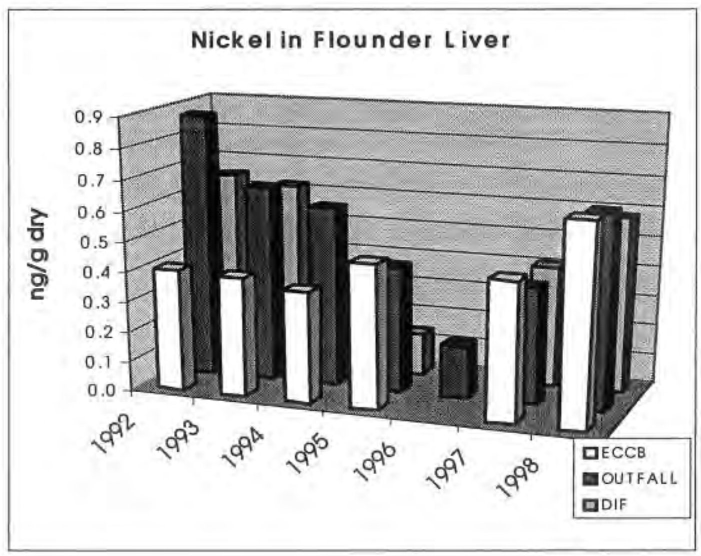
- **1998 fillet Hg, lowest at ECCB, highest at Outfall. 1998 Hg patterns in livers, similar to fillets.**
- **Liver Hg concentrations are generally similar at DIF and FOS and lowest at (except Hg at DIF in 92', 93').**
- **1998 levels are generally consistent since 1995.**

1992 - 1998 FLOUNDER RESULTS
SELECTED METALS (ug/g dry)







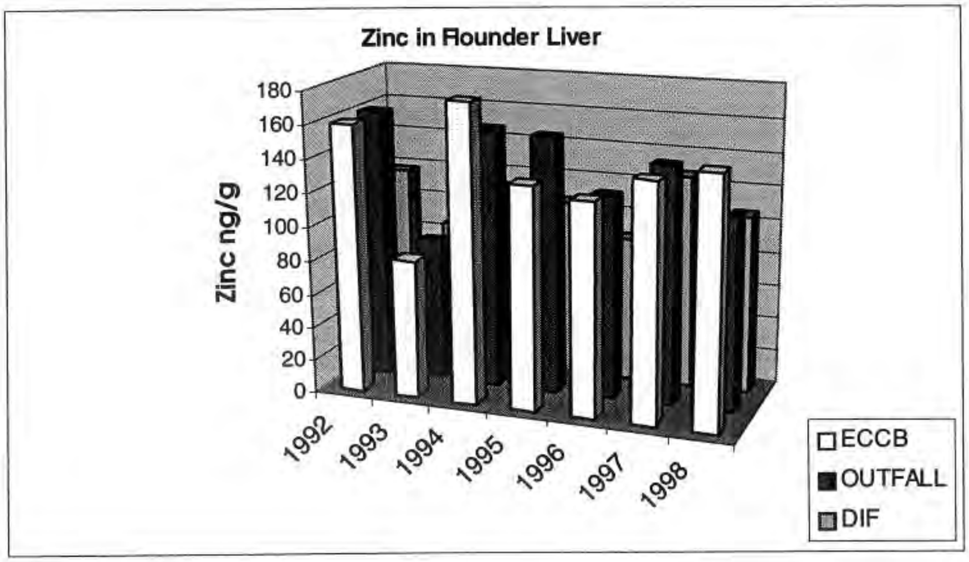


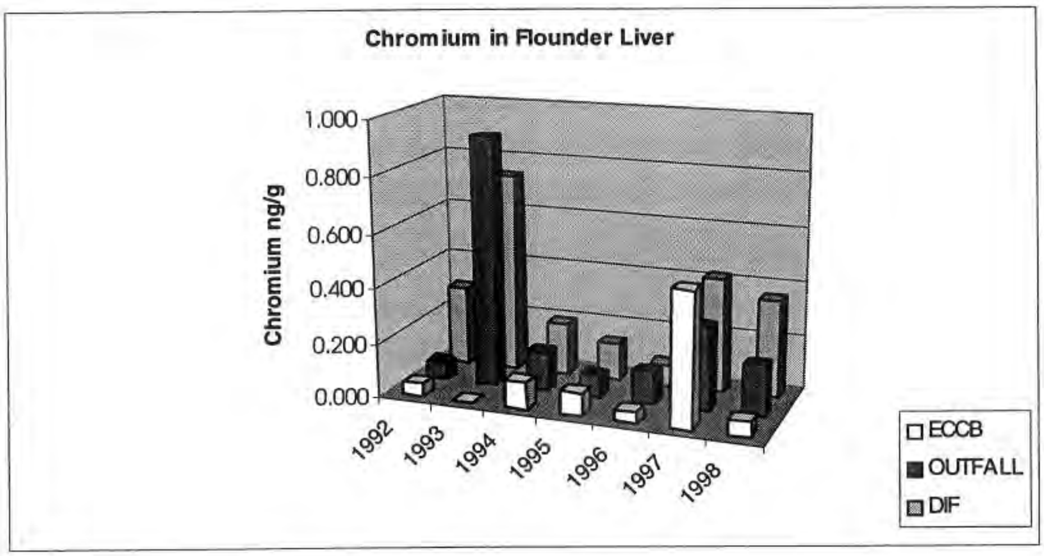
- **Generally, metals concentrations in livers are highest at the FOS and lowest at DI, unlike organic contaminant patterns.**
- **1998 levels are within the range of previous measurements and are generally lower; except Cu, Ni, Pb at ECCB, Cu, Ni at FOS and Ni at DIF.**
- **Overall, the trend is for similar or decreasing metals concentrations at all sites since 1992.**

Comparison of Selected Flounder Parameters to FDA and MWRA Thresholds

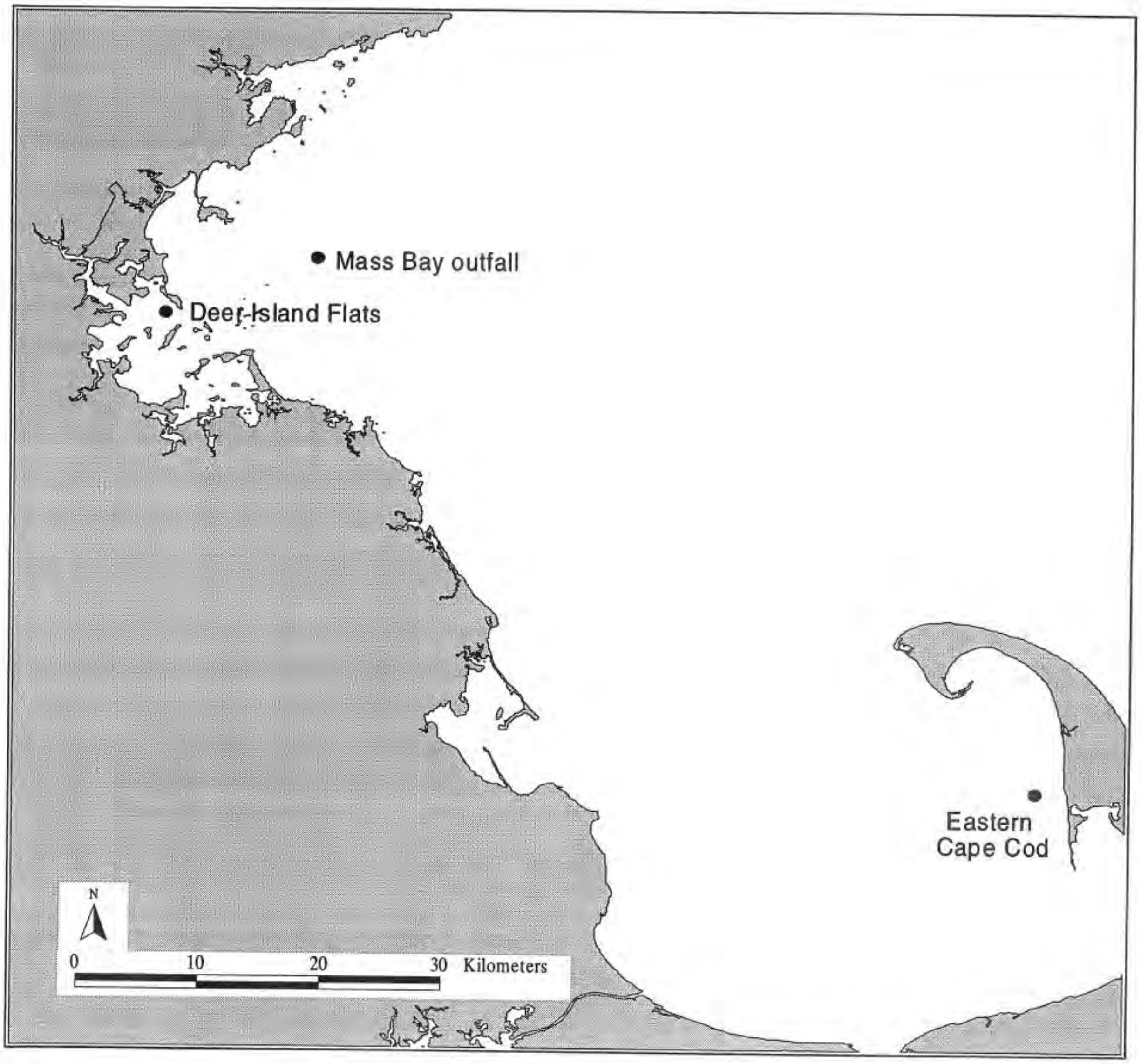
STATION	Total PCB (ng/g wet wt) Mean	s.d.	Total DDTs (ng/g DRY wt) Mean	s.d.	Total Chlordanes (ng/g wet wt) Mean	s.d.	Dieldrin (ng/g wet wt) Mean	s.d.	Mercury (Hg) (ug/g wet wt) Mean	s.d.
DIF(1)	52.4	*8.0*	29.9	*4.7*	3.0	*0.4*	0.55	*0.05*	0.05	*0.01*
OUTFALL(4)	19.7	*11.0*	11.9	*7.14*	1.0	*0.6*	0.22	*0.11*	0.06	*0.02*
ECCB(5)	8.10	*0.6*	5.74	*0.67*	0.3	*0.0*	0.14	*0.01*	0.03	*0.01*
FDA Limit	2000		(5000 ng/g wet)		300		300		1.0	
MWRA Caution Level (2 x Baseline; 1992-1997)	79.5		47.55		3.0		0.57		0.16	
MWRA Warning Level (80% FDA)	1600								0.8	

1992 - 1998 FLOUNDER RESULTS
Additional SELECTED METALS (ug/g dry





LOBSTER COLLECTION
September 1998



LOBSTER MEASUREMENTS

Physical/Biological Measurements

Parameter
CARAPAPICE LENGTH (mm)
WEIGHT (g)
SEX_RATIO (FEMALE: MALE)
EXTERNAL CONDITION
BLACK_GILL
EXT_TUMORS
PARASITES
SHELL_EROS

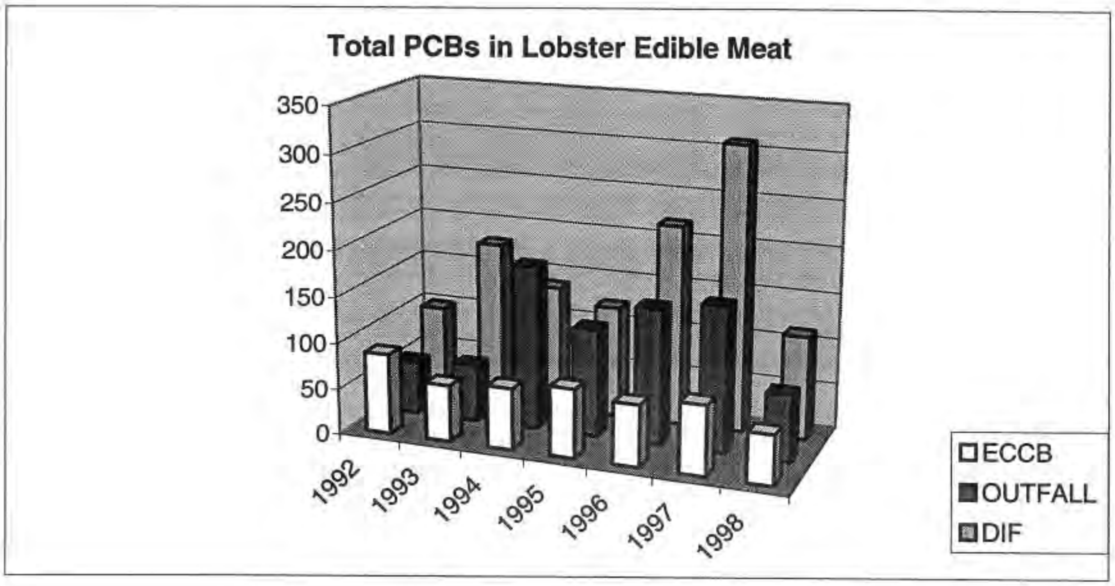
Parameter	N	Deer Island		Outfall		Cape Cod	
		Station Mean	S.E.	Station Mean	S.E.	Station Mean	S.E.
CARAP_LEN (mm)	15	113.0	3.6	114.6	2.7	116.3	1.6
WEIGHT (g)	15	458.5	19.5	518.7	14.8	497.1	20.8
SEX_RATIO F:M*	15	0.88	--	0.5	--	0.0	--

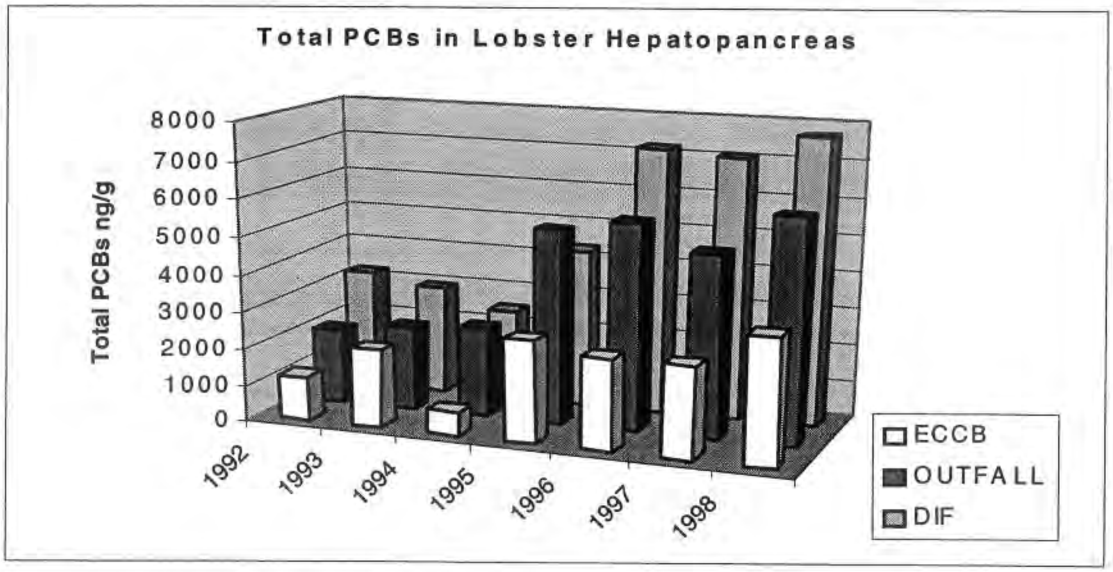
* A sex ratio of 0 indicates that all 15 lobsters were male.

CHEMICAL MEASUREMENTS

Sample Type	Number of Samples	Metals (Ag, Cd, Cr, Cu, Ni, Zn)	Hg	Pb	PCBs	PAHs	Pests	Lipids
Lobster Meat	9		!		!		!	!
Lobster Hepatopancreas	9	!	!	!	!	!	!	!

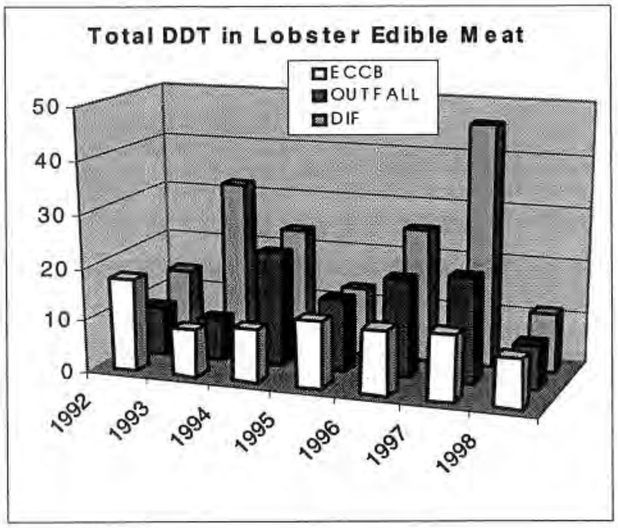
1992 - 1998 LOBSTER RESULTS
TOTAL PCBs (ng/g dry weight)

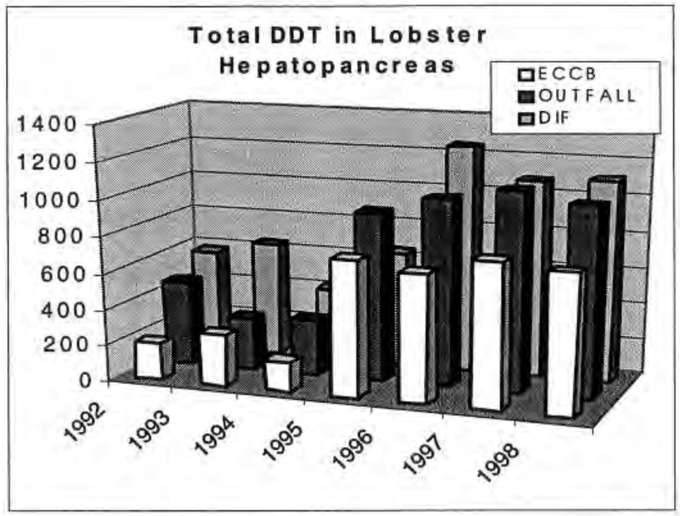


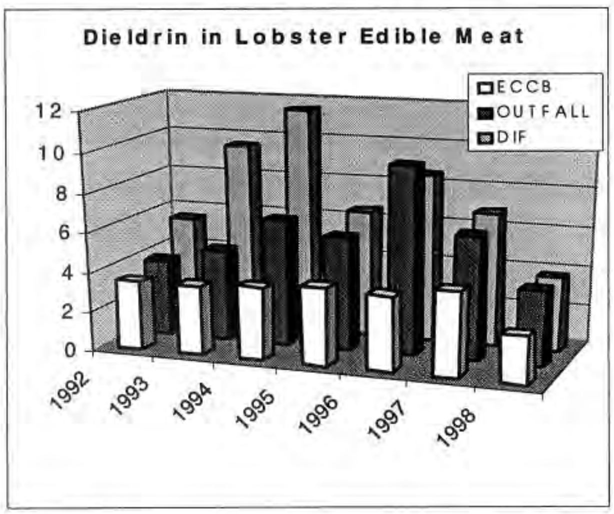


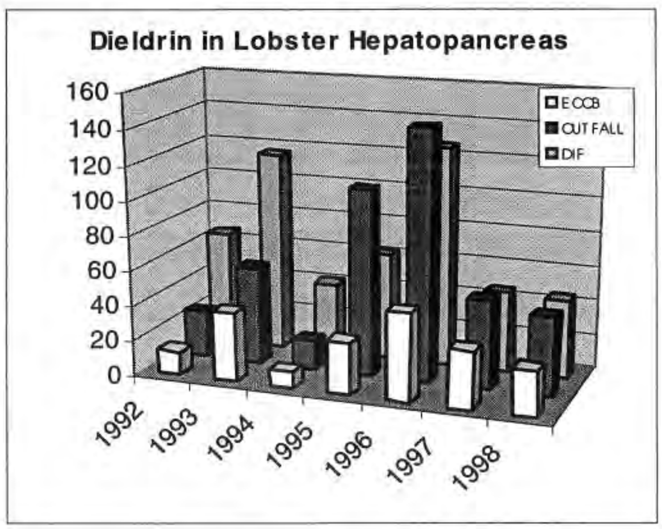
- **1998 Total PCB concentrations in lobster meat are lower than in recent years.**
- **1998 Total PCB concentrations in lobster hepatop. are consistent with recent years.**
- **Highest concentrations at DIF and lowest at ECCB, consistent with previous study years.**

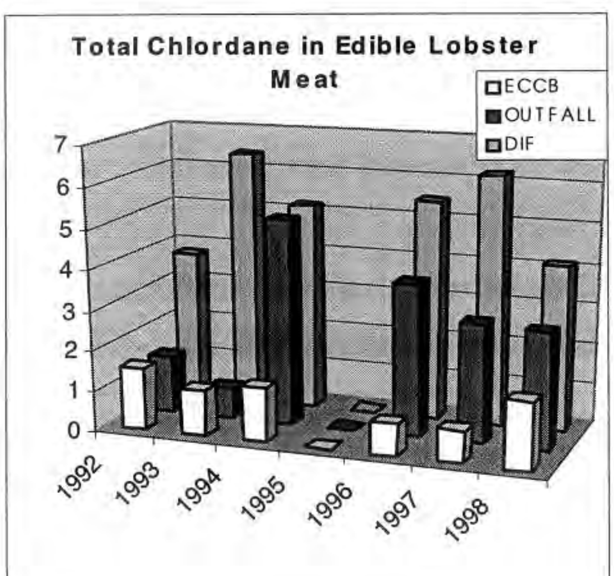
1992 - 1998 LOBSTER RESULTS
SELECTED PESTICIDES (ng/g dry weight)

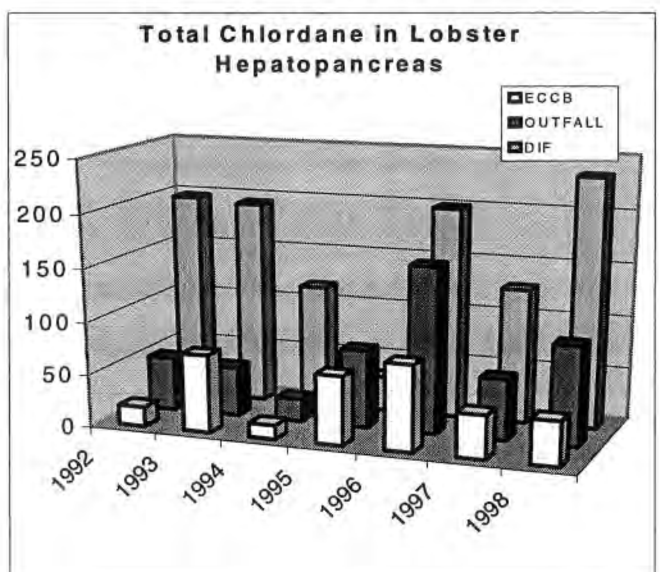




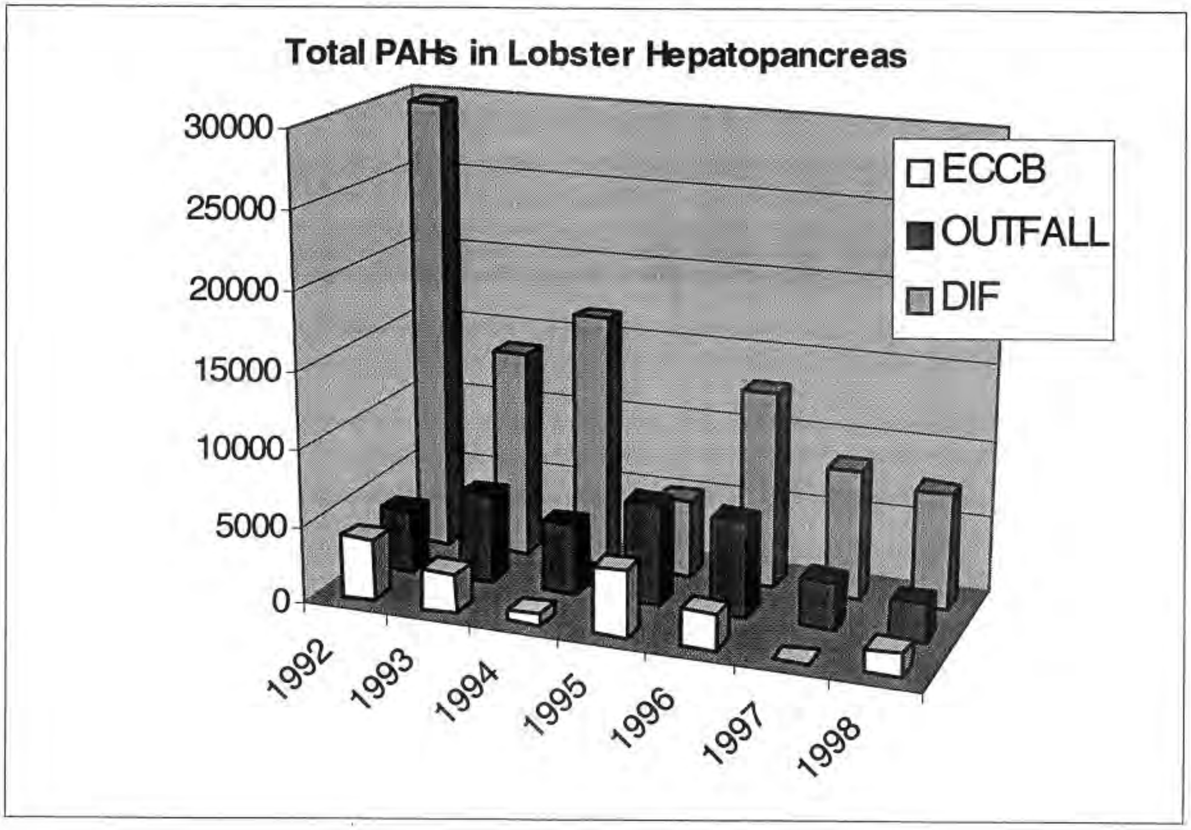






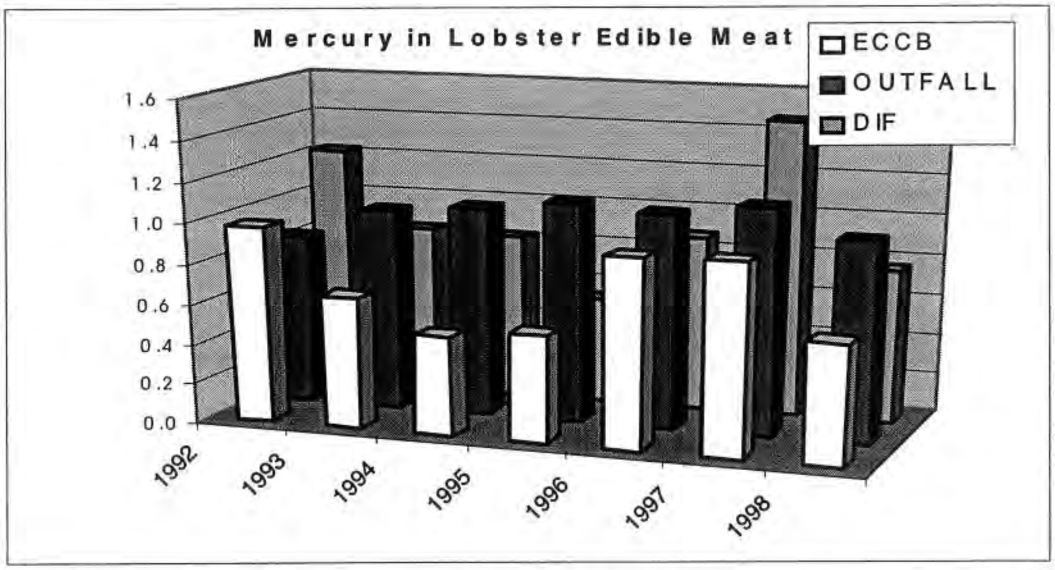


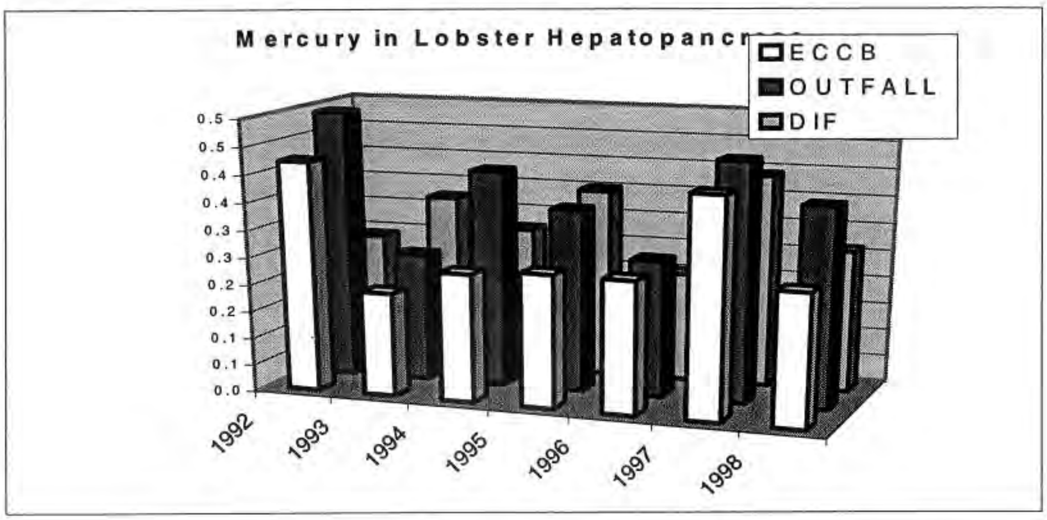
1992 - 1998 LOBSTER RESULTS TOTAL PAHS IN HEPATOPANCREAS (ng/g dry weight)



- **Total PAH concentrations in 1998 are consistent with previous years.**
- **The trend shows highest concentrations at DIF and lowest at ECCB.**
- **Decline in concentrations at DIF after 1992; corresponds to sludge removal at DI.**

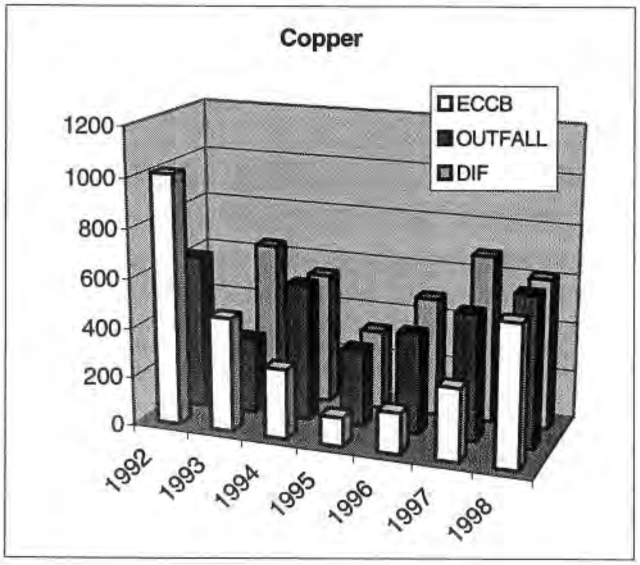
1992 - 1998 FLOUNDER RESULTS
SELECTED METALS (ug/g dry)

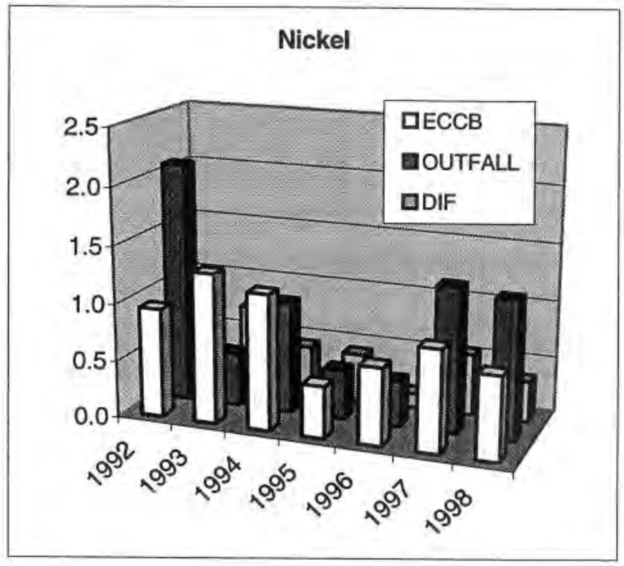


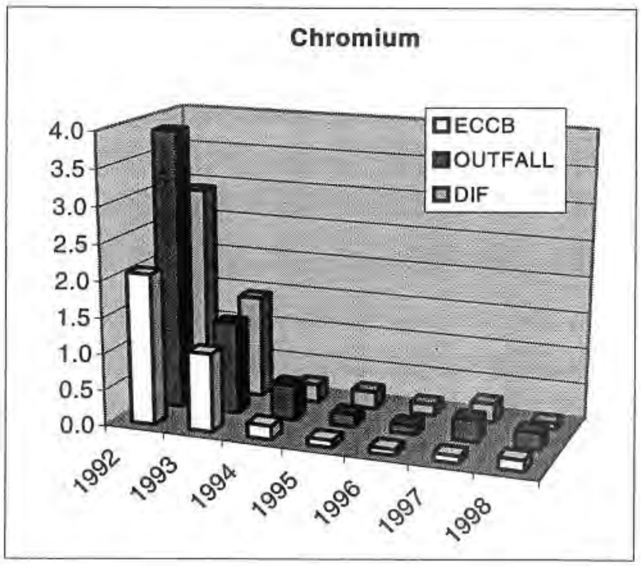


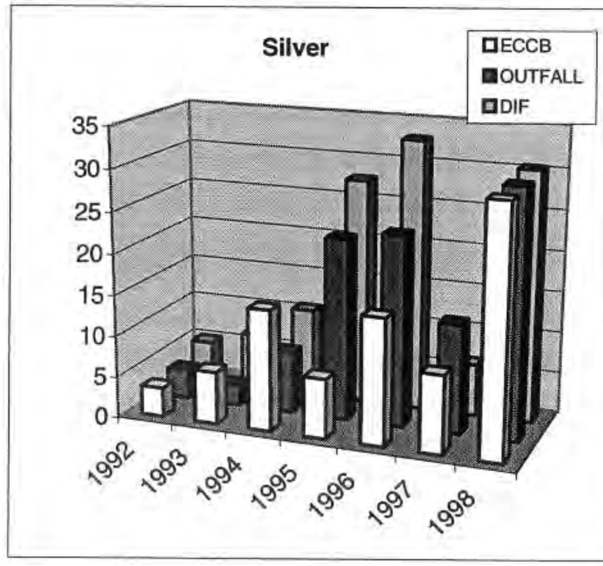
- **1998 lobster meat and hepatopancreas Hg concentrations are lower than 1997; within range of previous years.**
- **No discernable trends between stations or years.**

1992 - 1998 LOBSTER RESULTS
SELECTED METALS (ug/g dry)







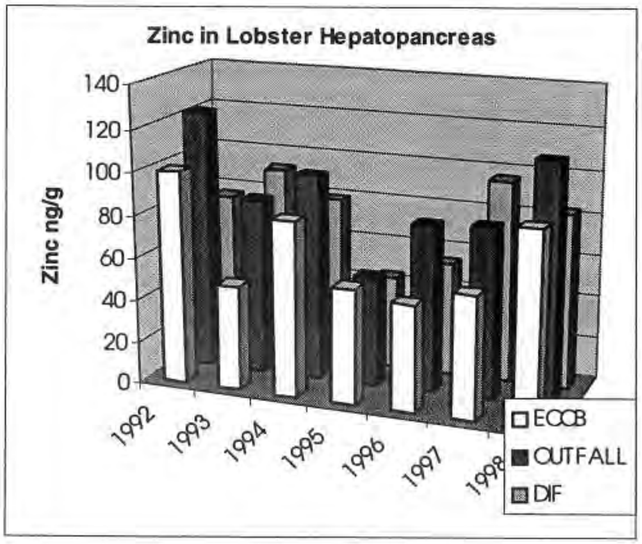


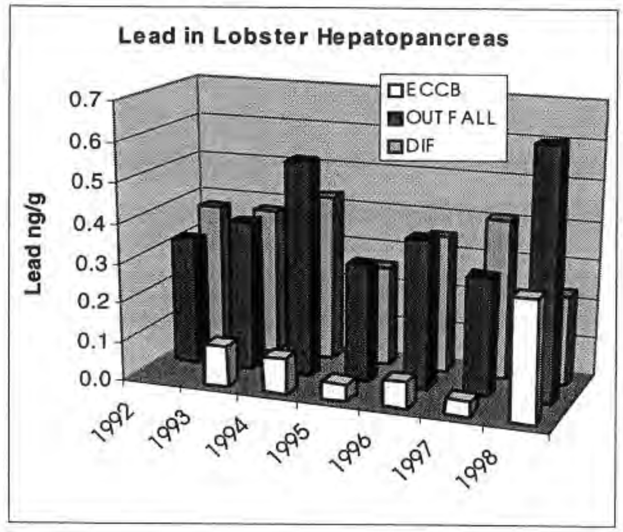
- **1998 levels are within the range of previous measurements; except for Ag.**
- **Generally, metals concentrations in lobster hepatopancreas have been constant over the study period; except for Ag and Cr.**

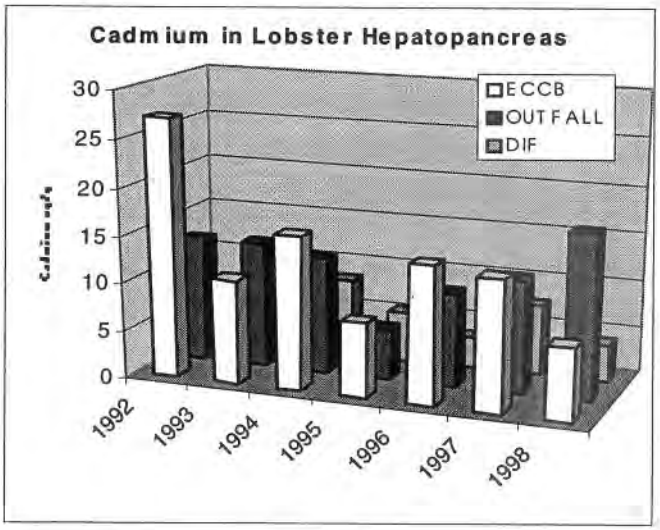
Comparison of Selected Lobster Parameters to FDA and MWRA Thresholds

STATION	Total PCB (ng/g wet wt) Mean	s.d.	Total DDTs (ng/g DRY wt) Mean	s.d.	Total Chlordanes (ng/g wet wt) Mean	s.d.	Dieldrin (ng/g wet wt) Mean	s.d.	Mercury (Hg) (ug/g wet wt) Mean	s.d.
DIF(1)	16.73	3.42	11.3	1.1	0.60	0.09	0.56	0.09	0.11	0.01
OUTFALL(4)	9.69	2.63	8.46	2.6	0.39	0.16	0.52	0.02	0.13	0.02
ECCB(5)	7.79	1.76	9.46	2.2	0.24	0.02	0.34	0.01	0.09	0.01
FDA Limit	2000		(5000 ng/g wet)		300		300		1.0	
MWRA Caution Level (2 x Baseline; 1992-1997)	36.1		31.6		0.84		1.9		0.32	
MWRA Warning Level (80% FDA)	1600								0.8	

▪ 1992 - 1998 LOBSTER RESULTS ADDITIONAL SELECTED METALS (ug/g dry)







Fish and Shellfish Monitoring
1998 Flounder Histopathology *(Dr. Michael Moore, WHOI)*

WINTER FLOUNDER MILESTONES

1975 Howe and Coates - migration south of the Cape (10's of miles) vs. North (~1 mile.) Hence a better station marker north of Cape.

1975 Murchelano describes finrot in NY Bight and associates with pollution.

1985 Murchelano and Wolke - tumors and vacuolated cells from Boston Harbor winter flounder.

1987 to 1991 - Moore - progression of vacuolation, definition of tumor types, initiation and initiation of monitoring database.

1988 Gardner et al. - Quincy Bay study - risk assessment and health advisory.

Gardner et al (1989) , Myers et al (1994) and HOM - linkage of tumors and vacuolated cells to contaminants - PAH and pesticides especially

1990 NOAA Reproductive Success study - no linkage to contaminants in Boston samples

1991 to present Moore, Hillman et al. - 5 station survey.

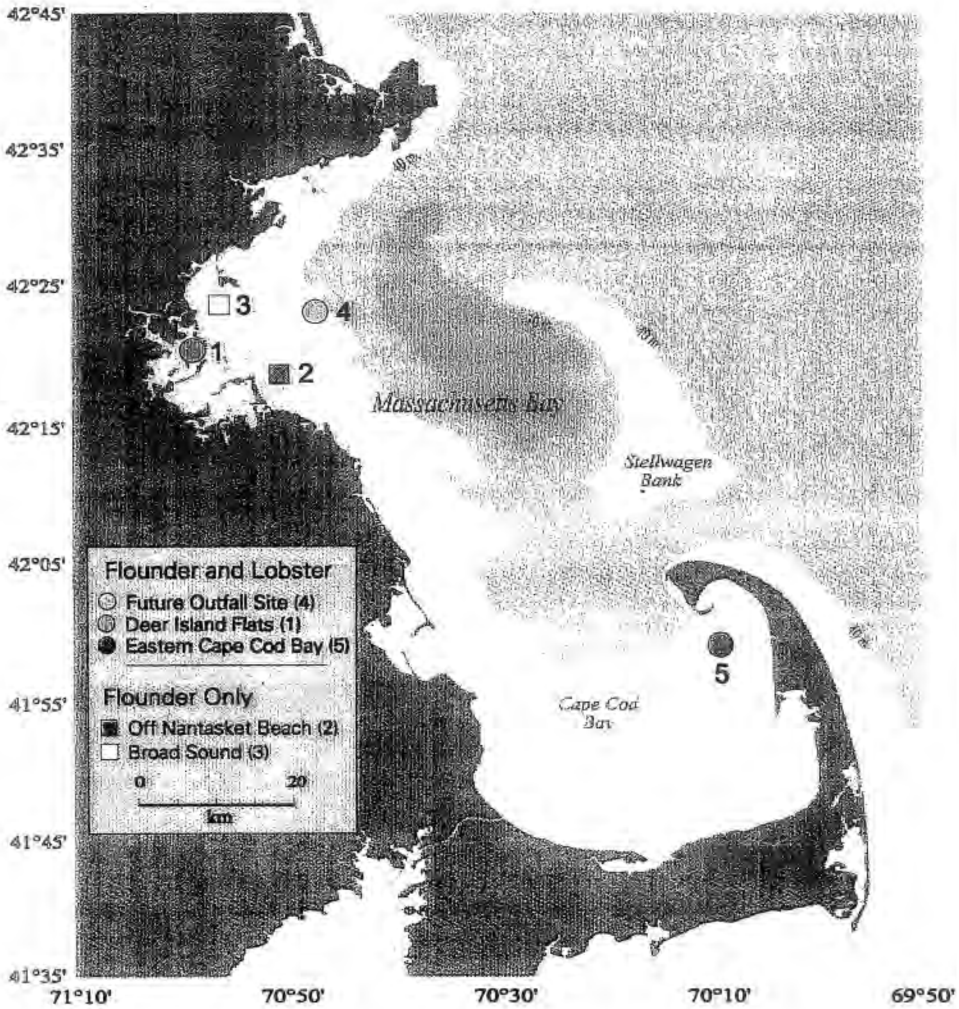
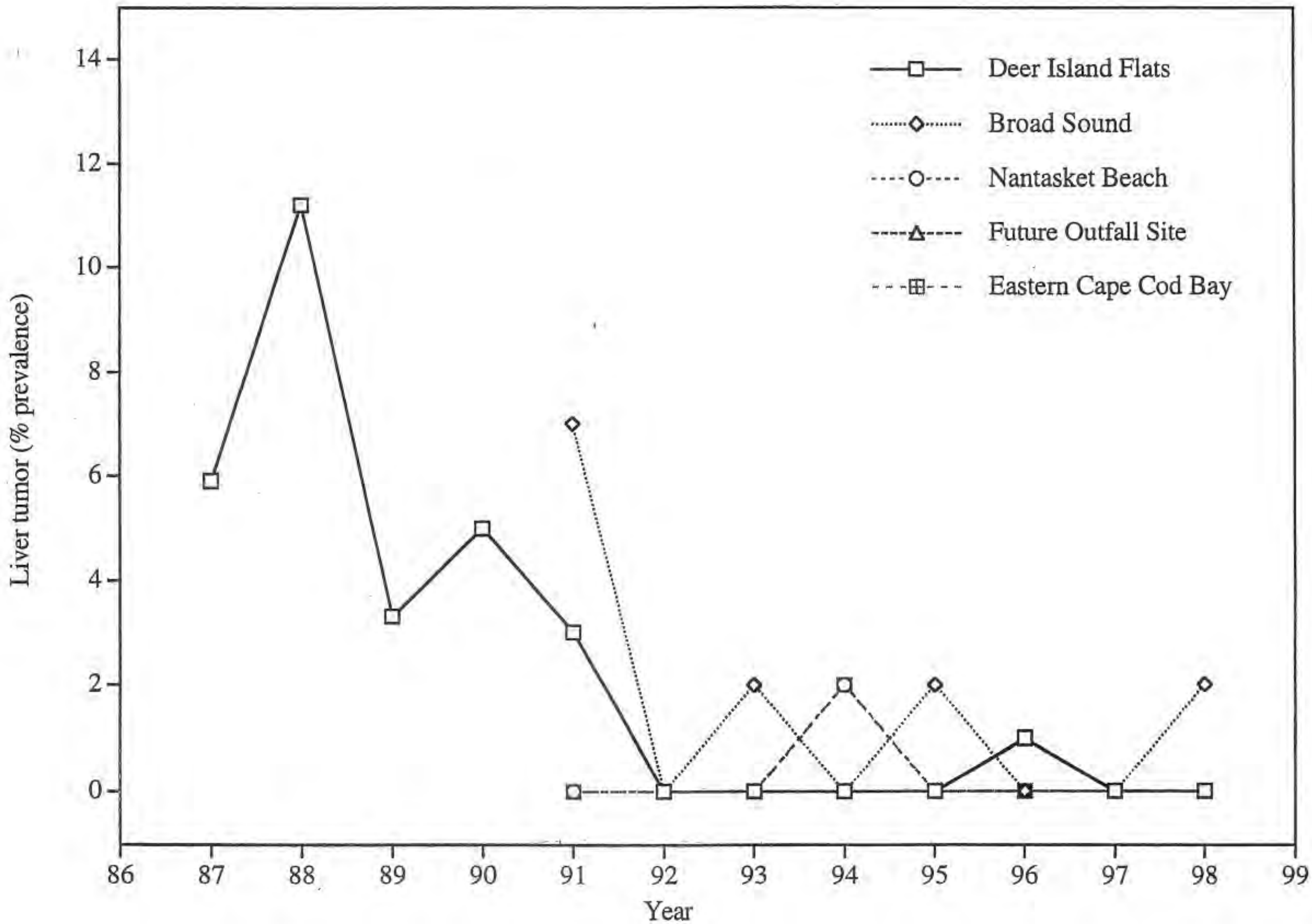


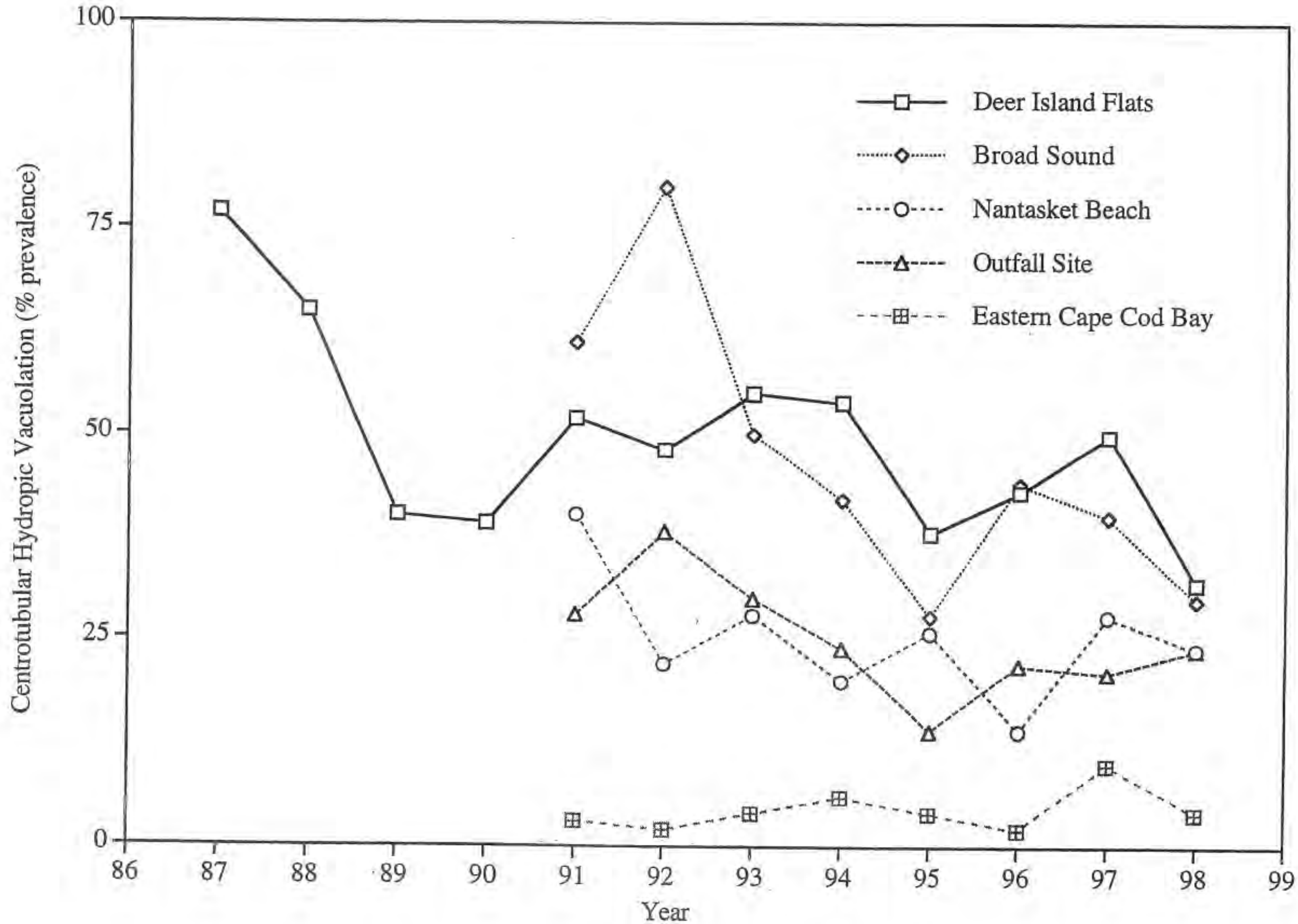
Figure 1. Flounder Sampling Stations.

Table 1 - Catch per unit effort (# of fish per min. of bottom time) for winter flounder trawled in April/May

	1991	1992	1993	1994	1995	1996	1997	1998
Deer Island	0.38	0.23	0.15	0.39	0.10	0.16	0.11	0.69
Nantasket Beach	0.48	1.29	1.52	0.76	0.88	0.77	0.43	0.56
Broad Sound		2.80	0.49	0.42	0.29	0.23	0.59	2.57
Future Outfall	0.13	0.48	0.62	0.24	0.60	0.31	0.81	2.62
Eastern Cape Cod Bay	0.67	0.49	0.77	0.42	0.21	1.38	0.32	0.23

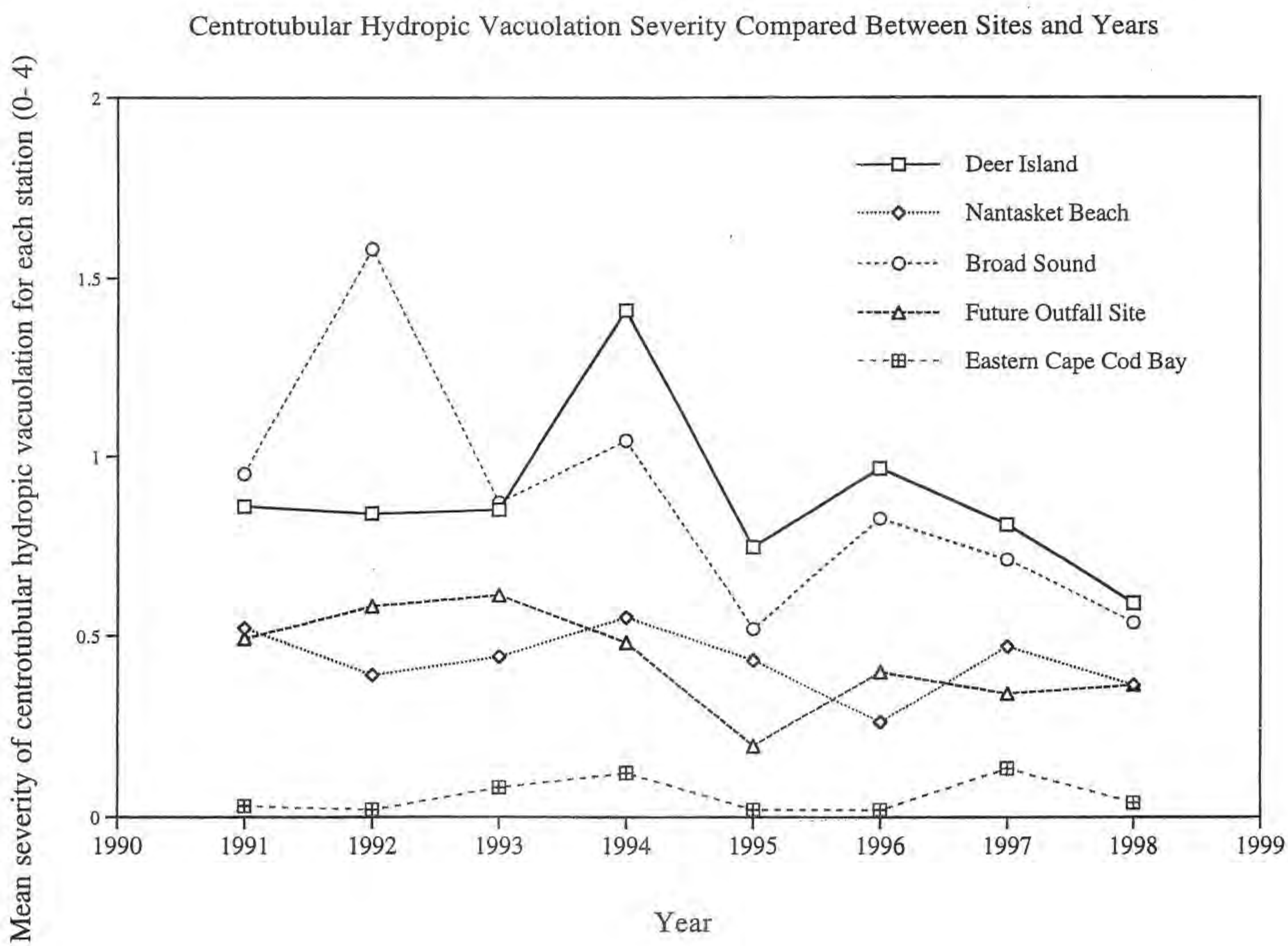
The same vessel and net was used at all times


Liver tumor (% prevalence)
0
2
4
6
8
10
12
14
86
87
88
89
90
91
92
93
94
95
96
97
98
99
Year
Deer Island Flats
Broad Sound
Nantasket Beach
Future Outfall Site
Eastern Cape Cod Bay



Deer Island Flats
Broad Sound
Nantasket Beach
Outfall Site
Eastern Cape Cod Bay
Centrotubular Hydropic Vacuolation (% prevalence)
100
75
50
25
0
86
87
88
89
90
91
92
93
94
95
96
97
98
99
Year

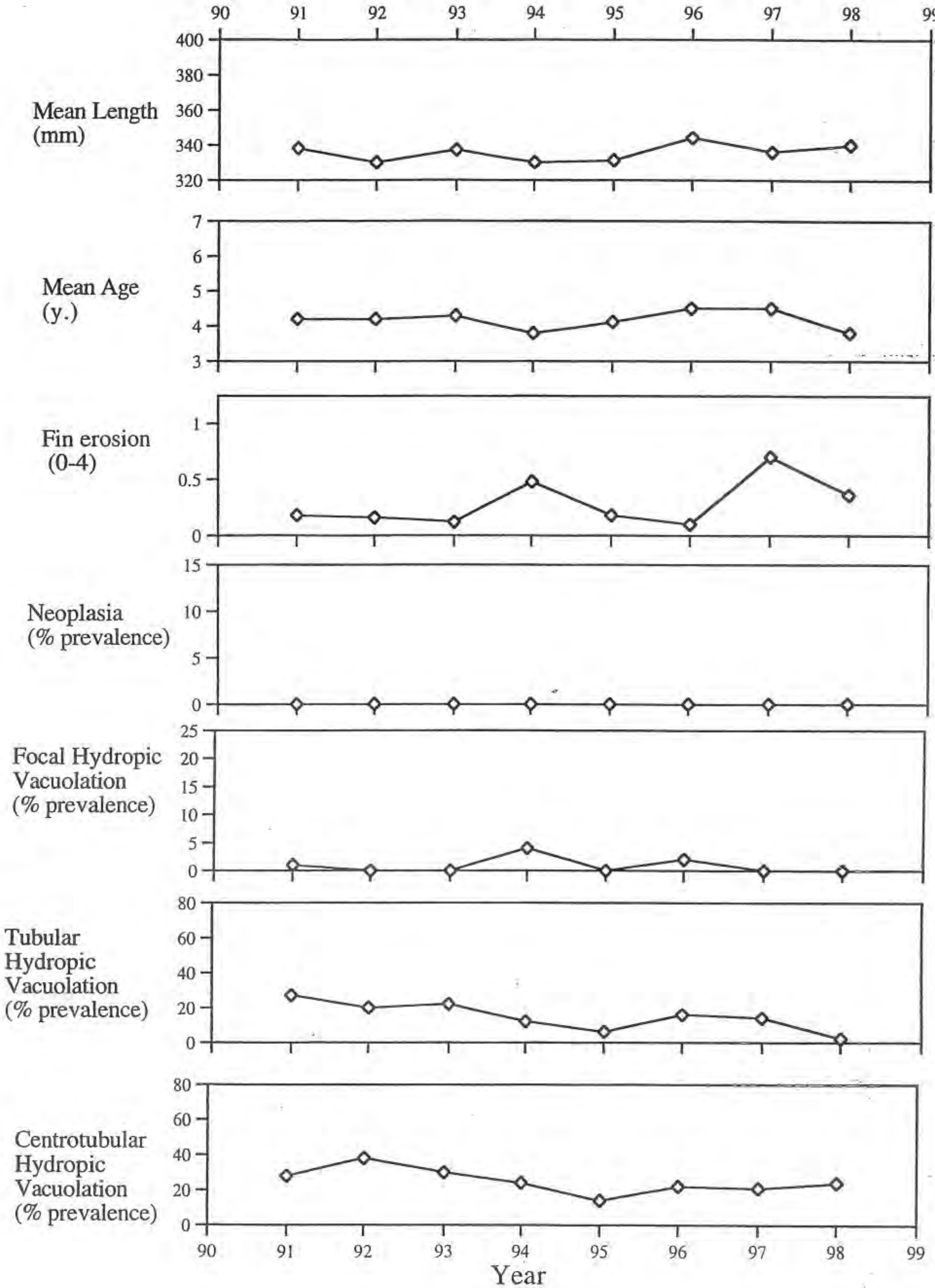
136



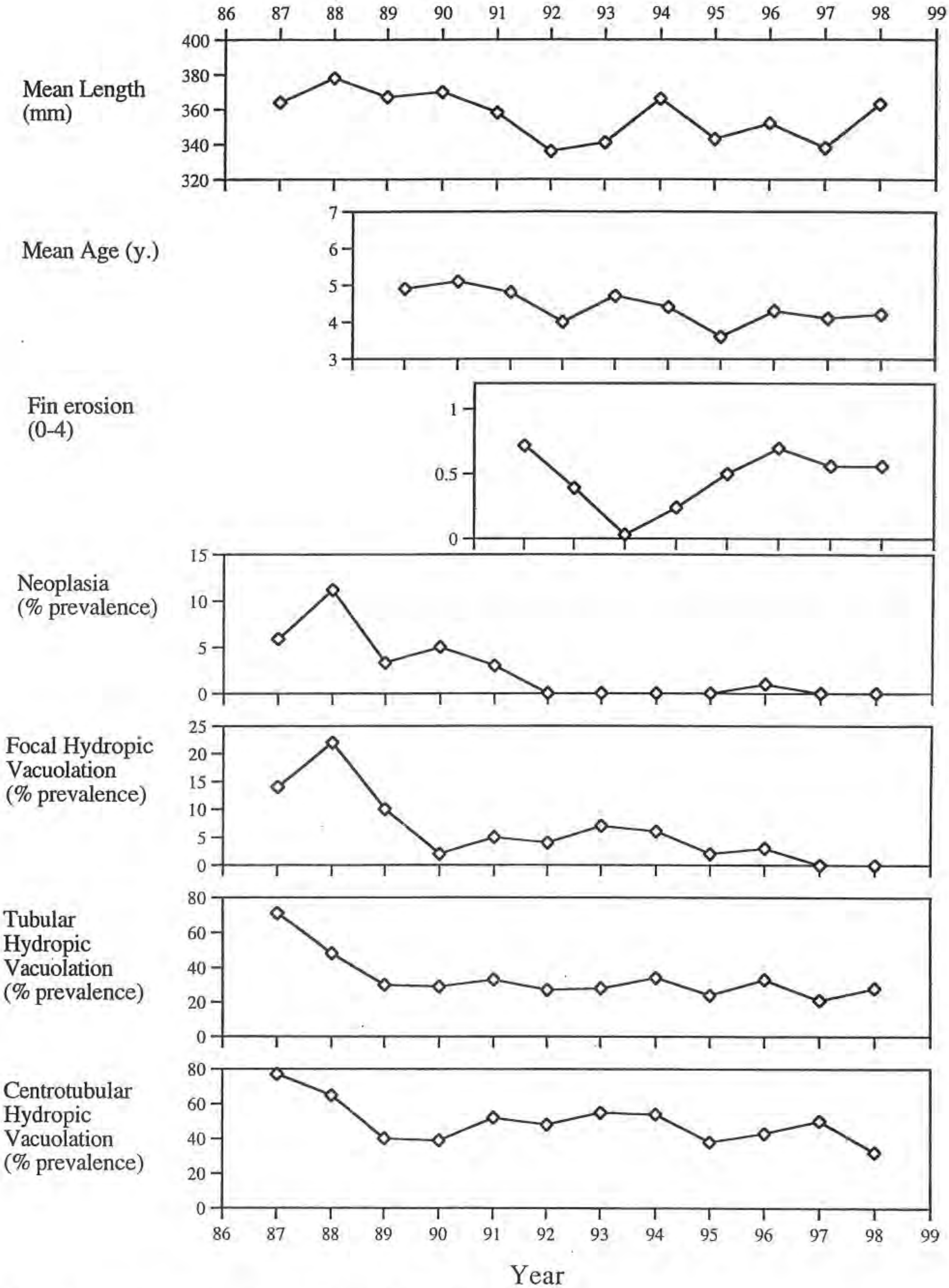
Centrotubular Hydropic Vacuolation Severity Compared Between Sites and Years
Mean severity of centrotubular hydropic vacuolation for each station (0- 4)
Year
2
1.5
1
0.5
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
Deer Island
Nantasket Beach
Broad Sound
Future Outfall Site
Eastern Cape Cod Bay

137

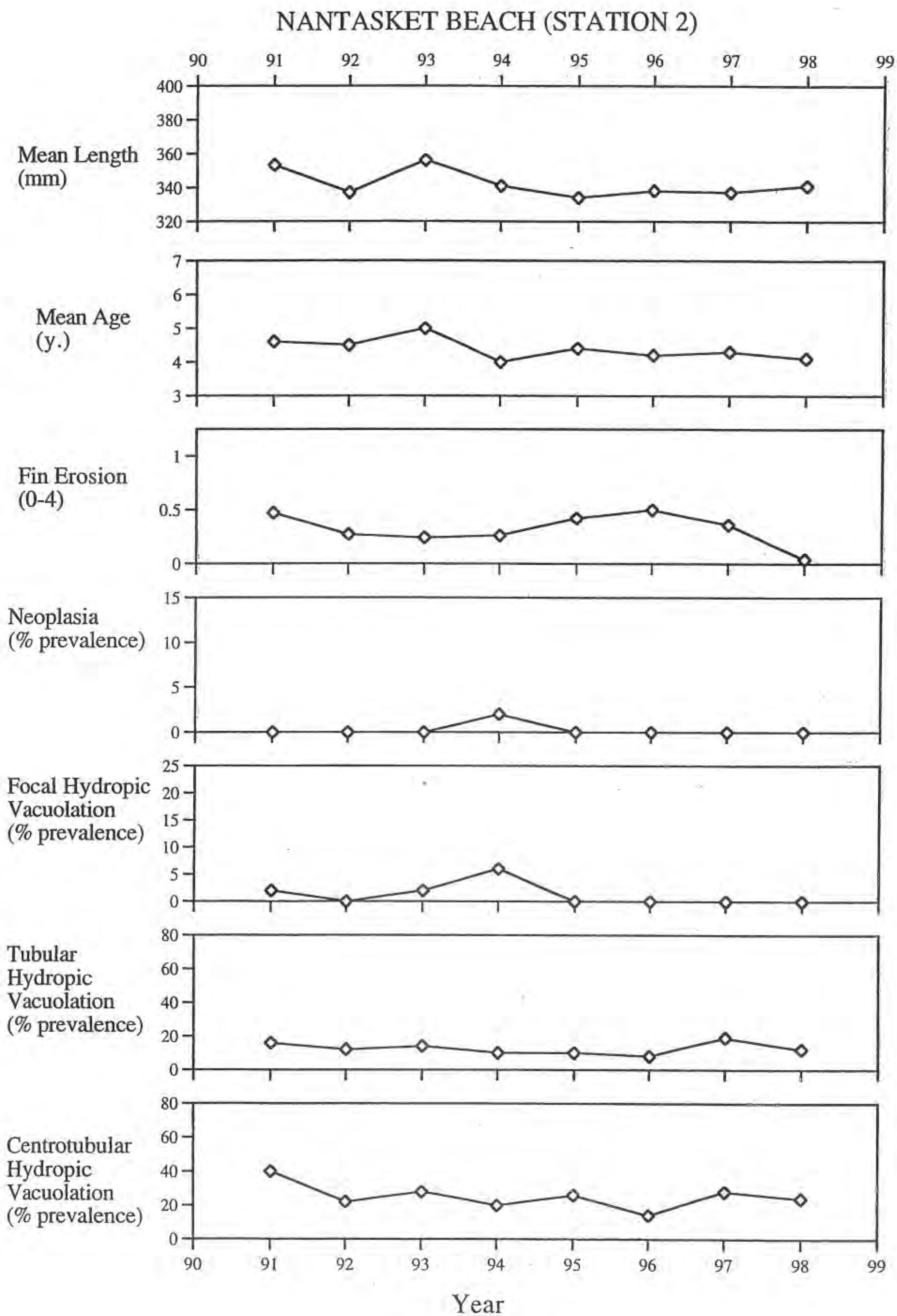
FUTURE OUTFALL SITE (STATION 4)

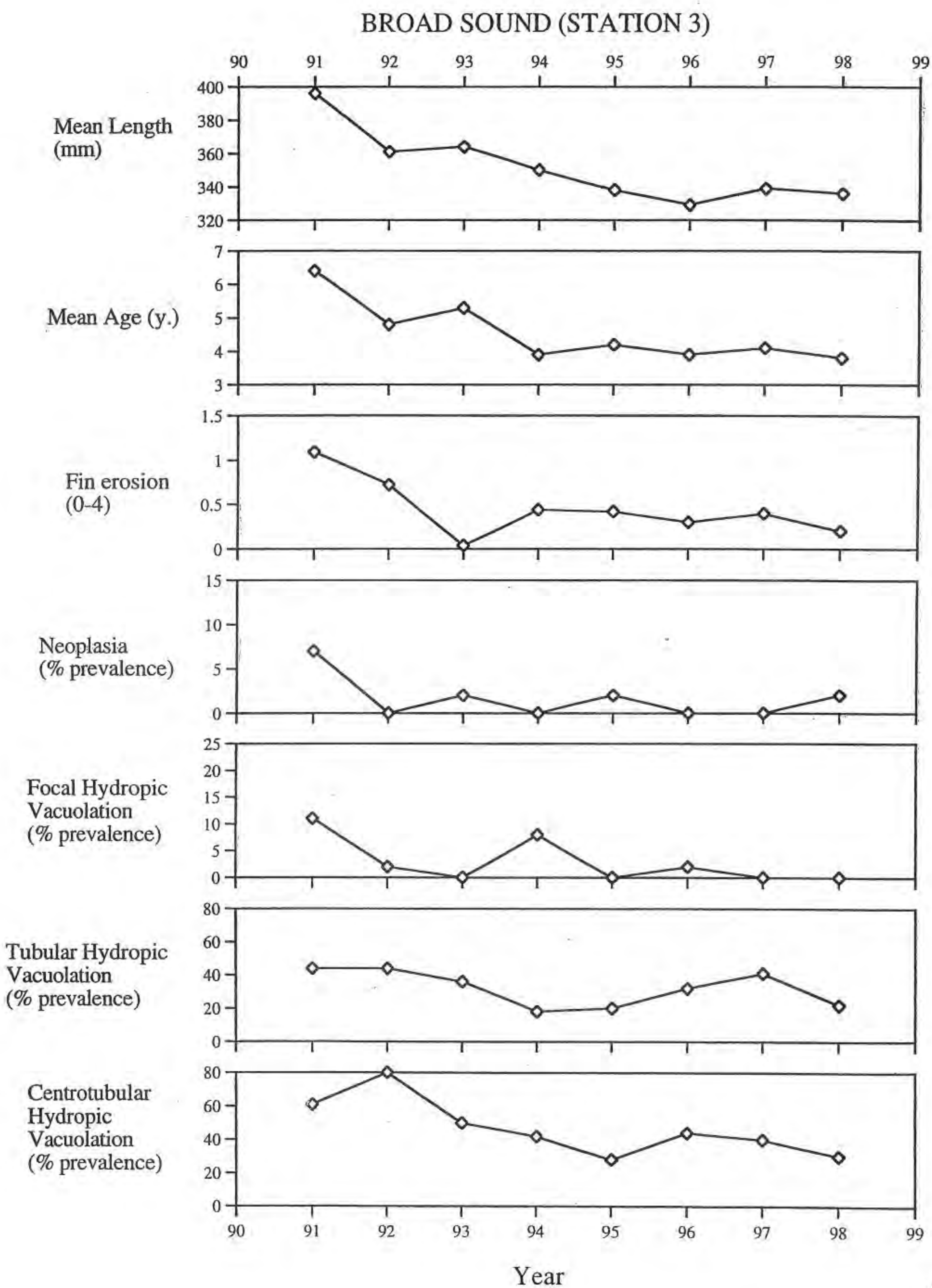


DEER ISLAND (STATION 1)

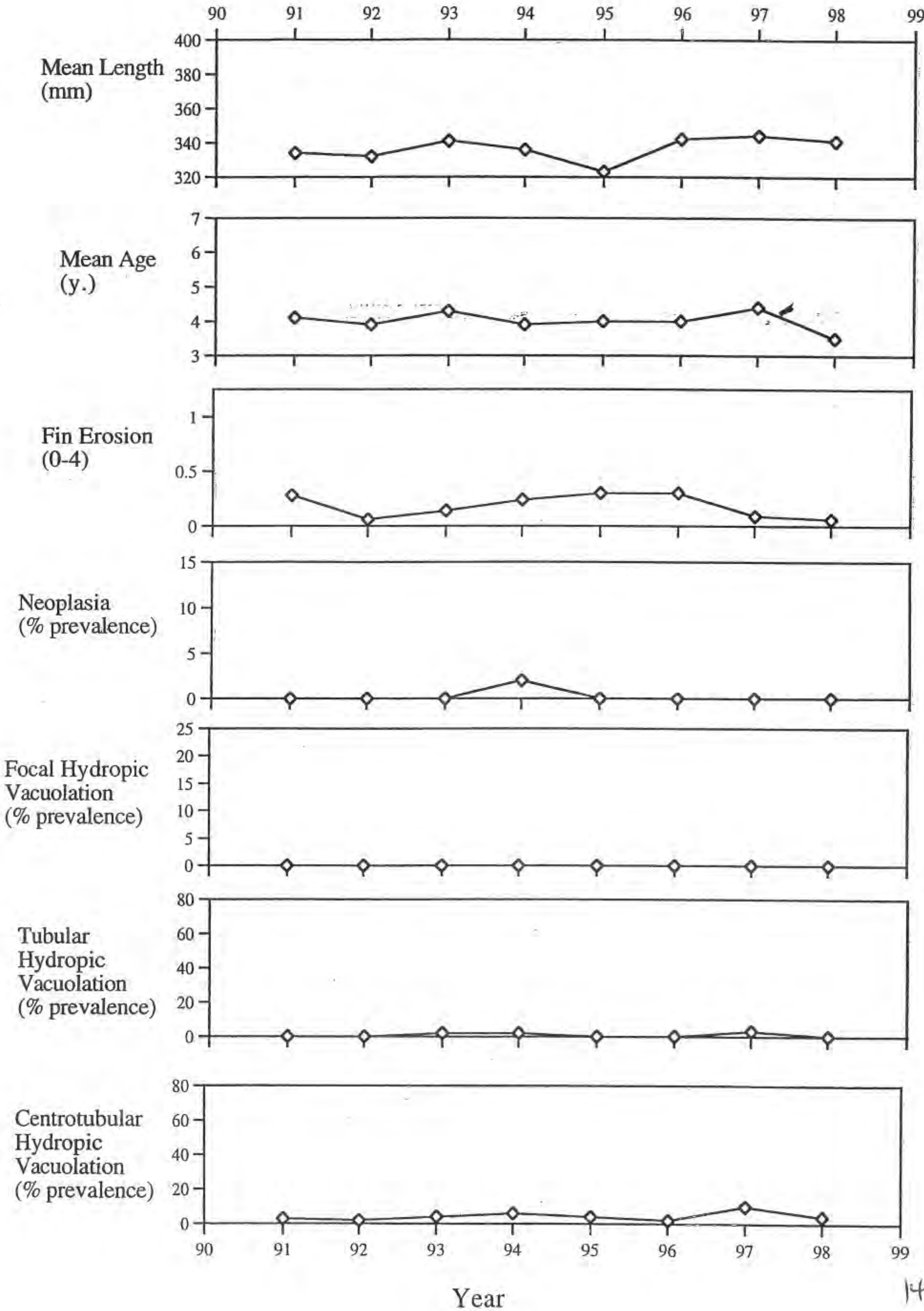


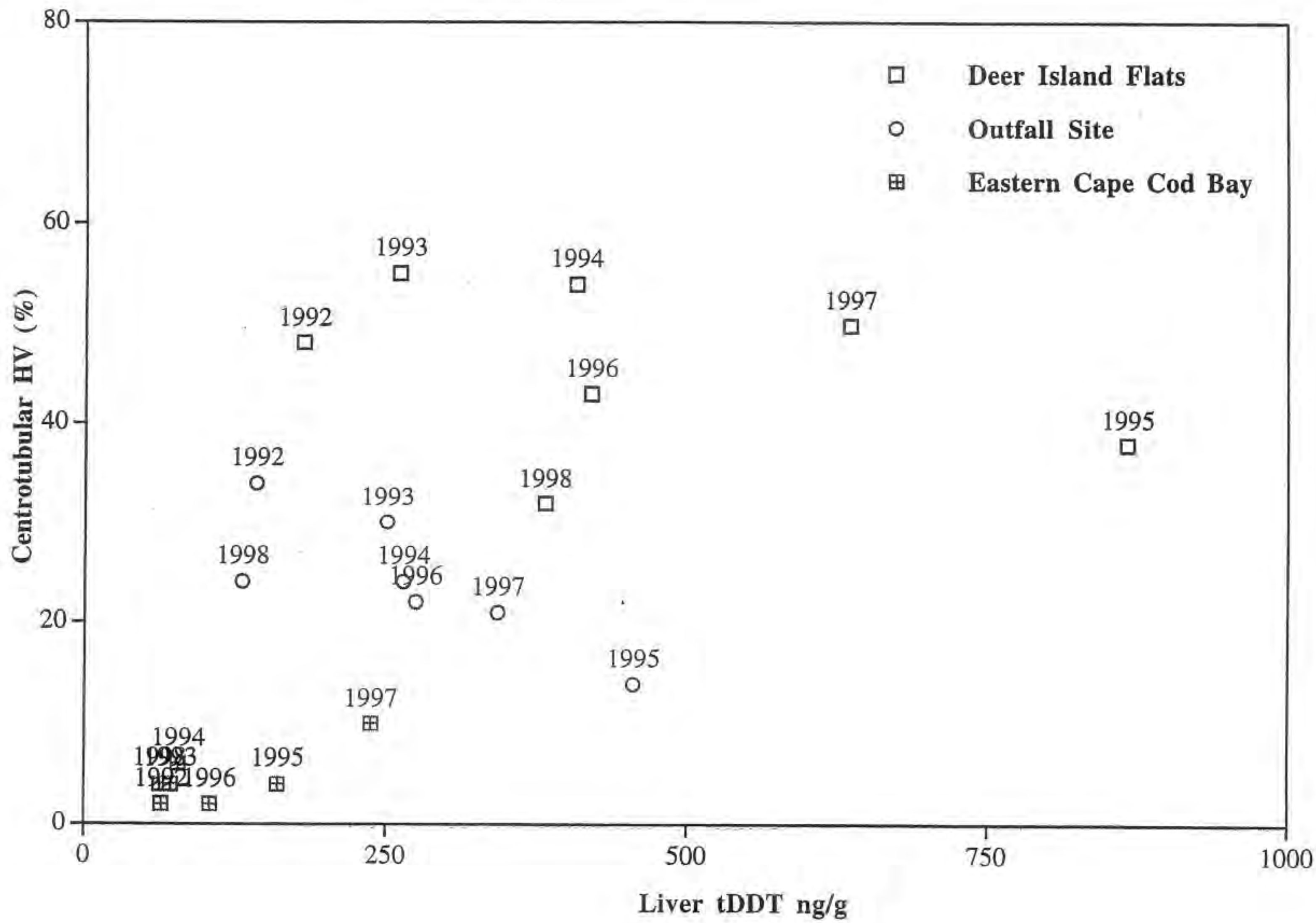
Liver slices examined per fish: 1 for 1987 to 1990, 3 thereafter

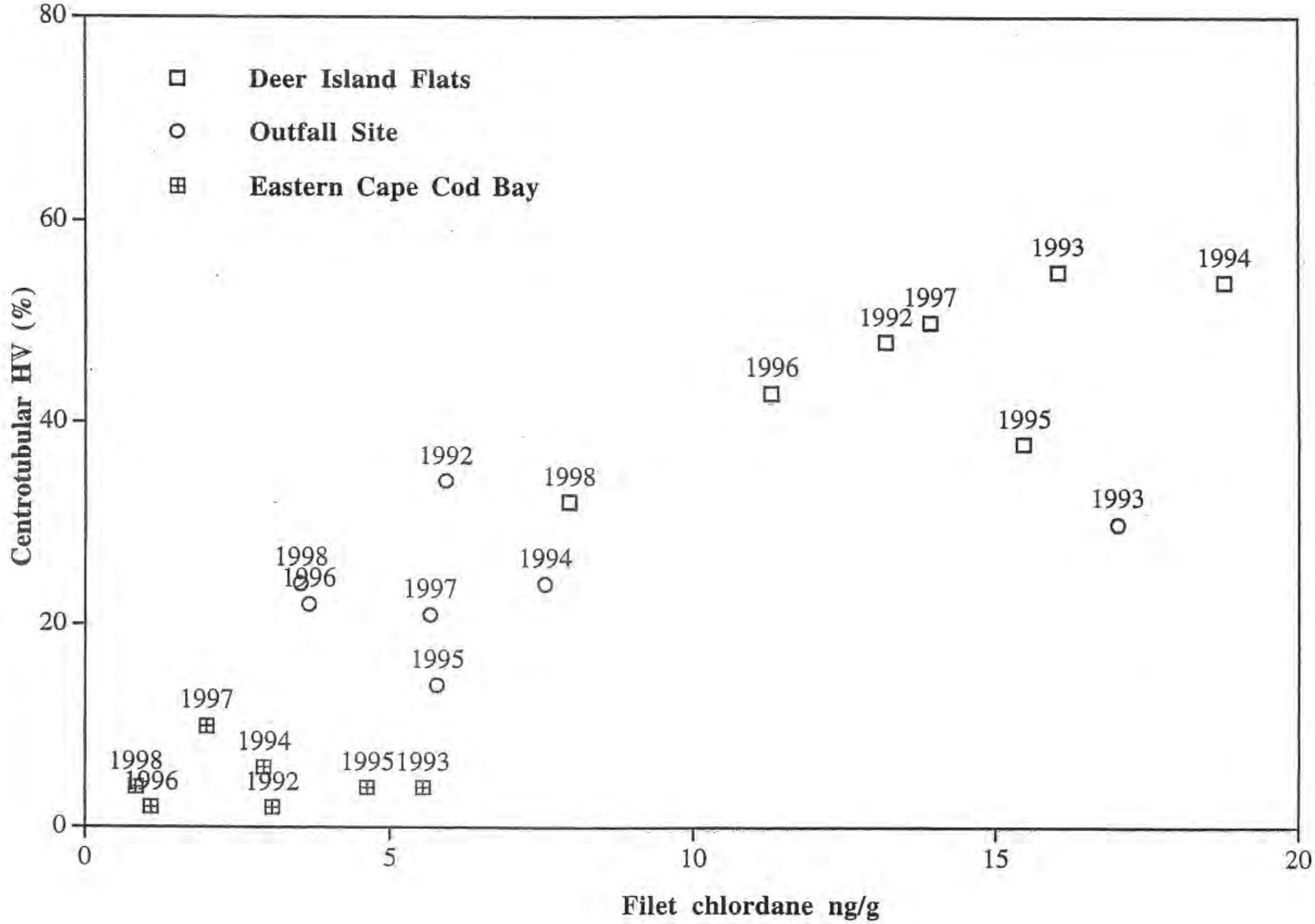

NANTASKET BEACH (STATION 2)
Mean Length (mm)
Mean Age (y.)
Fin Erosion (0-4)
Neoplasia (% prevalence)
Focal Hydropic Vacuolation (% prevalence)
Tubular Hydropic Vacuolation (% prevalence)
Centrotubular Hydropic Vacuolation (% prevalence)
90
91
92
93
94
95
96
97
98
99
Year

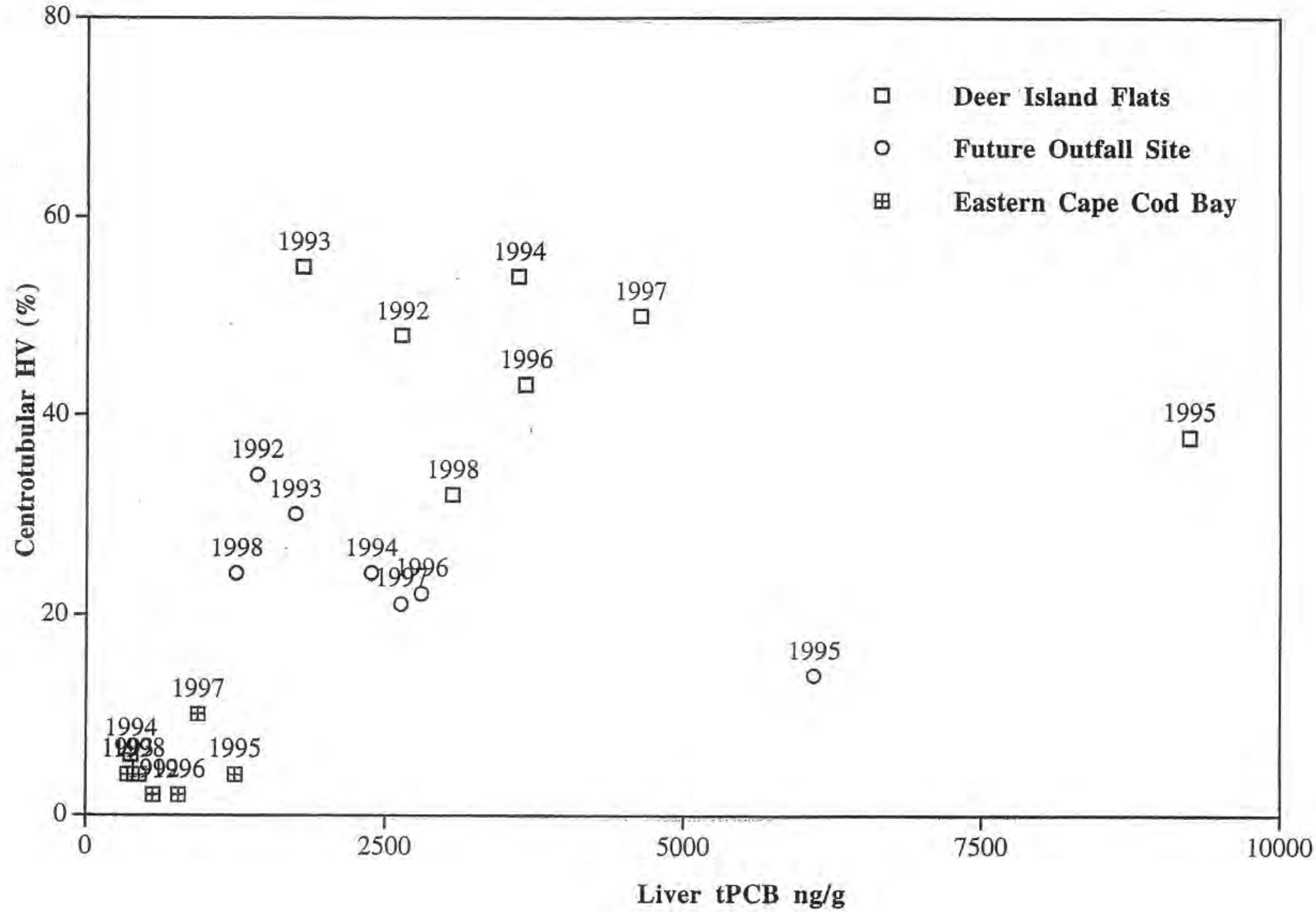

BROAD SOUND (STATION 3)
Mean Length (mm)
Mean Age (y.)
Fin erosion (0-4)
Neoplasia (% prevalence)
Focal Hydropic Vacuolation (% prevalence)
Tubular Hydropic Vacuolation (% prevalence)
Centrotubular Hydropic Vacuolation (% prevalence)
Year

EASTERN CAPE COD BAY (STATION 5)

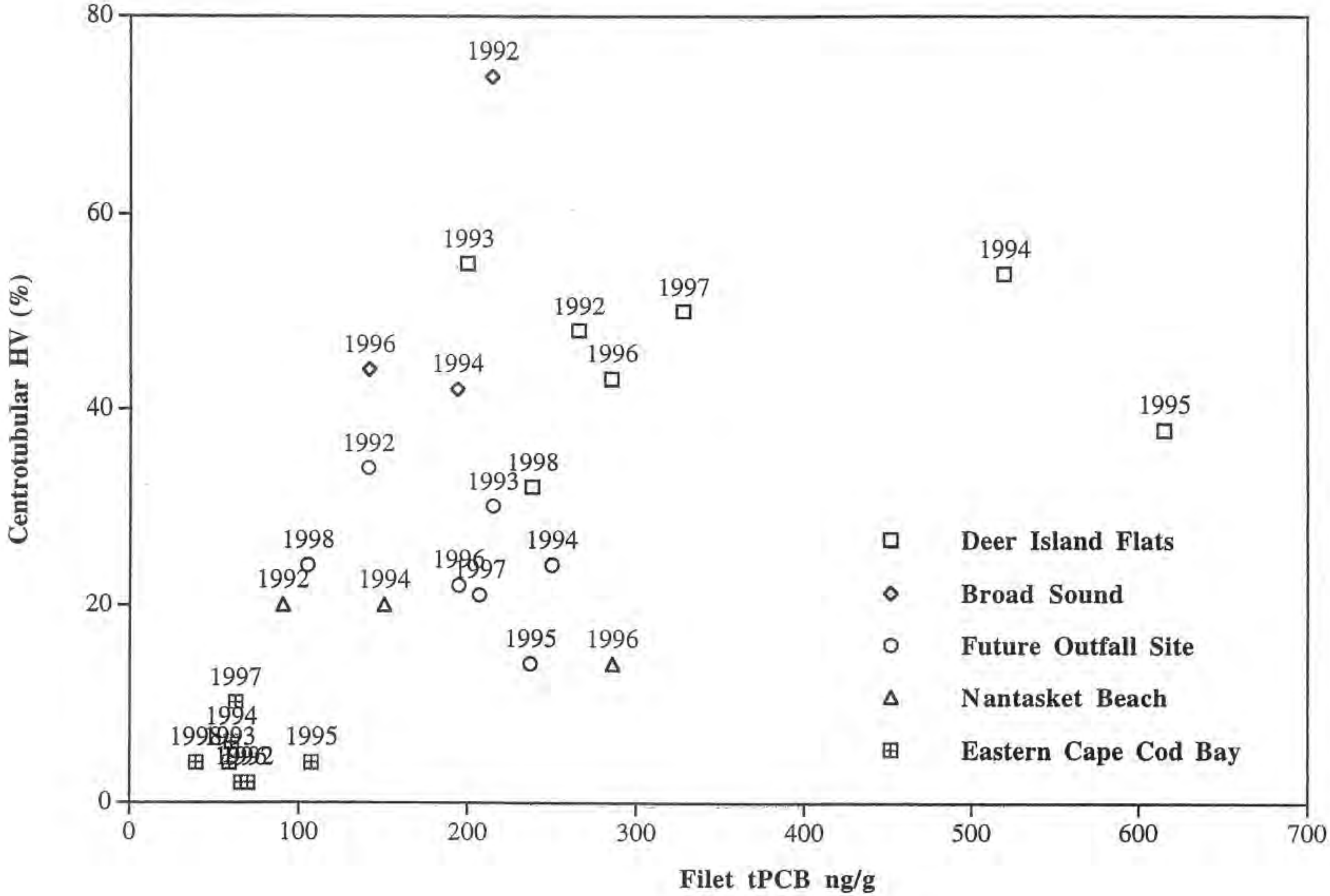


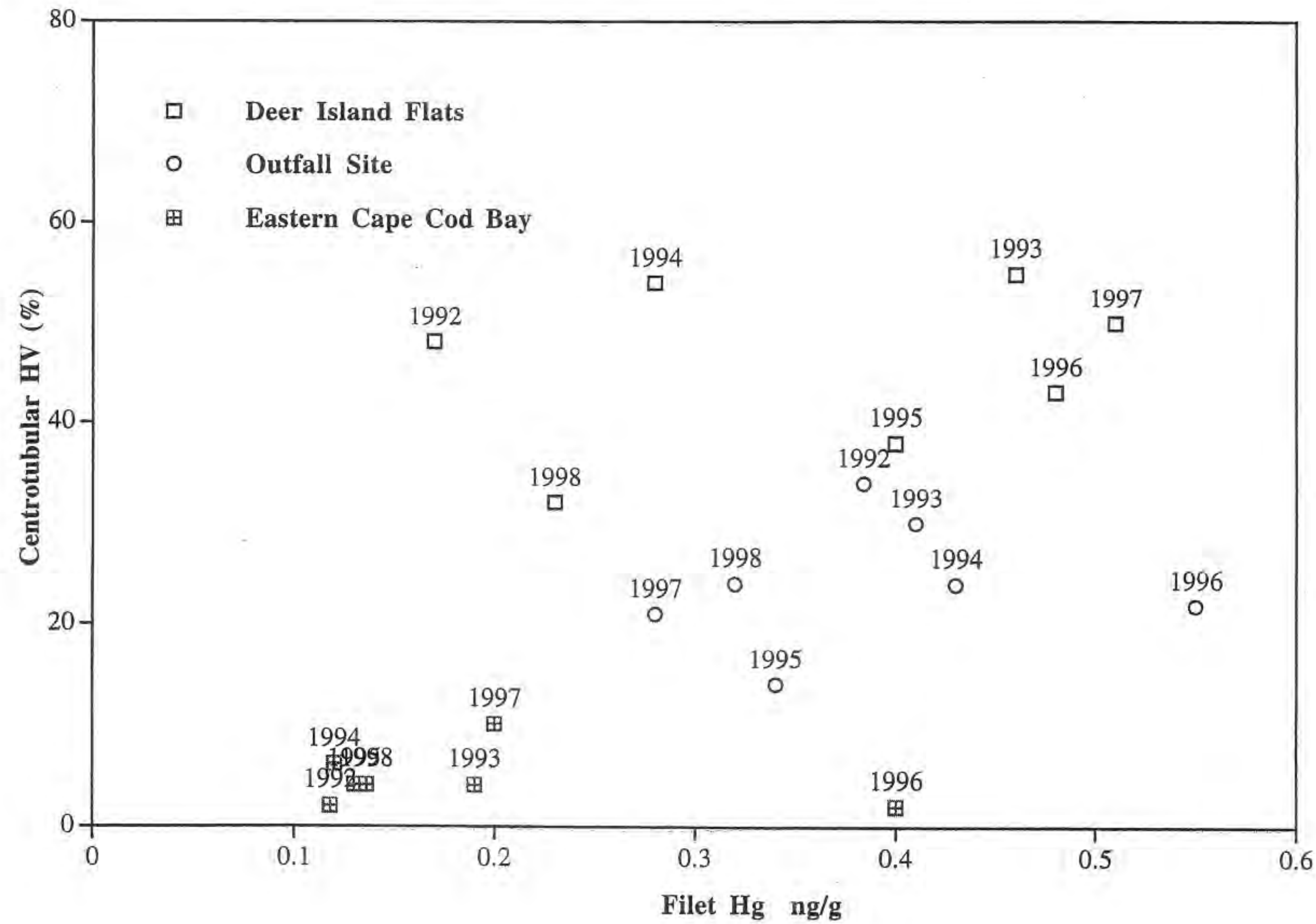

Deer Island Flats
Outfall Site
Eastern Cape Cod Bay
Centrotubular HV (%)
Liver tDDT ng/g
0
20
40
60
80
0
250
500
750
1000
1992
1993
1994
1995
1996
1997
1998

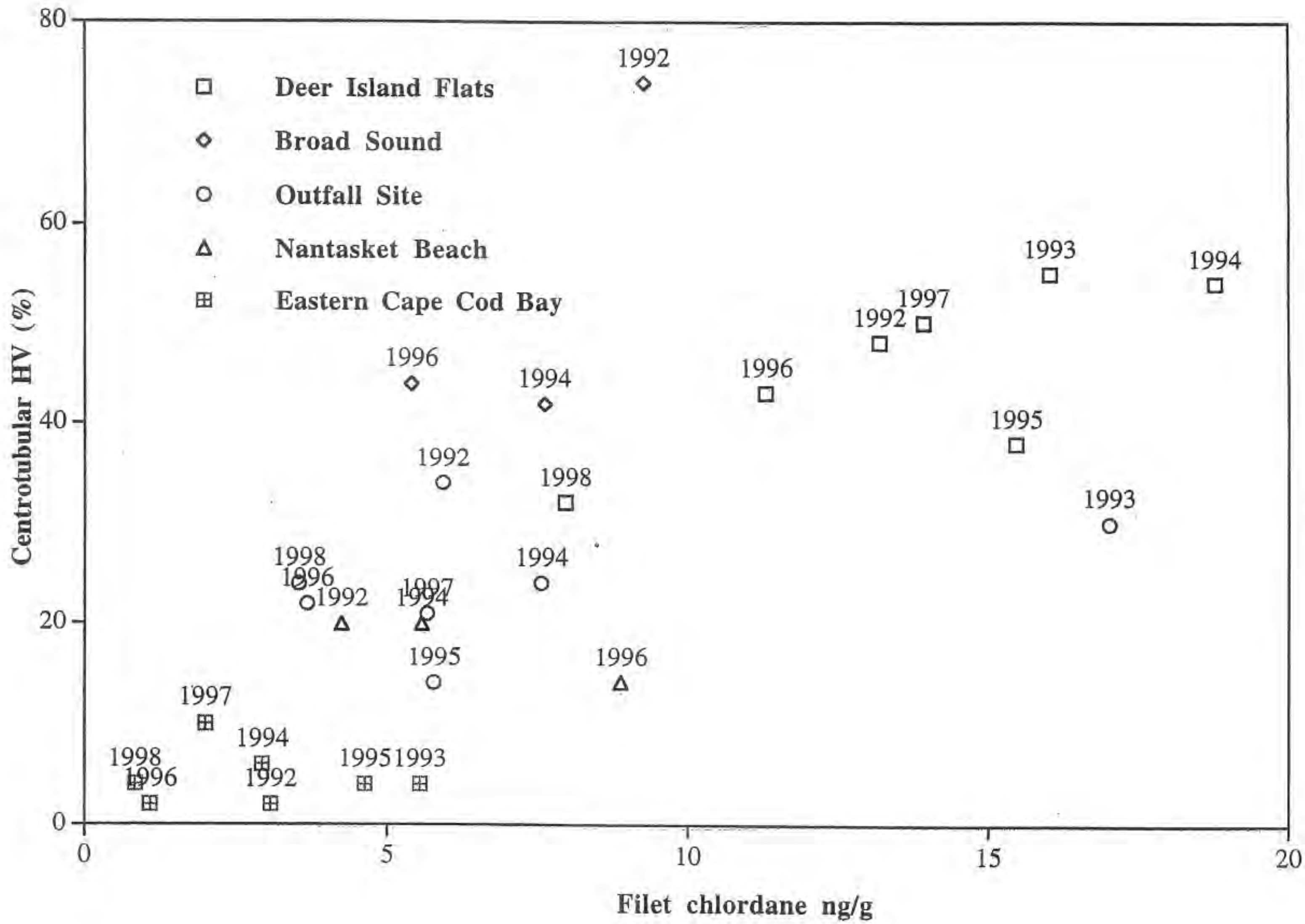

Deer Island Flats
Outfall Site
Eastern Cape Cod Bay
Centrotubular HV (%)
Filet chlordane ng/g
0
20
40
60
80
0
5
10
15
20
1993
1994
1997
1992
1996
1995
1993
1992
1998
1994
1998
1996
1997
1995
1997
1994
1998
1996
1992
1995
1993

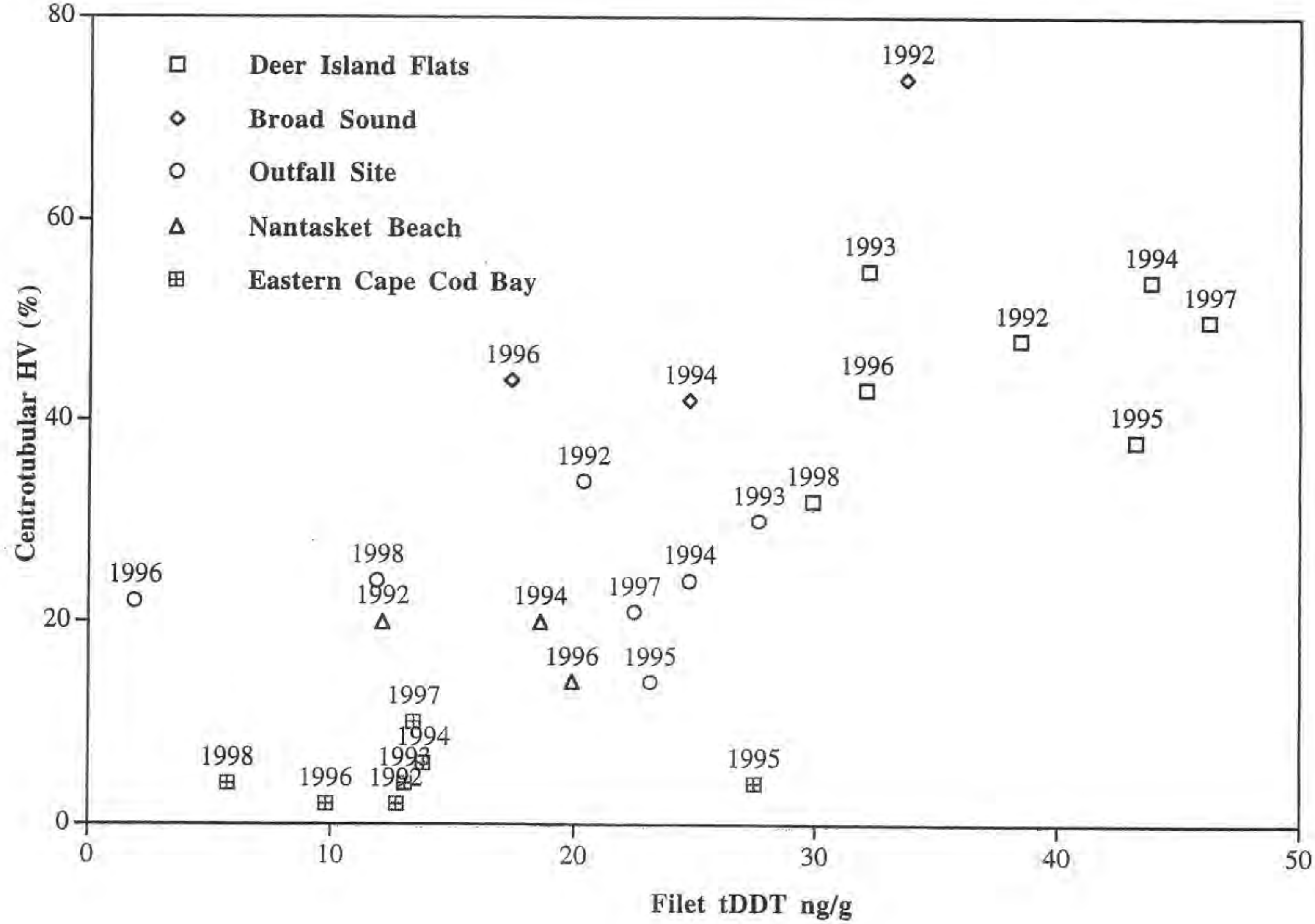


Deer Island Flats
Future Outfall Site
Eastern Cape Cod Bay
Centrotubular HV (%)
Liver tPCB ng/g
0
20
40
60
80
0
2500
5000
7500
10000
1992
1993
1994
1995
1996
1997
1998


Centrotubular HV (%)
Filet tPCB ng/g
Deer Island Flats
Broad Sound
Future Outfall Site
Nantasket Beach
Eastern Cape Cod Bay


Deer Island Flats
Outfall Site
Eastern Cape Cod Bay
Centrotubular HV (%)
Filet Hg ng/g
0
20
40
60
80
0
0.1
0.2
0.3
0.4
0.5
0.6
1992
1993
1994
1995
1996
1997
1998


Deer Island Flats
Broad Sound
Outfall Site
Nantasket Beach
Eastern Cape Cod Bay
Centrotubular HV (%)
Filet chlordane ng/g
0
20
40
60
80
0
5
10
15
20
1992
1993
1994
1995
1996
1997
1998



Deer Island Flats
Broad Sound
Outfall Site
Nantasket Beach
Eastern Cape Cod Bay
Centrotubular HV (%)
Filet tDDT ng/g
0
20
40
60
80
0
10
20
30
40
50
1992
1993
1994
1995
1996
1997
1998

Water Column Monitoring and Nutrient Cycling

Modeling Results for 1993 and 1994 *(Mr. Jim Fitzpatrick, HydroQual)*

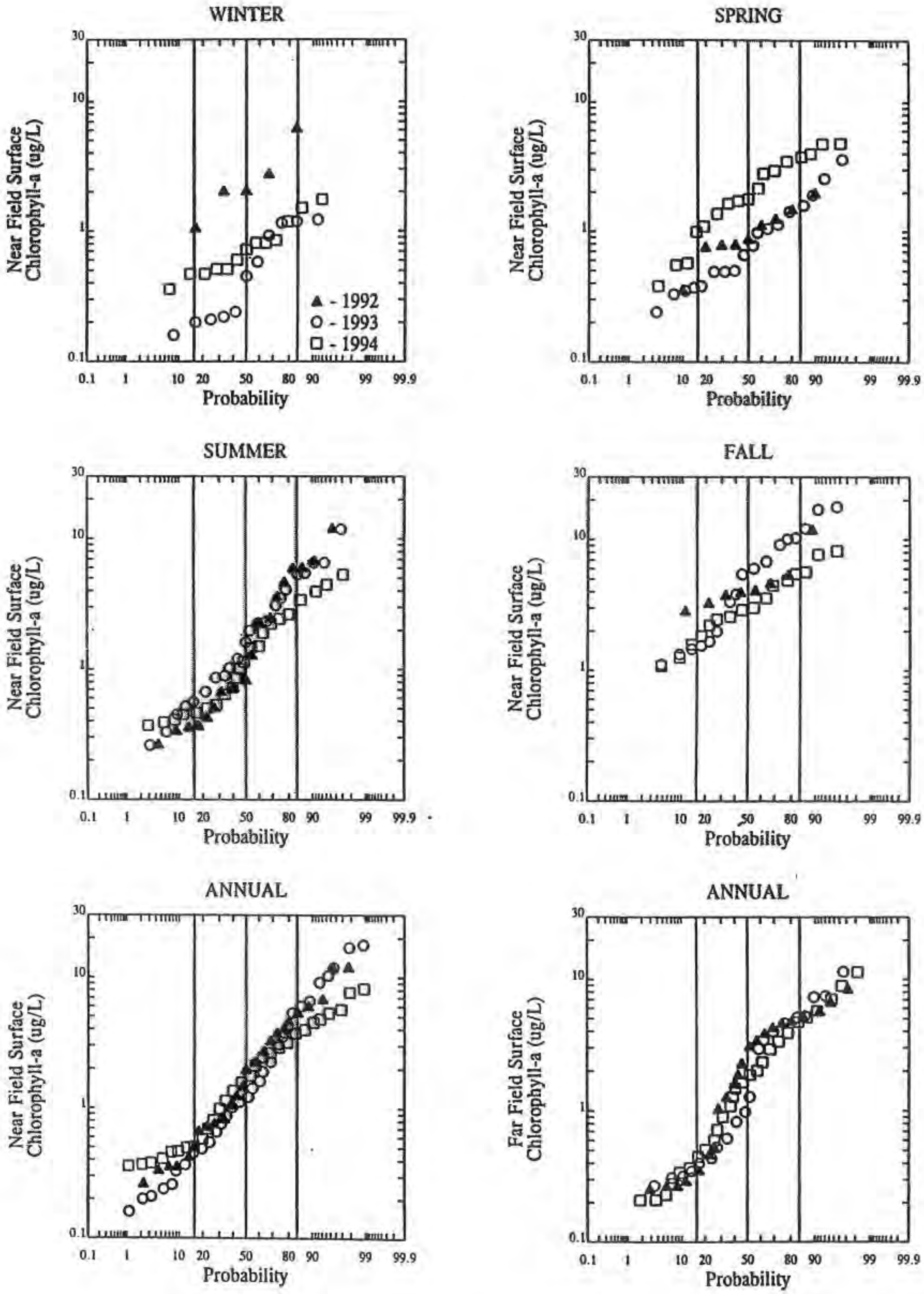


Figure 3-11. Seasonal and Annual Probability Distributions of Surface Chlorophyll-a

Surface Chl-a 1992 -1994

Kelly et al
Cibik et al

△ - 1992
○ - 1993
□ - 1994

nearfield - seasonal

nearfield, farfield - annual

- different years dominated different seasons

winter 1992
spring 1994
fall 1993 - high conc in 1993

Asterionellopsis

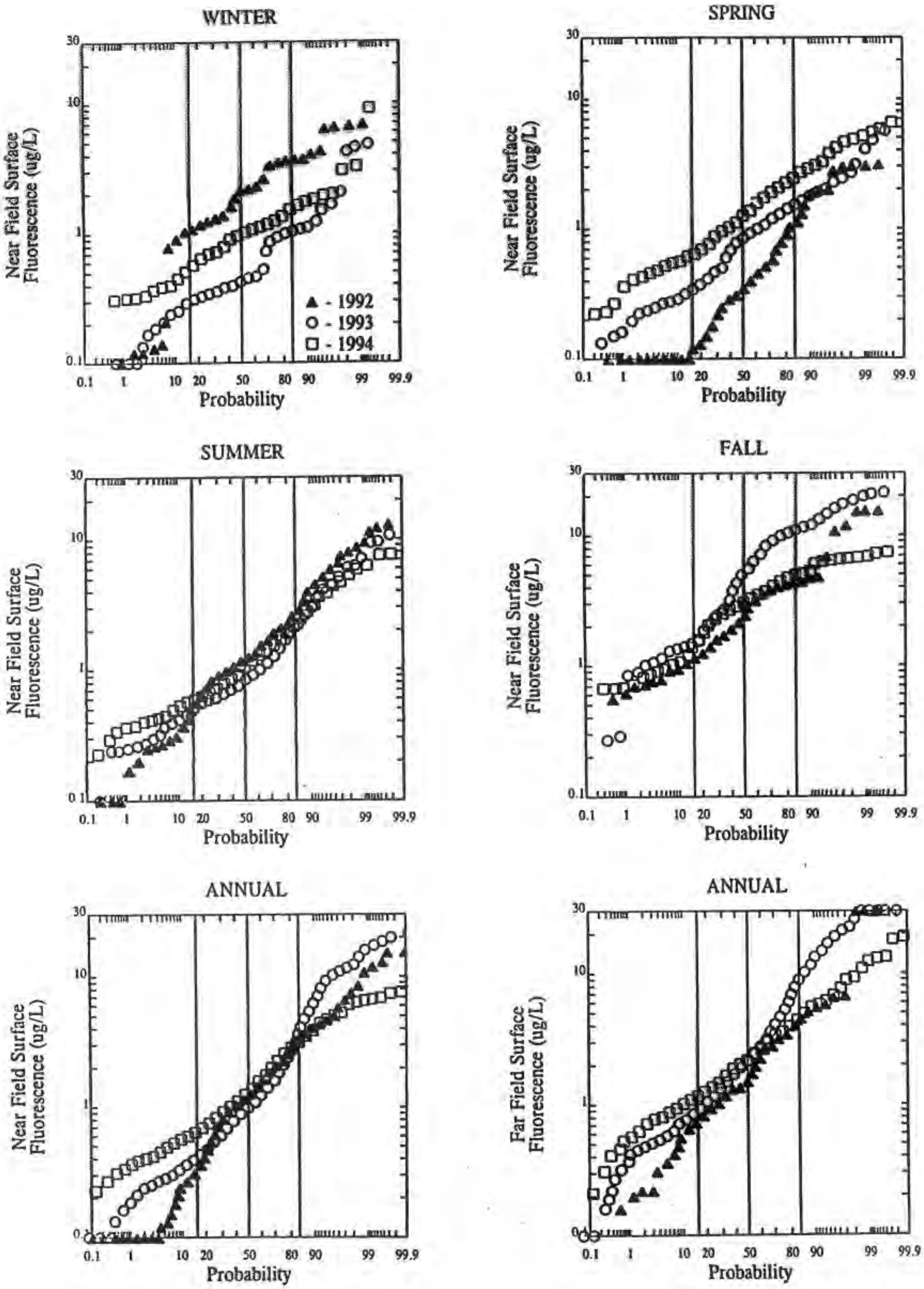


Figure 3-13. Seasonal and Annual Probability Distributions of Surface Fluorescence

- a little more obvious in the fluorescence data

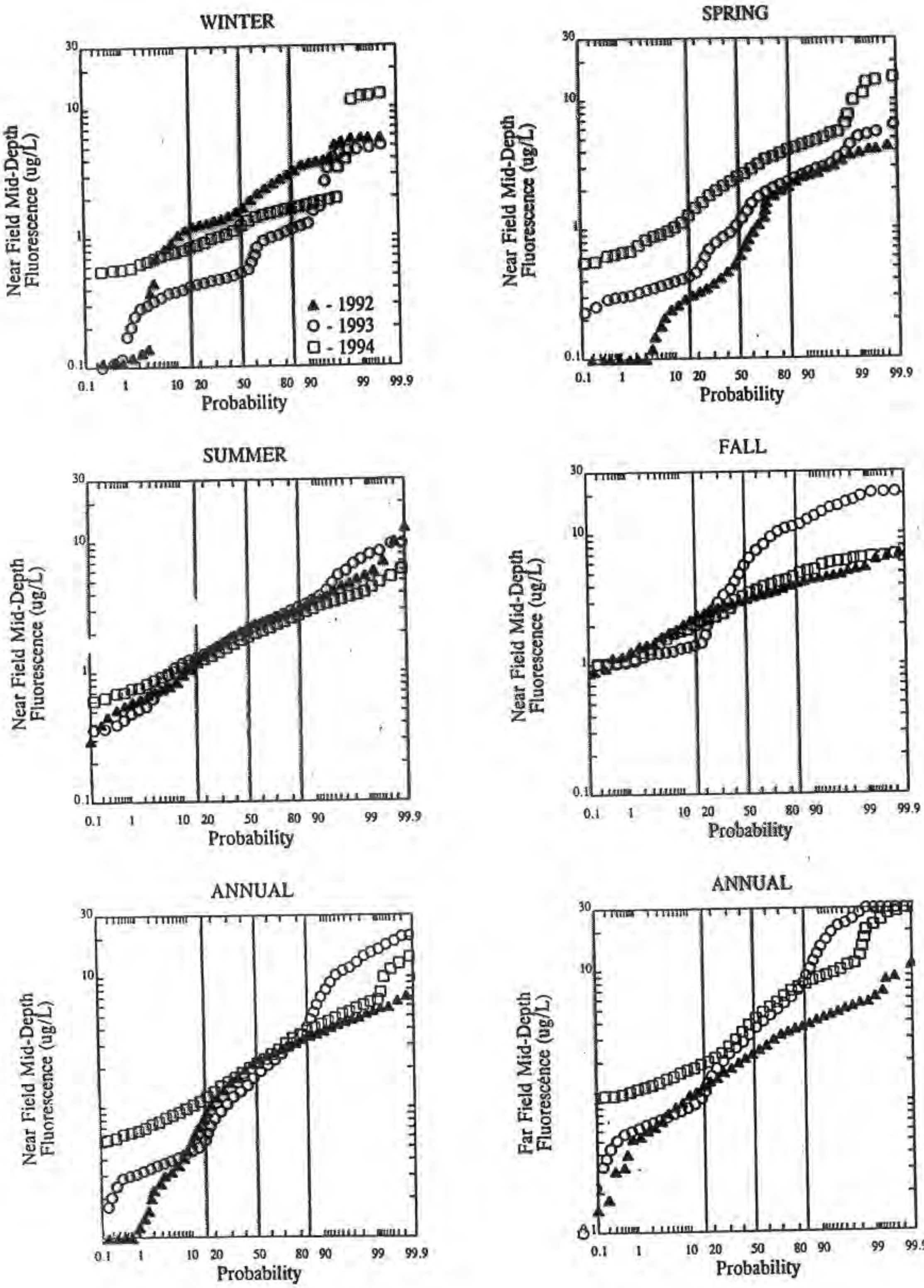


Figure 3-14. Seasonal and Annual Probability Distributions of Mid-Depth Fluorescence

- Again you can see it in the mid-depth fluorescence

- So there is evidence that blooms occur at different times during the three years

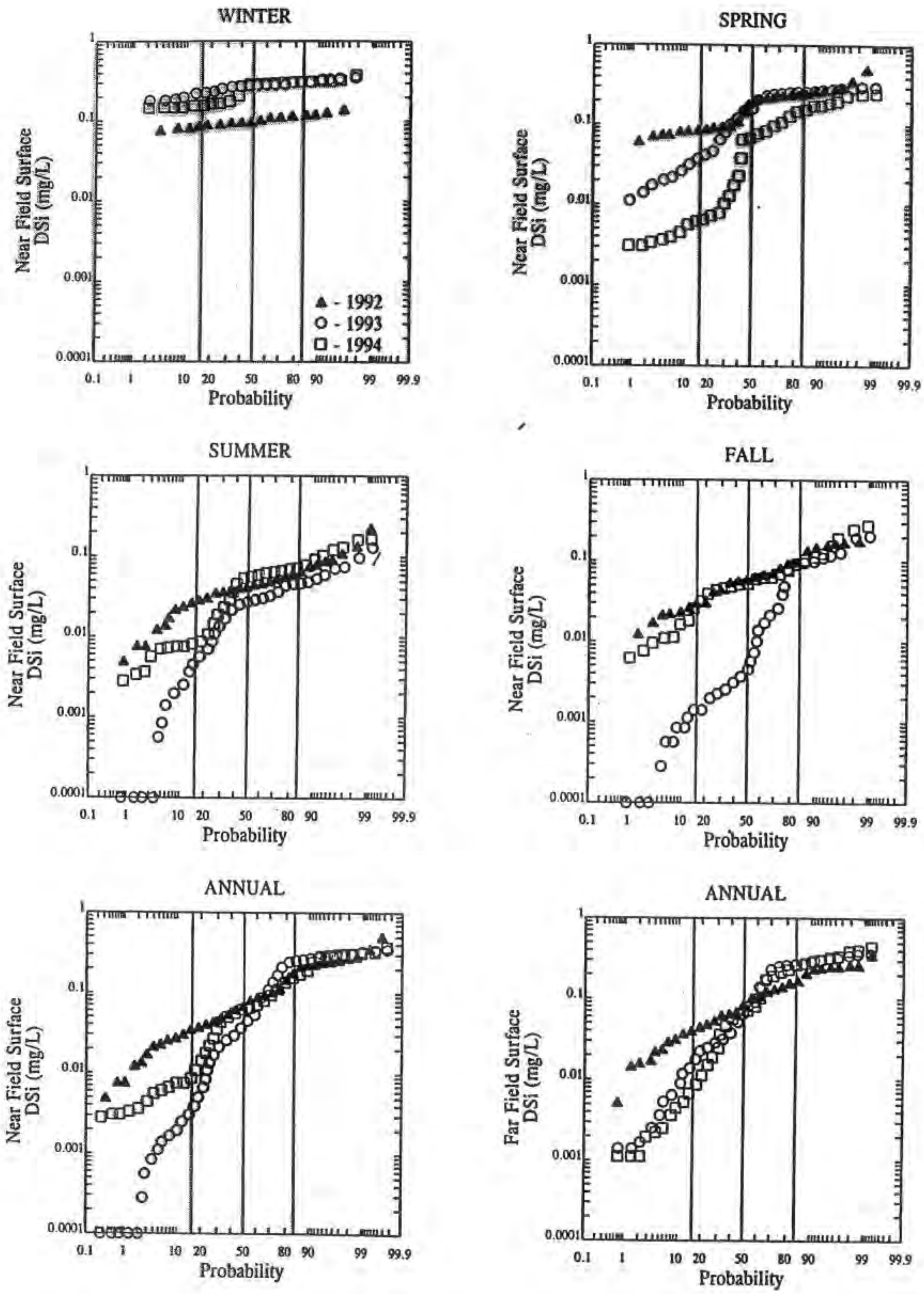


Figure 3-18. Seasonal and Annual Probability Distributions of Surface DSi

- Differences in Surface ΔSi
- Appear to be associated with blooms
- Probably dealing with diatom blooms

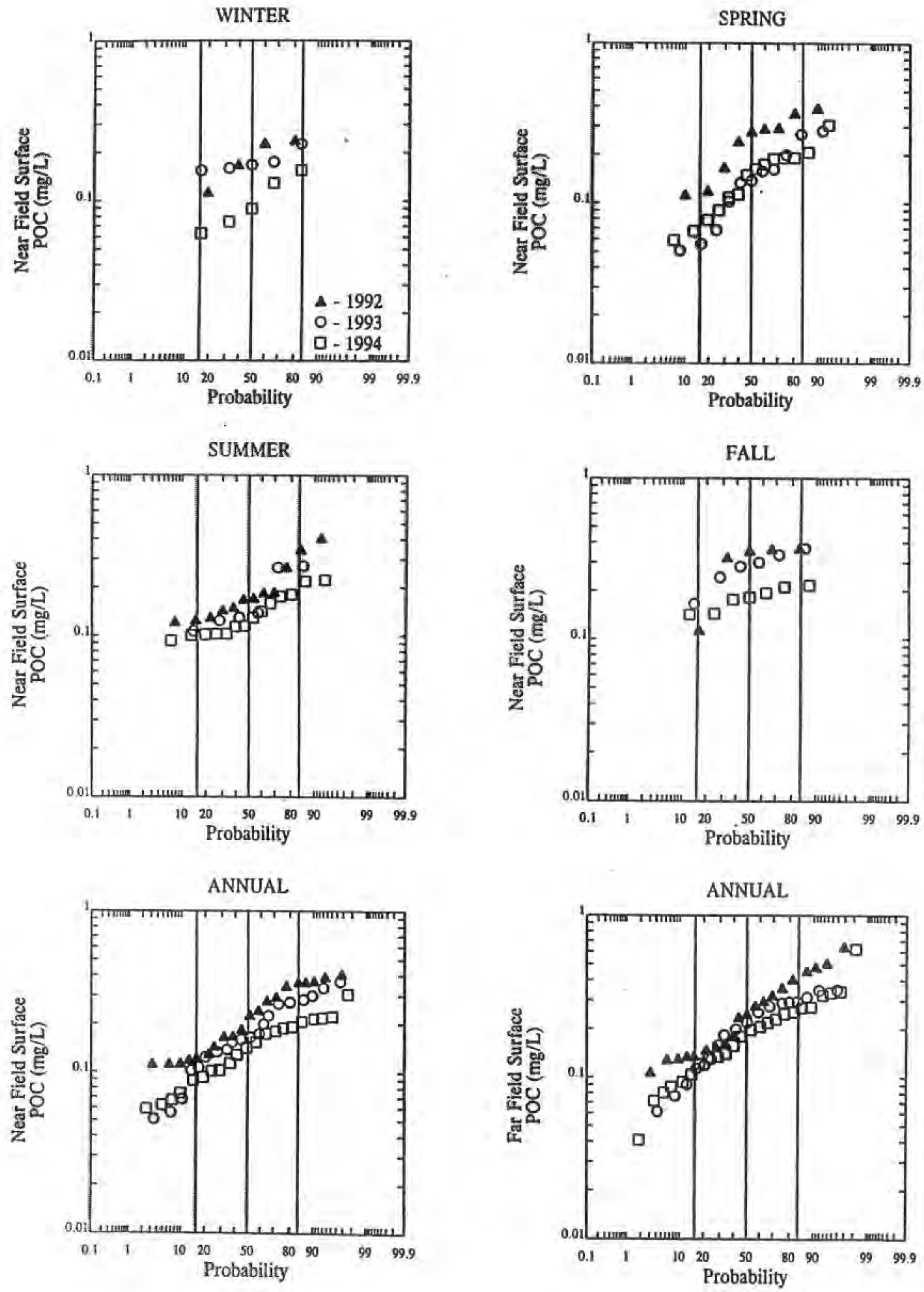


Figure 3-15. Seasonal and Annual Probability Distributions of Surface POC

- POC data are more sparse but the evidence of different amounts of biomass are not as clear

- Possibly different species with different C:Chl

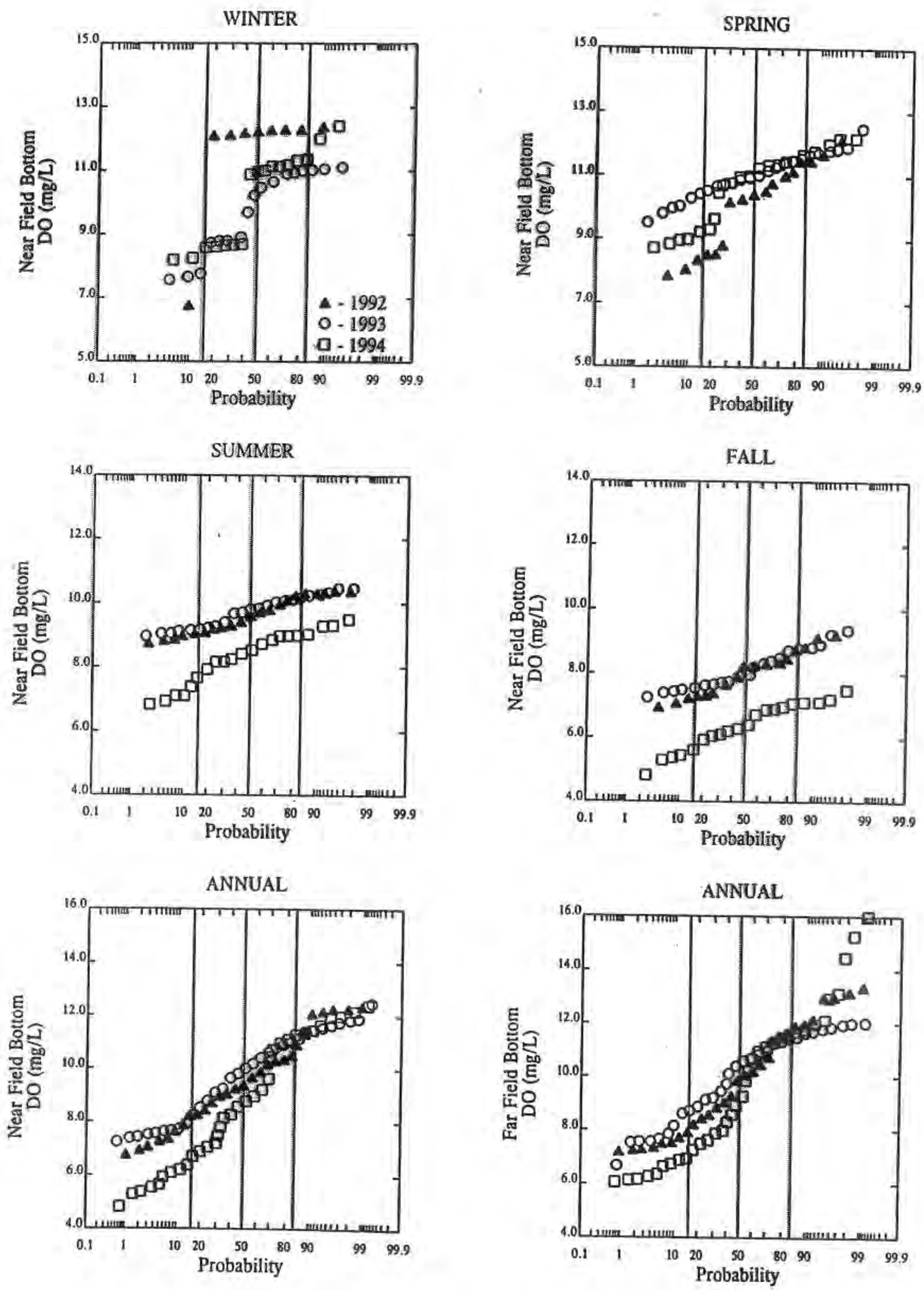


Figure 3-21. Seasonal and Annual Probability Distributions of Bottom DO

- Observed differences in bottom DO
- especially Summer and Fall 1994
- The gap increase from summer to fall so the rate of ~~dec~~ decline is not the same from year to year
- Standard never < 6.0 mg/L
- MWRA could potentially have been blamed
- Data shows natural variability such as the does occur without the relocated outfall
- Low DO's observed more often in the nearfield location
- Why lower DO in 1994?

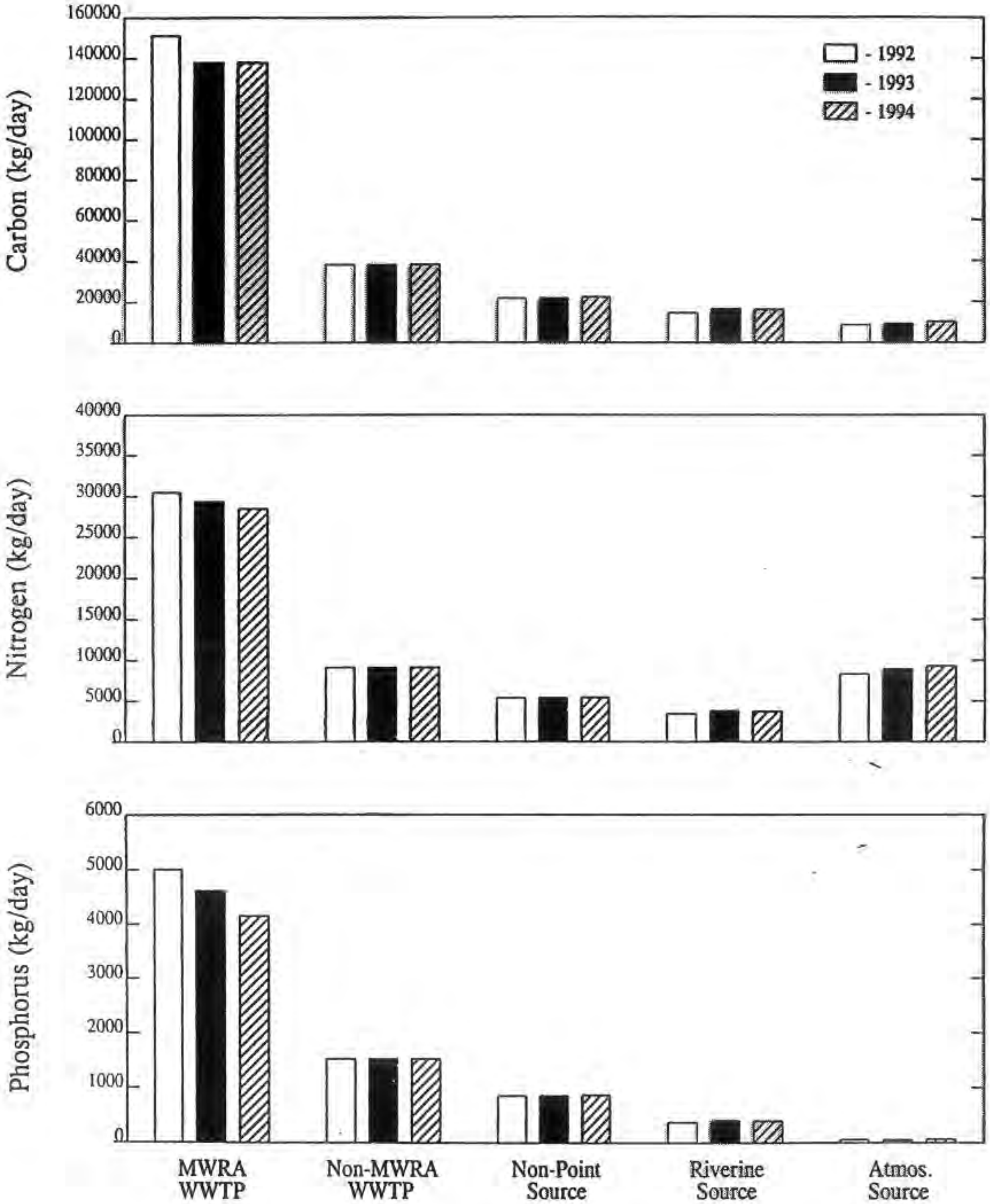


Figure 2-1. Loading Comparison of Sources for 1992 through 1994

- Loading Similar between the 3 years

  - 1992
  - 1993
  - 1994

- Similar River Flows

- Similar meteorological forcings

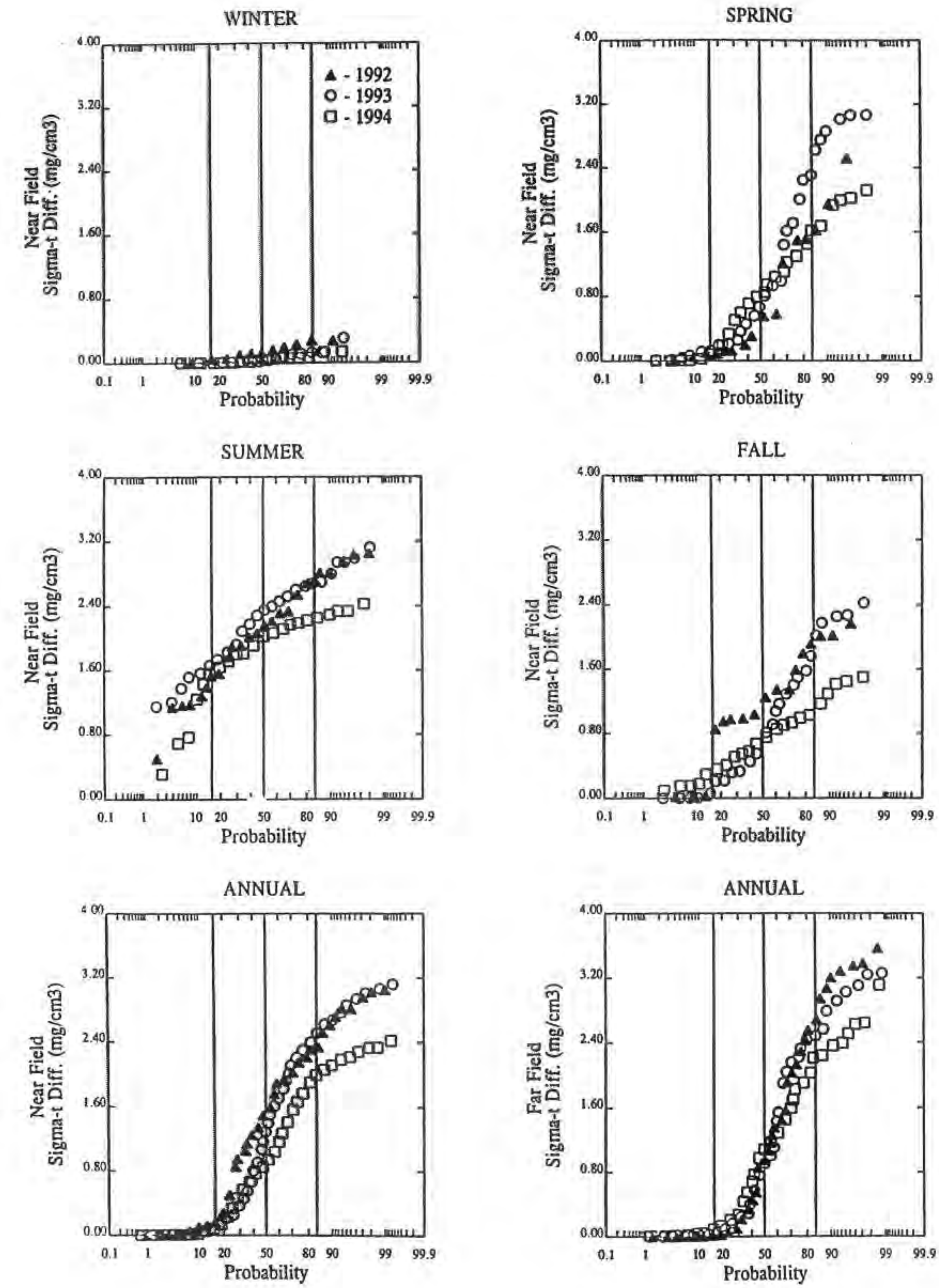


Figure 3-10. Seasonal and Annual Probability Distributions of Density Stratification

- Lower DO trapped in bottom waters for a longer period of time

- higher temps at the same time as higher salinity

- less stratification 1994

- higher sal could be indicitive of ocean water from boundary

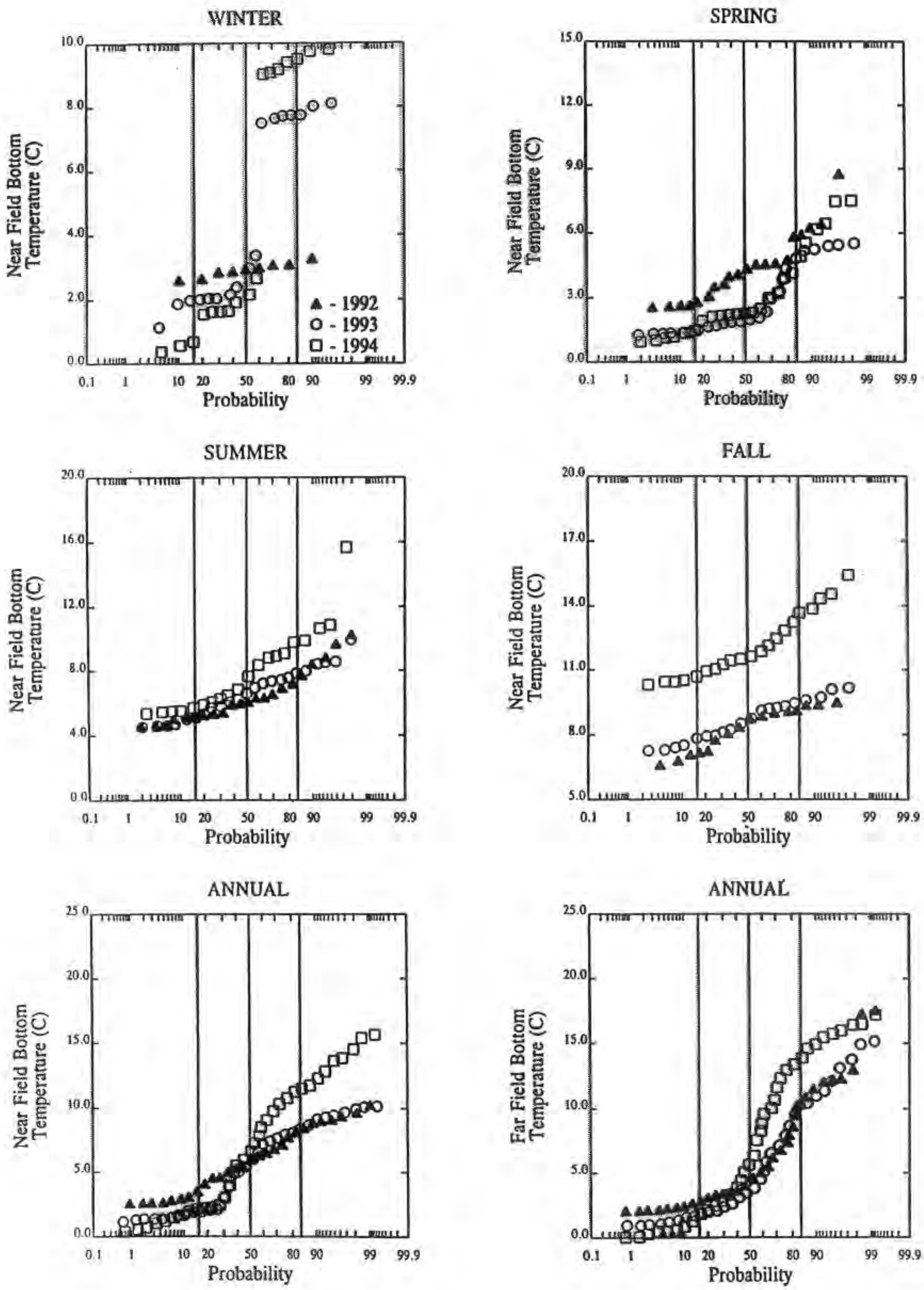


Figure 3-5. Seasonal and Annual Probability Distributions of Bottom Temperature

- Temperature ?
- Higher bottom Temp
- Surface Temps Similar
- More mixing ? -
- warm temps from boundary ?

- Could contribute to higher oxidation rates

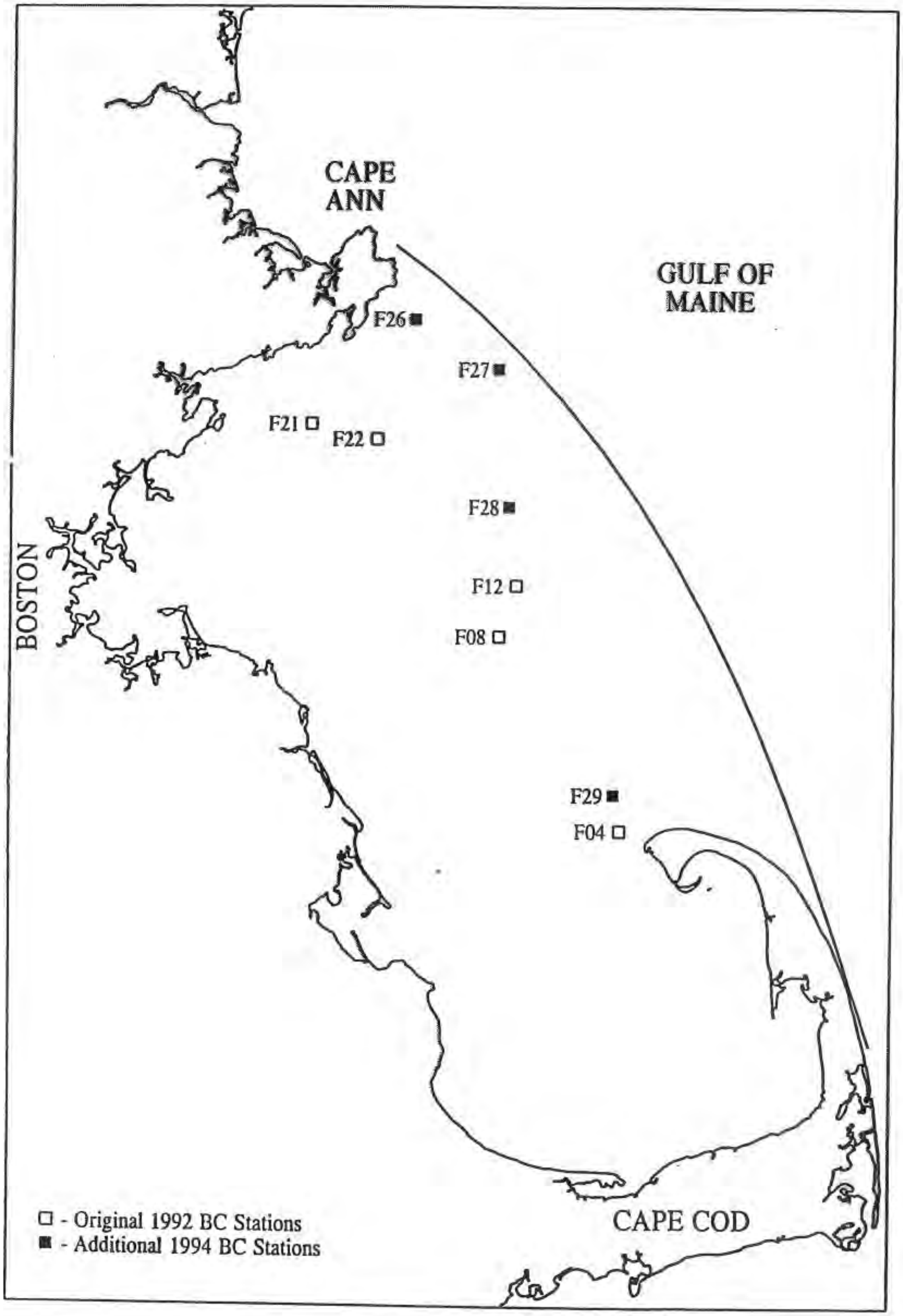


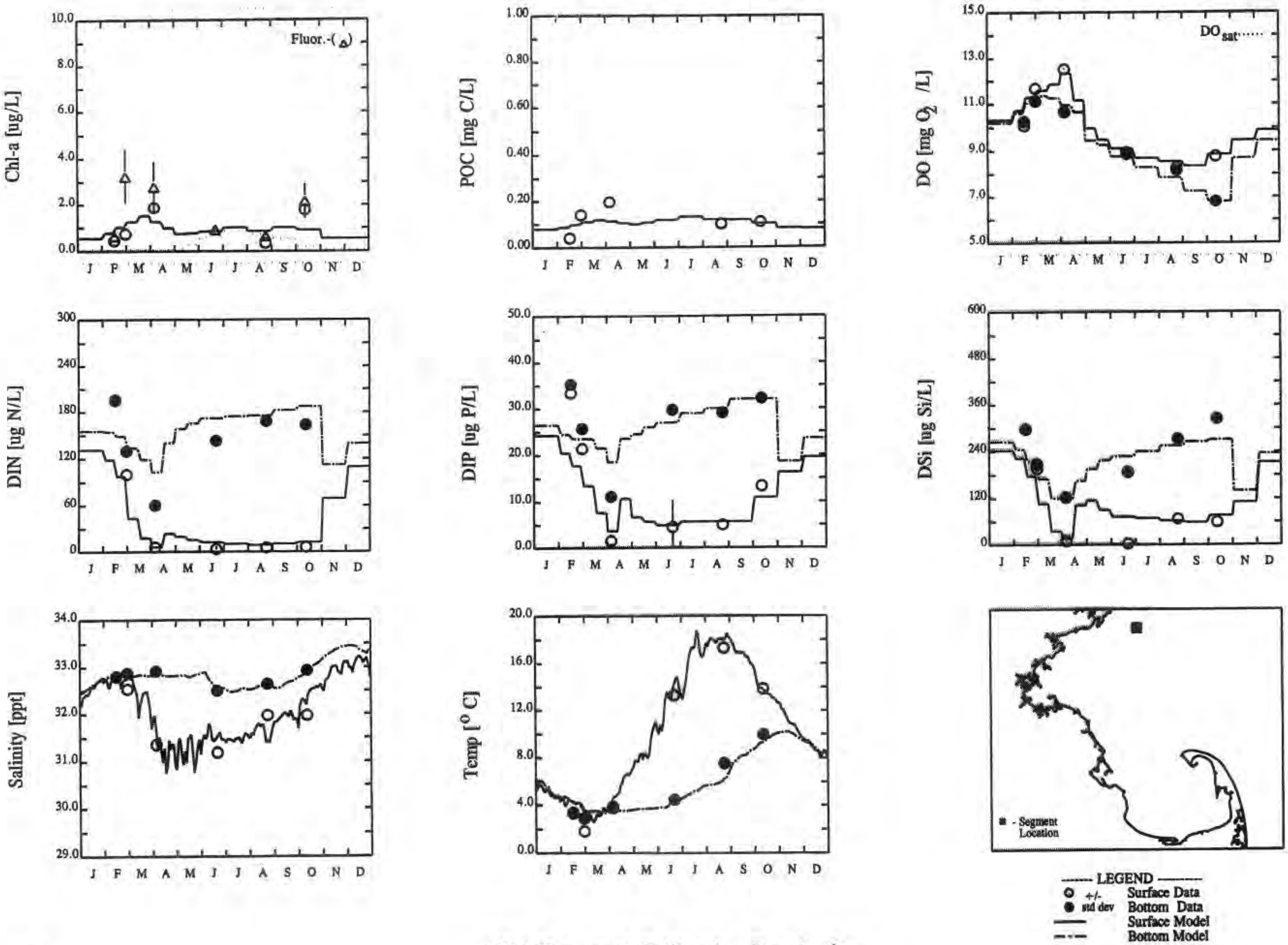
Figure 3-22. Stations Used for Boundary Condition Data

- How ~~can~~ will the model reproduce different conditions if the forcings are the same

- Boundary Conditions ?

- ~~Lo~~ Large Open Boundary

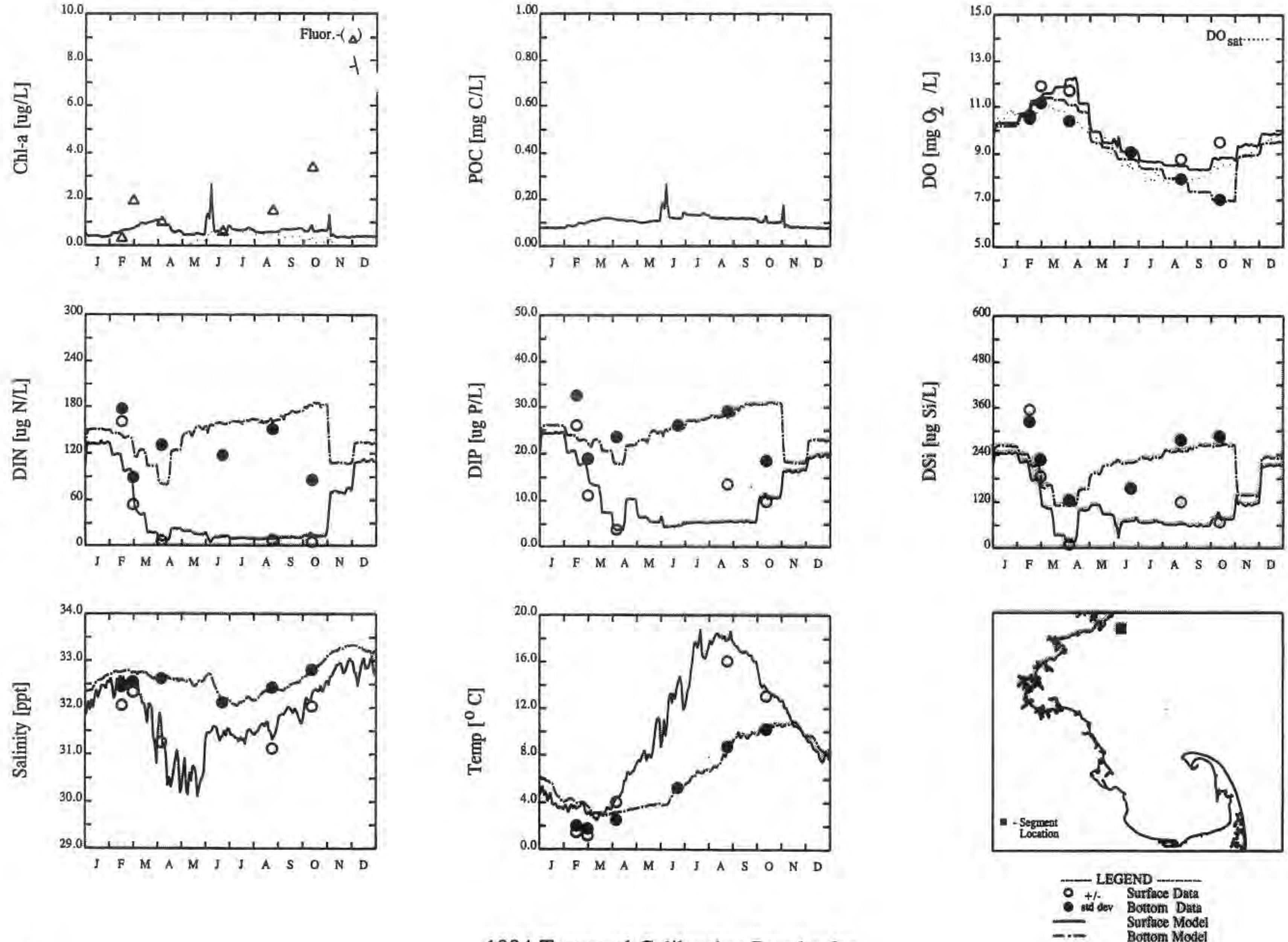
- Limited Data



1994 Temporal Calibration Results for
Grid Cell (19,17) Vs Data Station F27

171

DATE: Sun Apr 11 TIME: 12:34:44
Run No.



1994 Temporal Calibration Results for
Grid Cell (18,18) Vs Data Station F26

172

DATE: Sun Apr 11 TIME: 18:29:45

Run No.

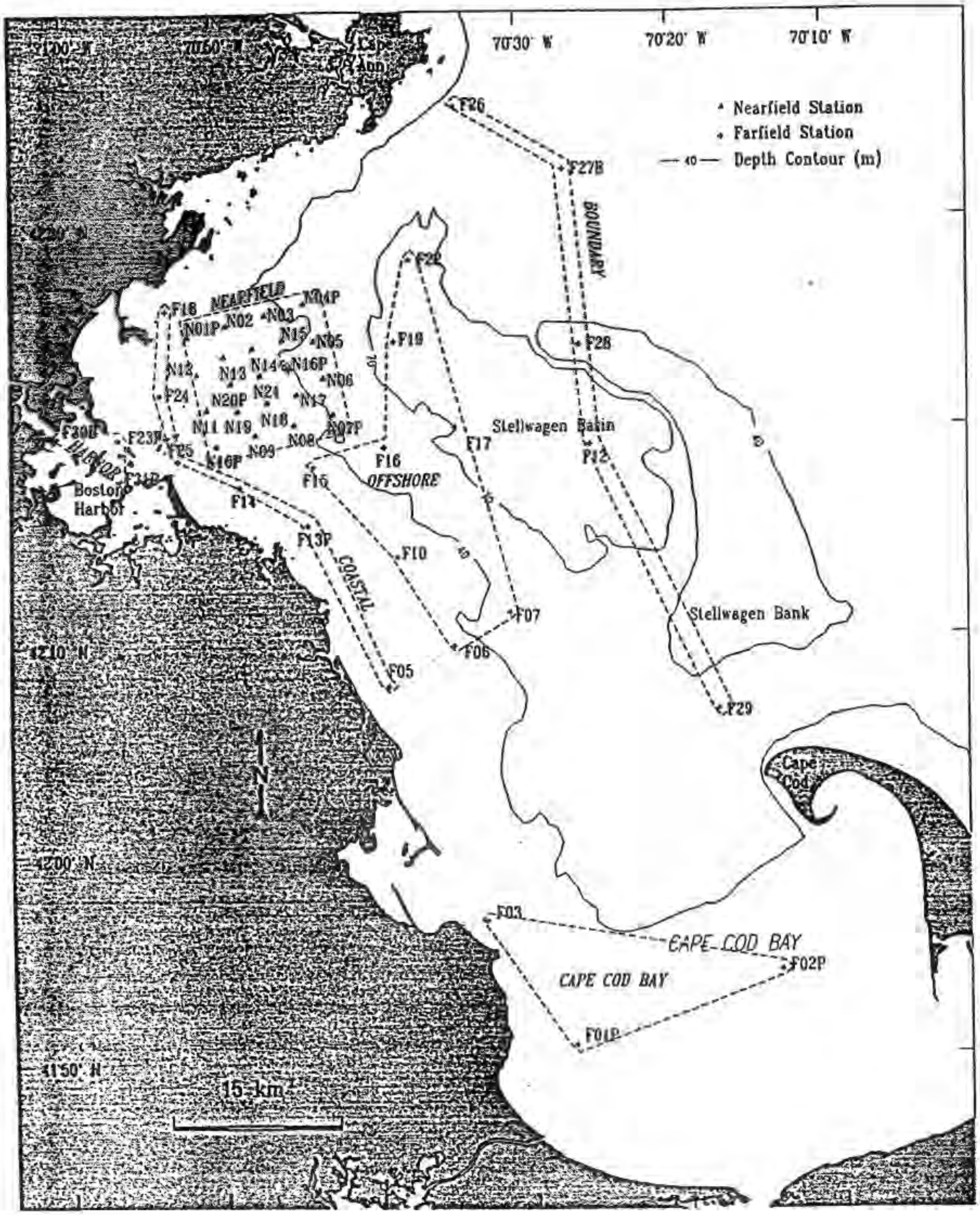
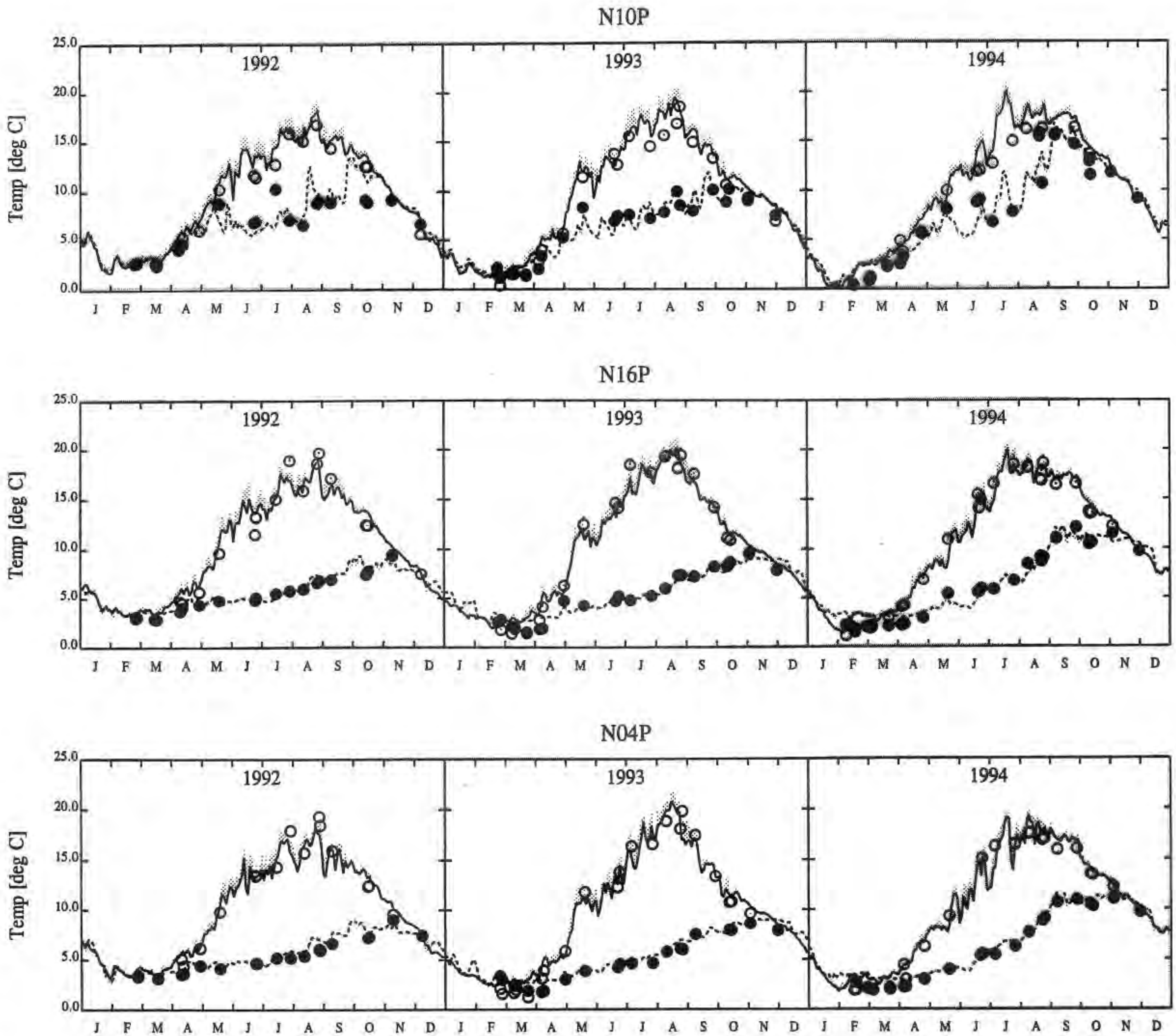


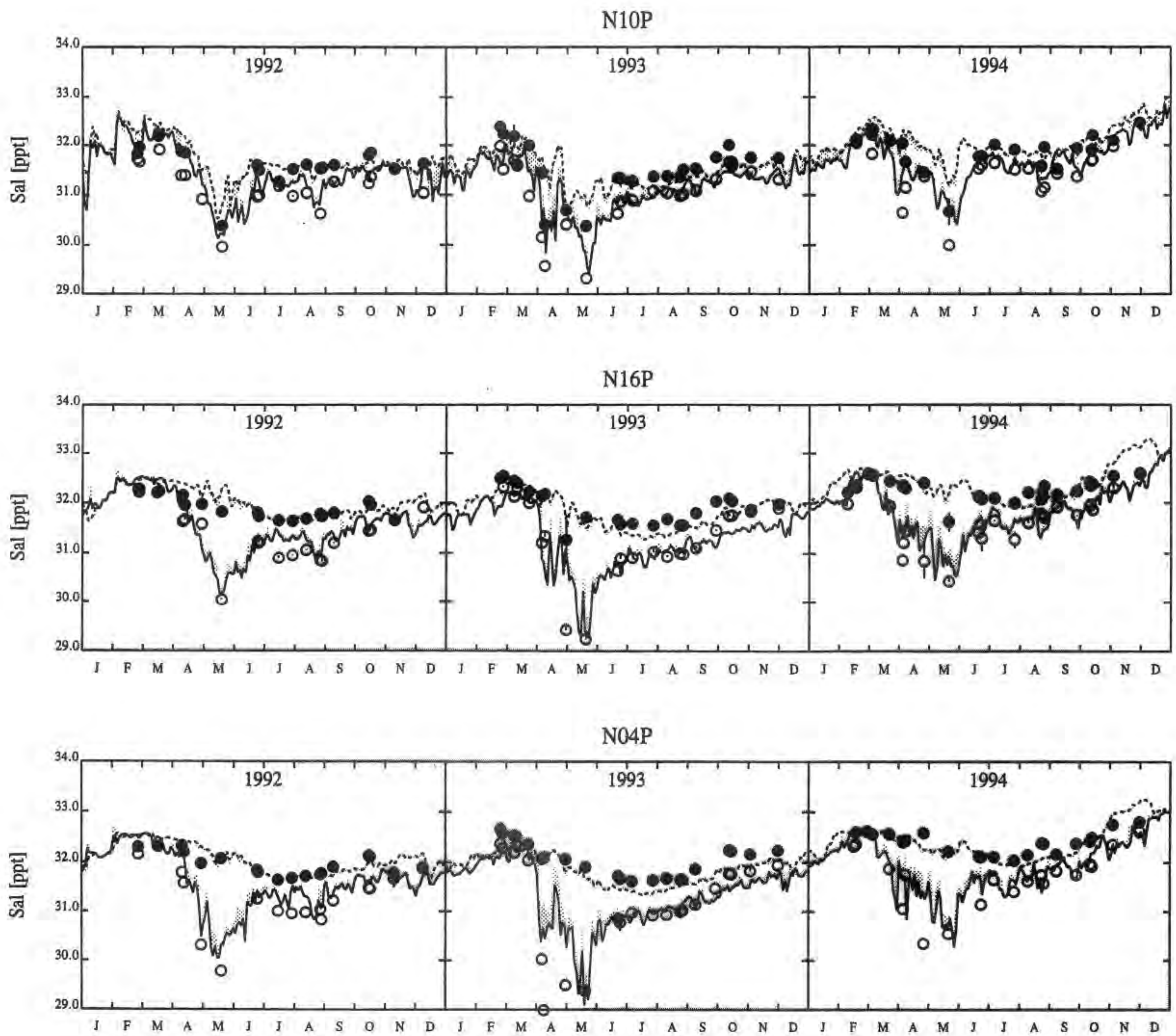
Figure 3-2. Water Quality Sampling Stations in Massachusetts and Cape Cod Bays 1994

173

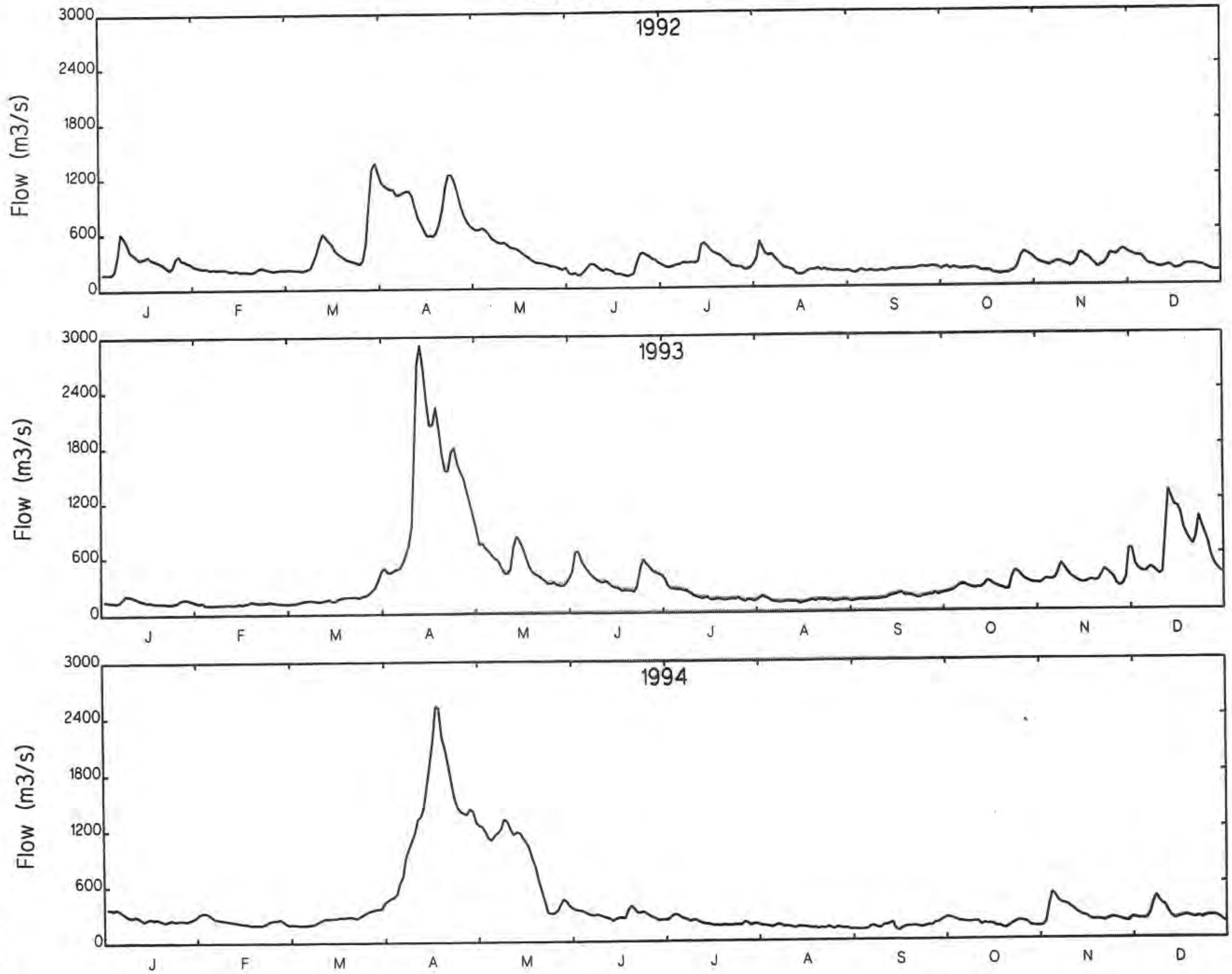
- 1994 stations locations modified to improve boundary conditions

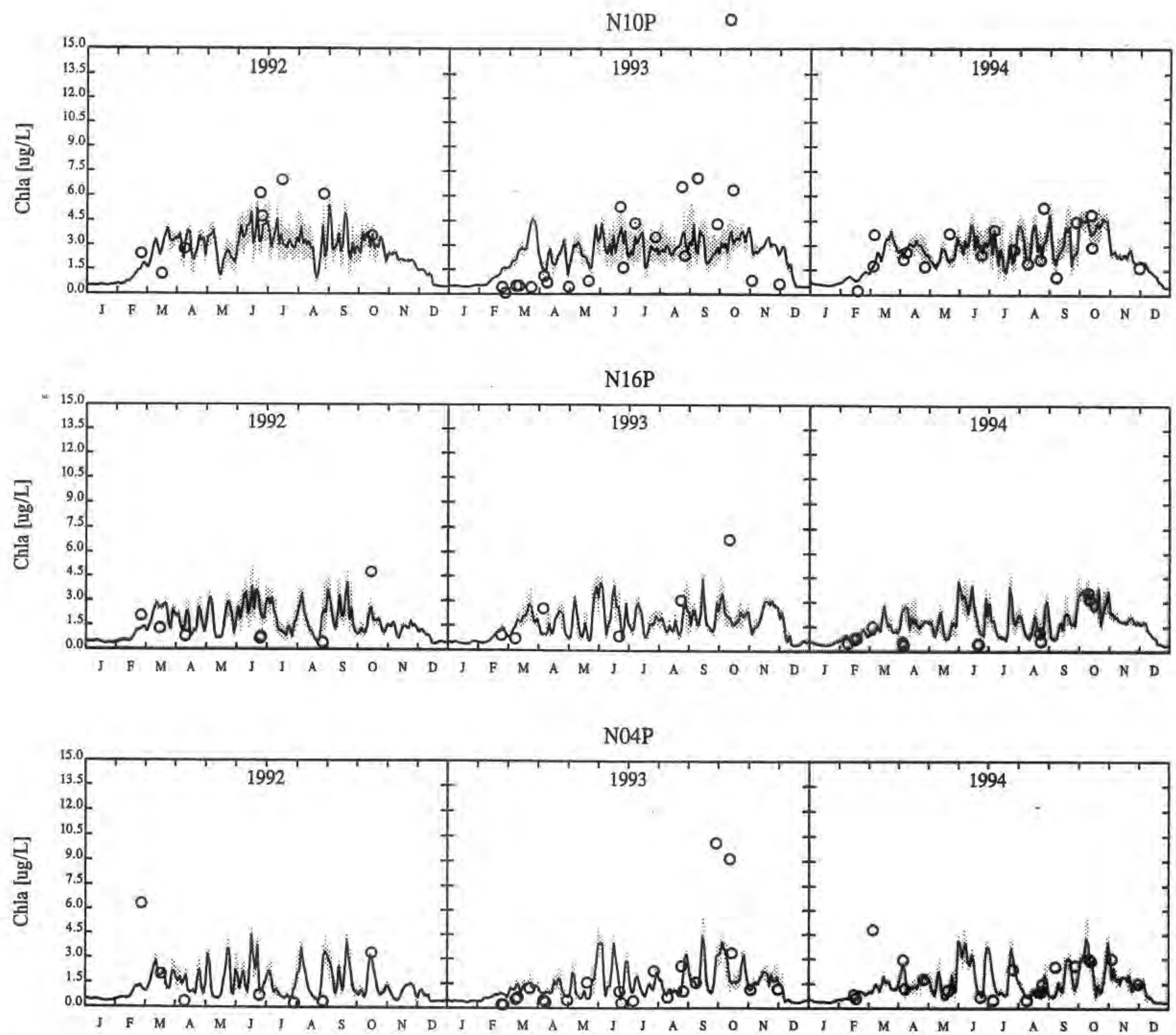
- With improved BC and new Hydro we decided to rerun 1992 as we modeled 1993 and 1994

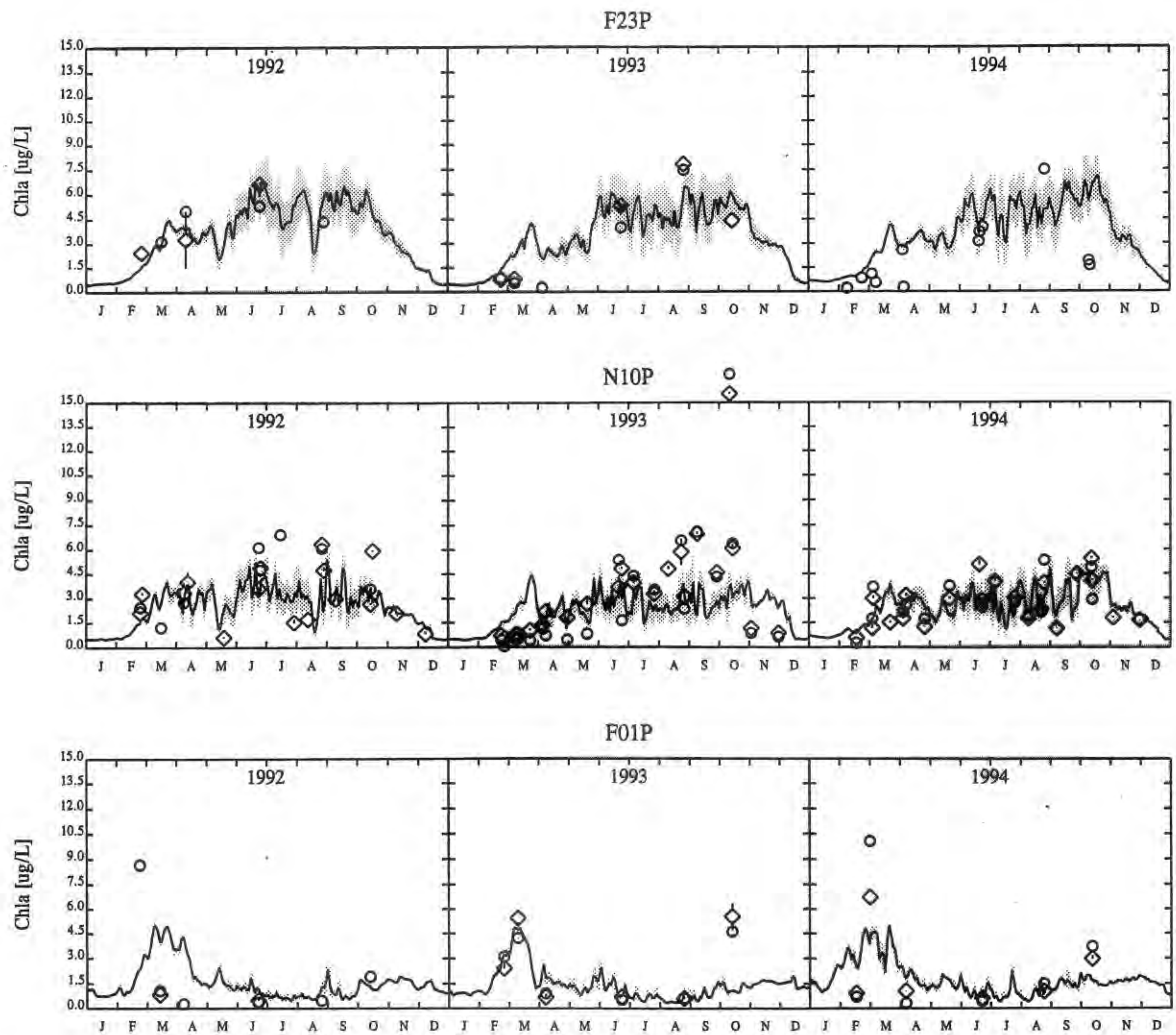

N10P
N16P
N04P
Temp [deg C]
1992
1993
1994
J F M A M J J A S O N D

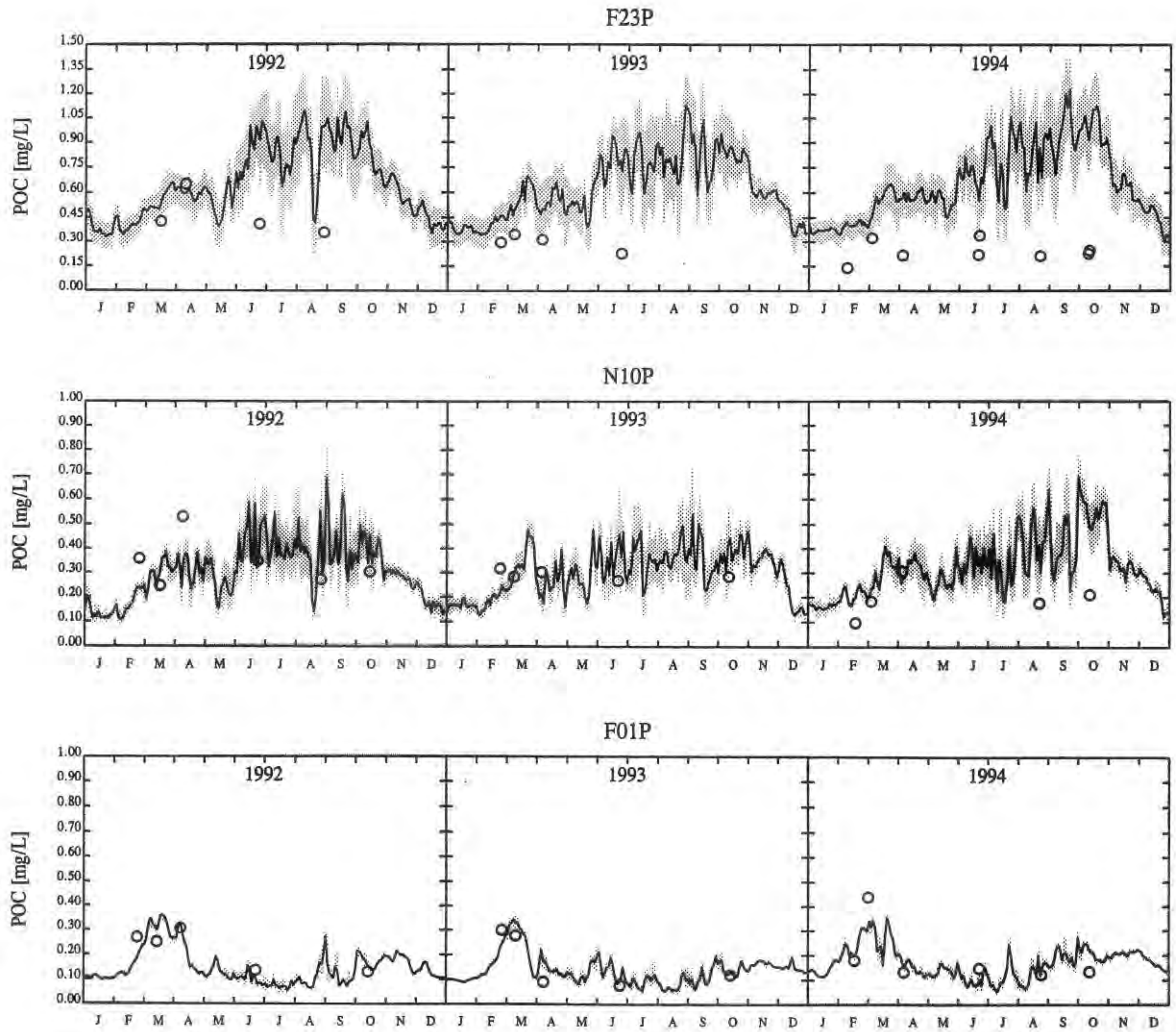

N10P
N16P
N04P
Sal [ppt]
1992
1993
1994
J F M A M J J A S O N D

Penobscot River Flow




N10P
N16P
N04P
1992
1993
1994
Chla [ug/L]
15.0
13.5
12.0
10.5
9.0
7.5
6.0
4.5
3.0
1.5
0.0
J F M A M J J A S O N D


F23P
N10P
F01P
1992
1993
1994
Chla [ug/L]
15.0
13.5
12.0
10.5
9.0
7.5
6.0
4.5
3.0
1.5
0.0
J F M A M J J A S O N D


F23P
N10P
F01P
POC [mg/L]
1992
1993
1994
J F M A M J J A S O N D
1.50 1.35 1.20 1.05 0.90 0.75 0.60 0.45 0.30 0.15 0.00
1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00

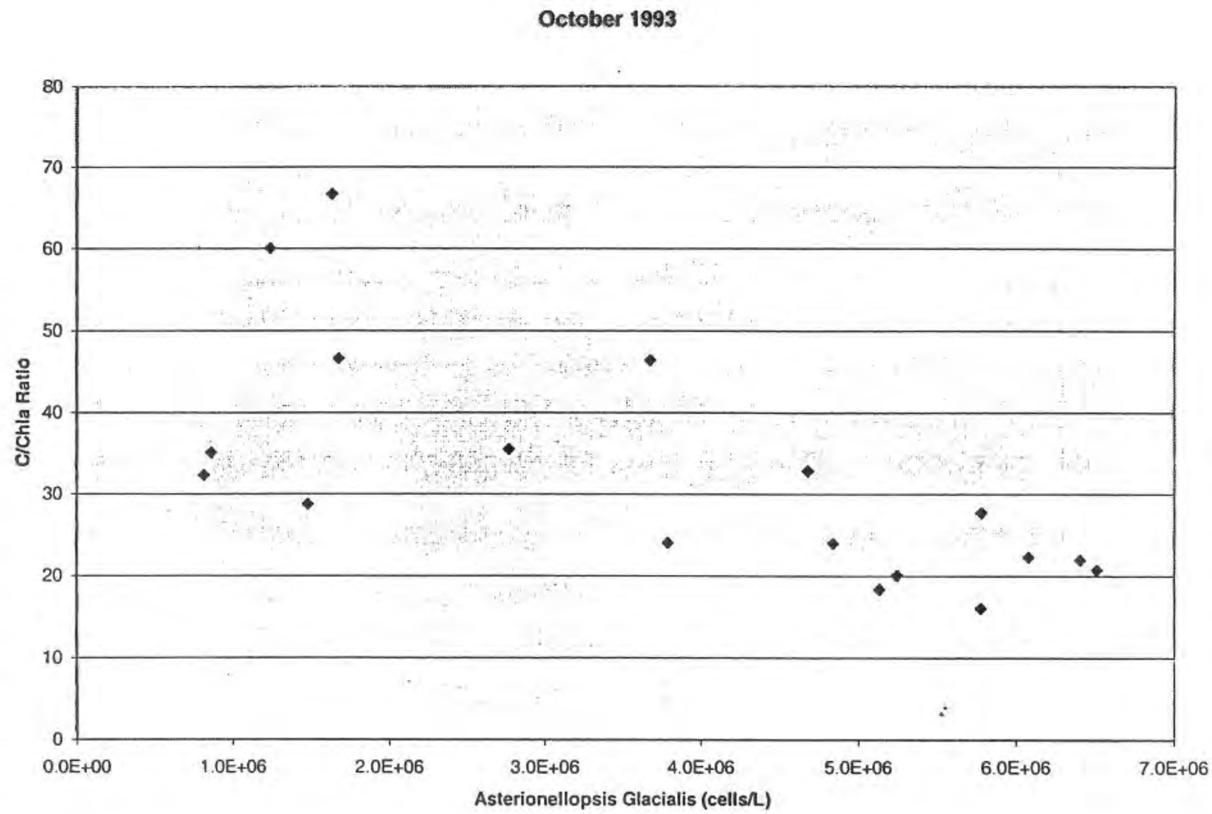
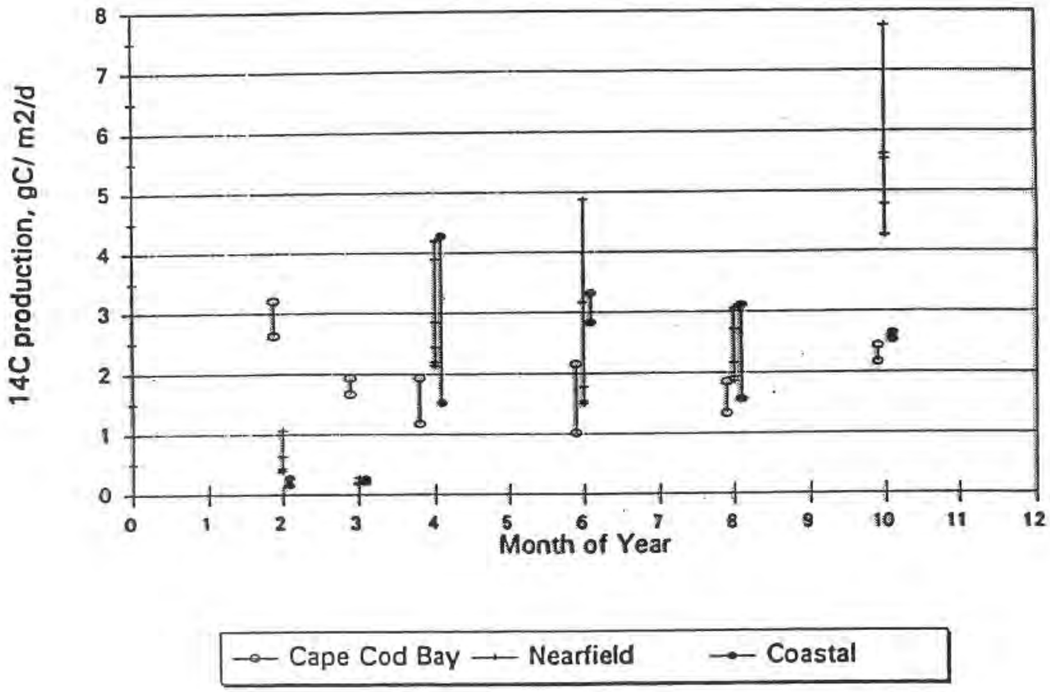


Figure A-3. C/Chlorophyll-a Ratio vs. *A. glacialis* concentration for October 1993



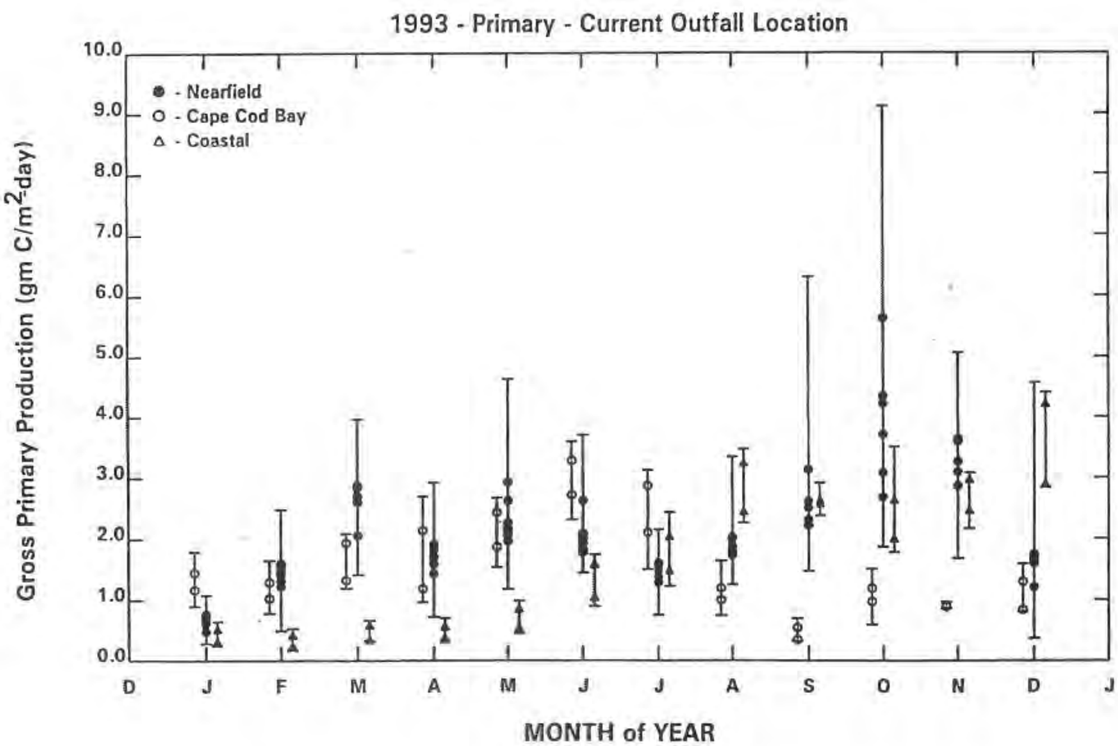
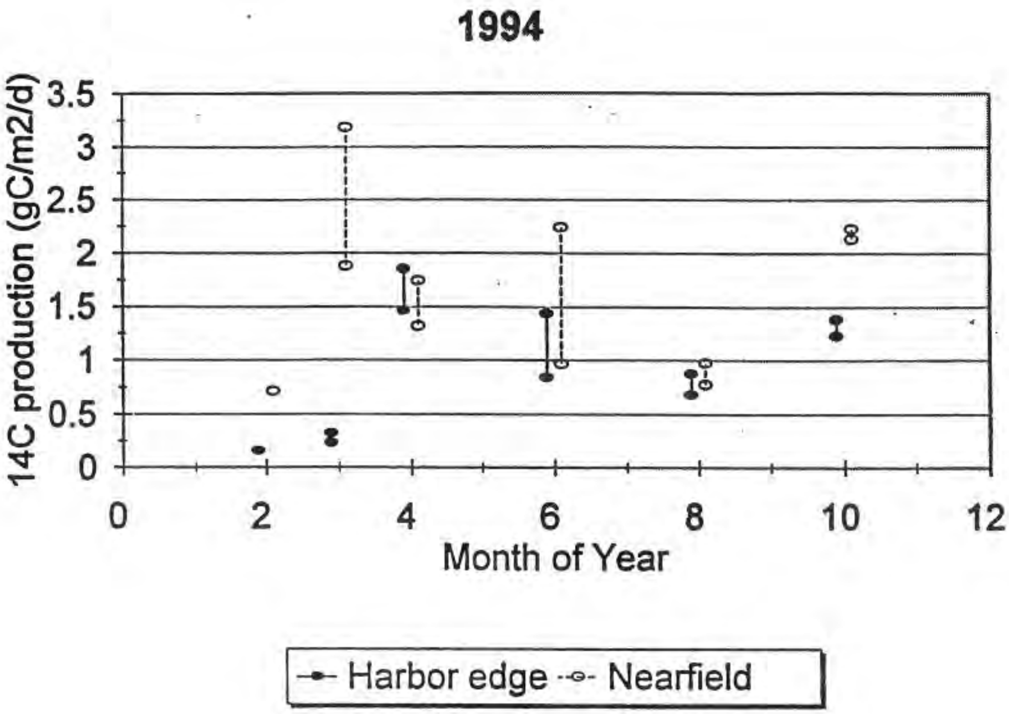


Figure 4-30. Gross Primary Productivity 1993



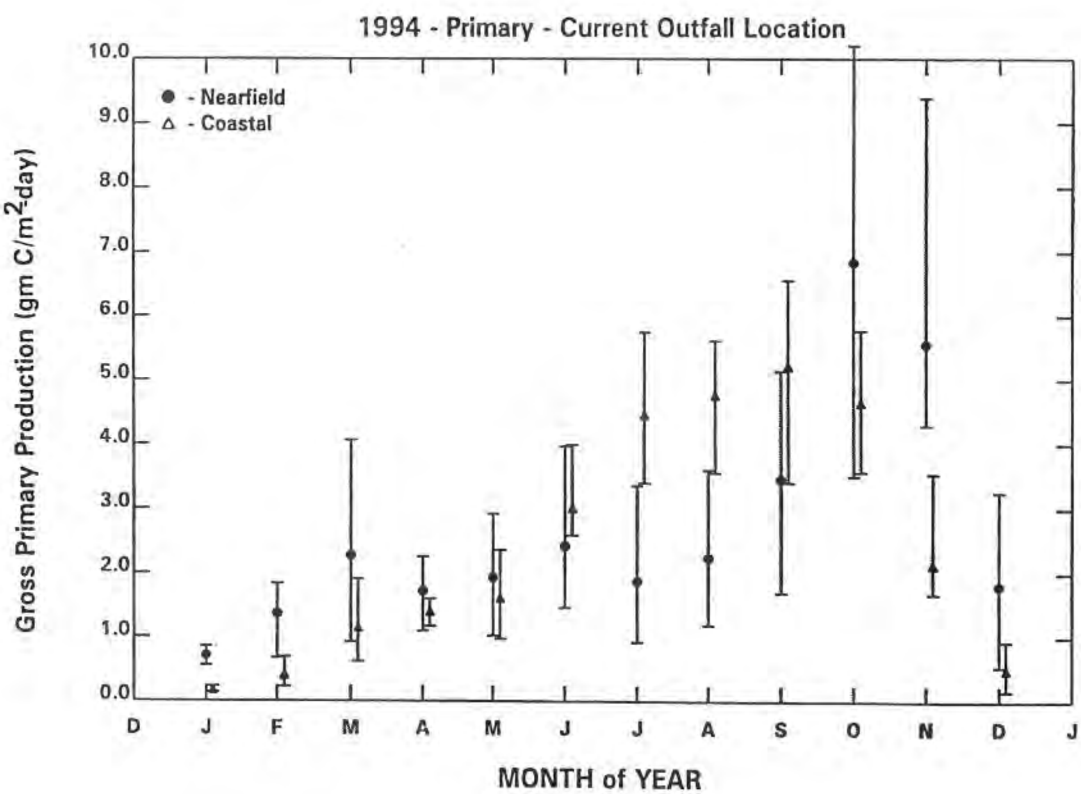
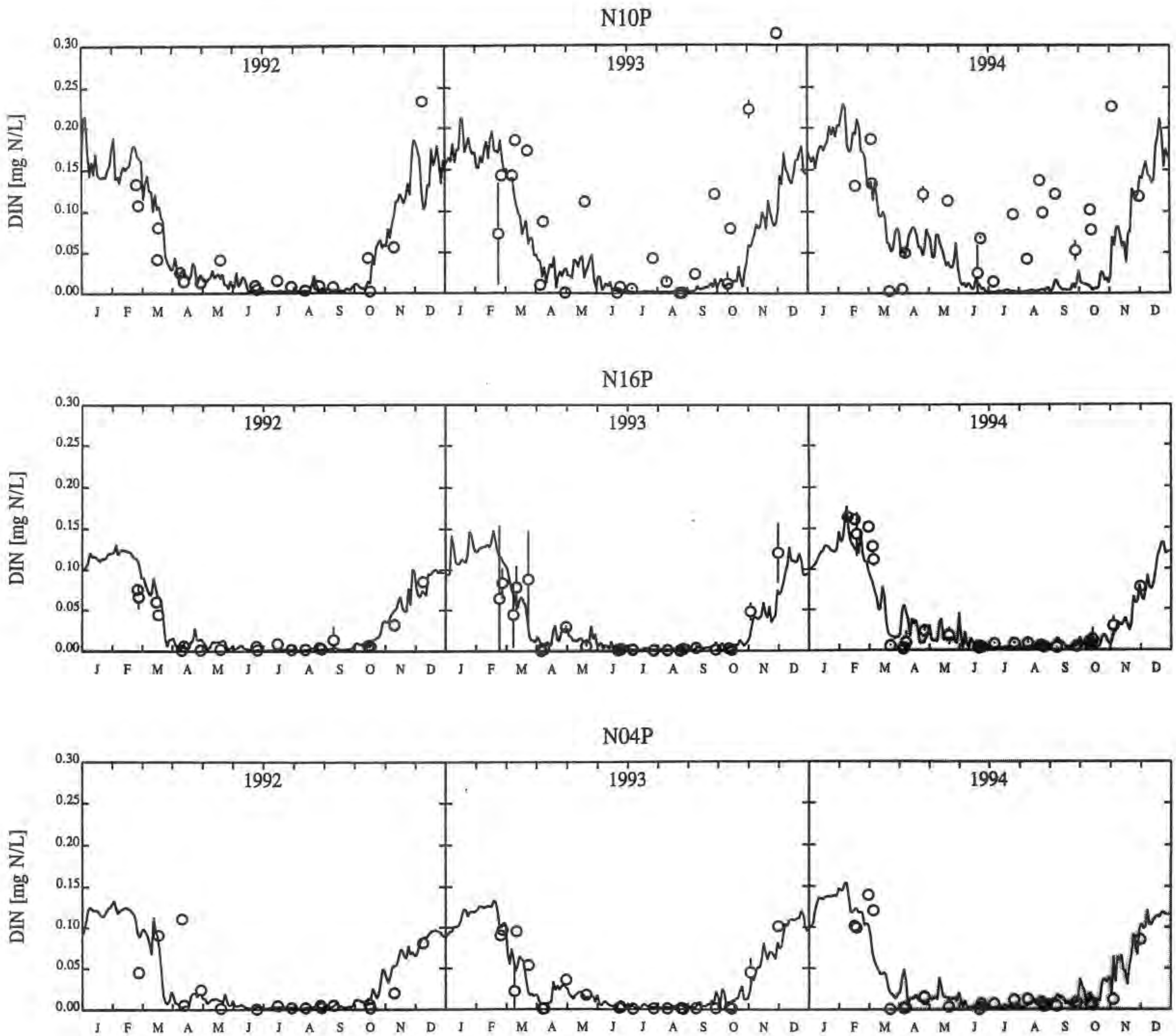
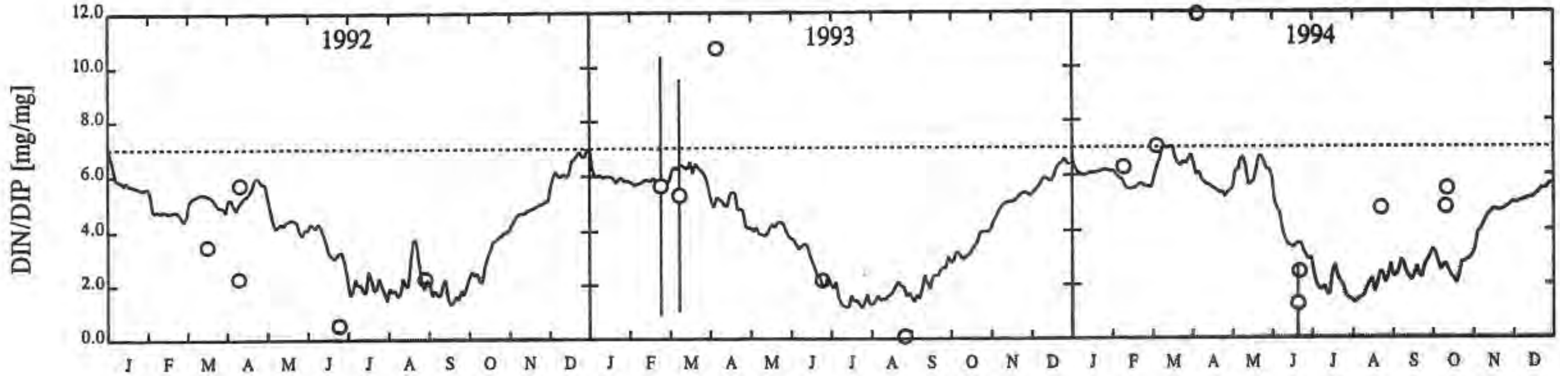


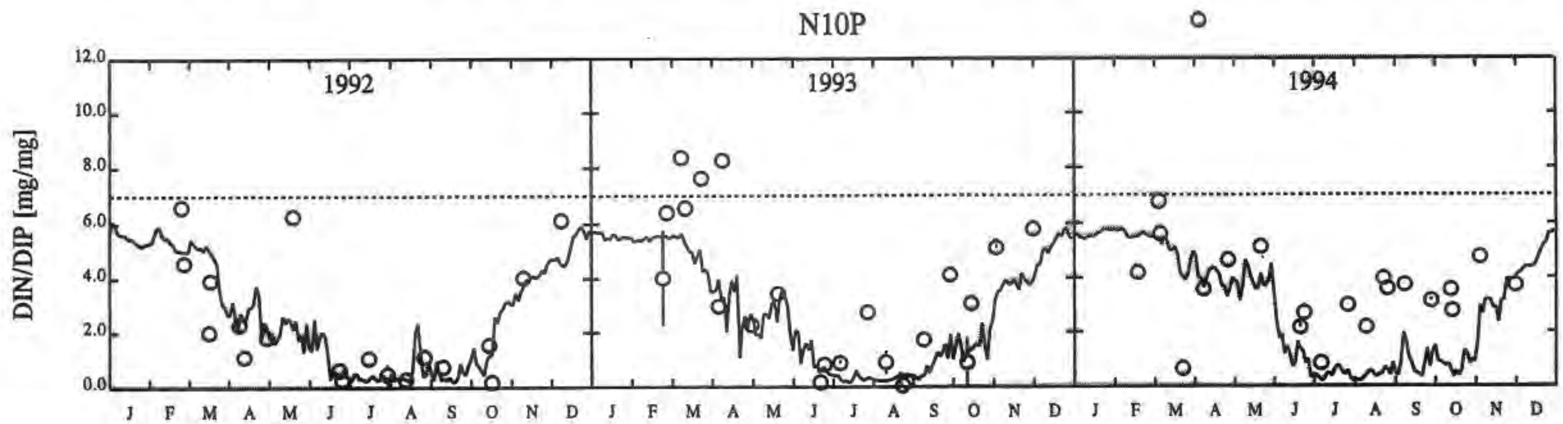
Figure 4-31. Gross Primary Productivity 1994


N10P
N16P
N04P
1992
1993
1994
DIN [mg N/L]
0.00
0.05
0.10
0.15
0.20
0.25
0.30
J F M A M J J A S O N D

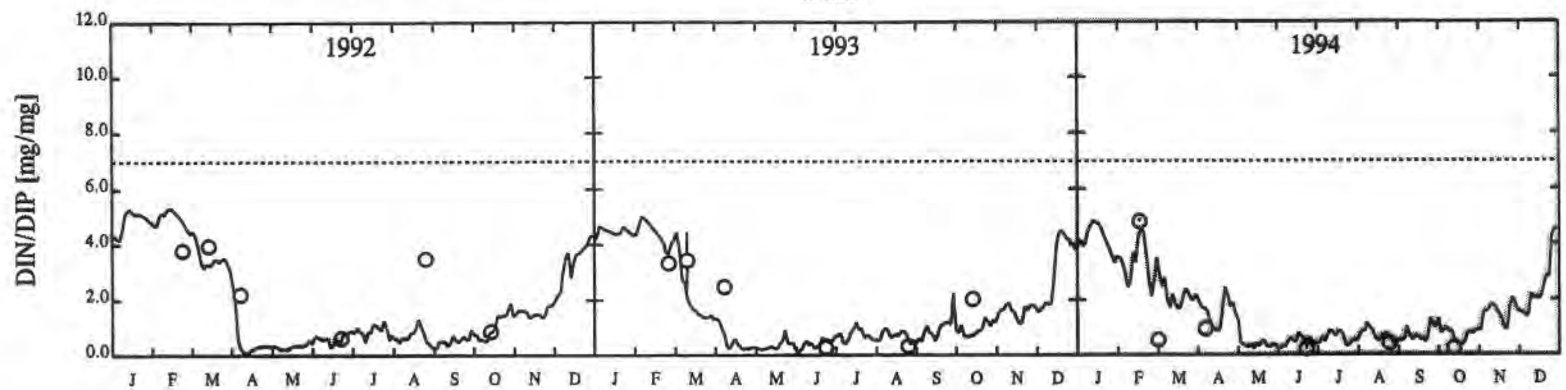
F23P

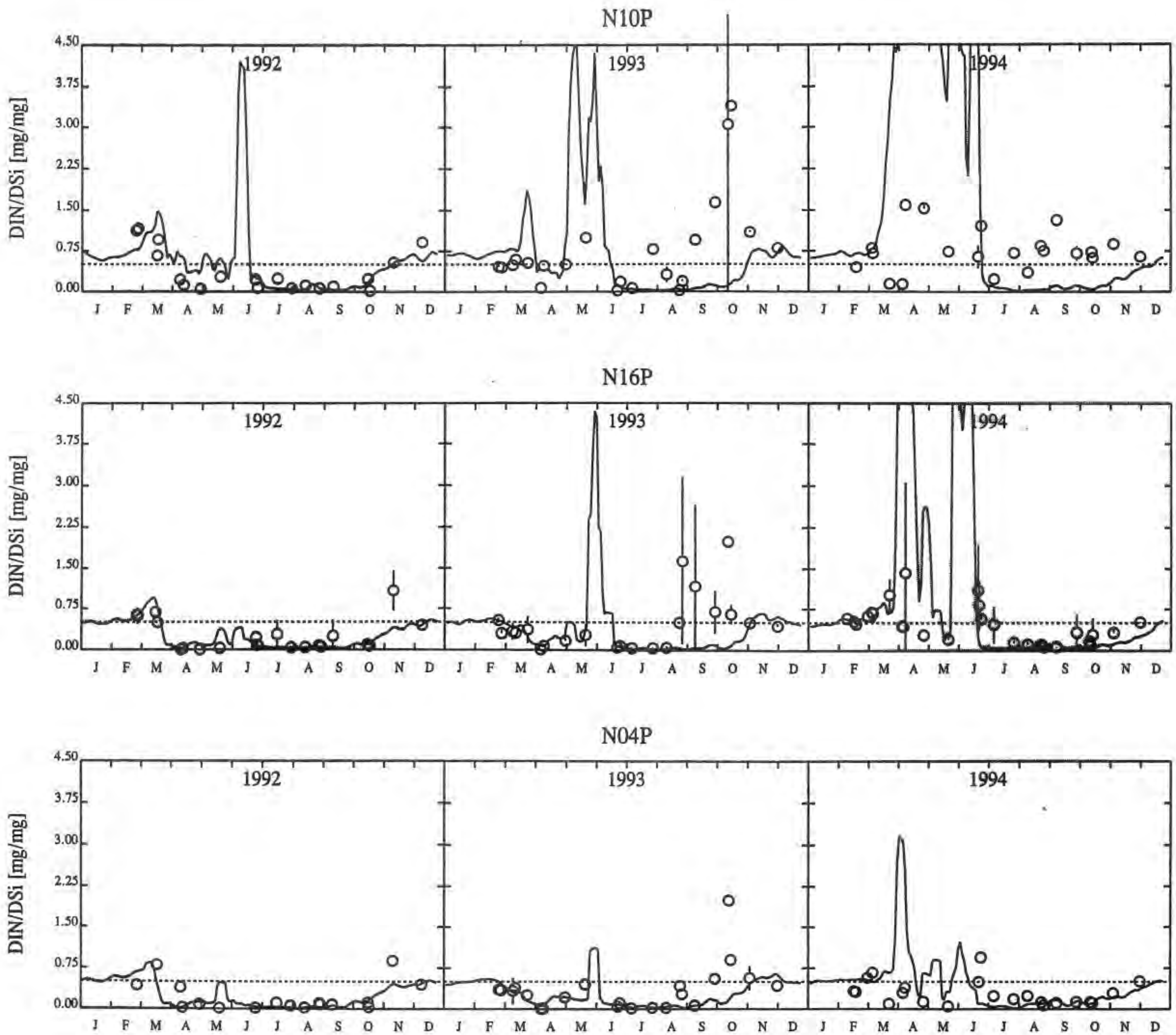


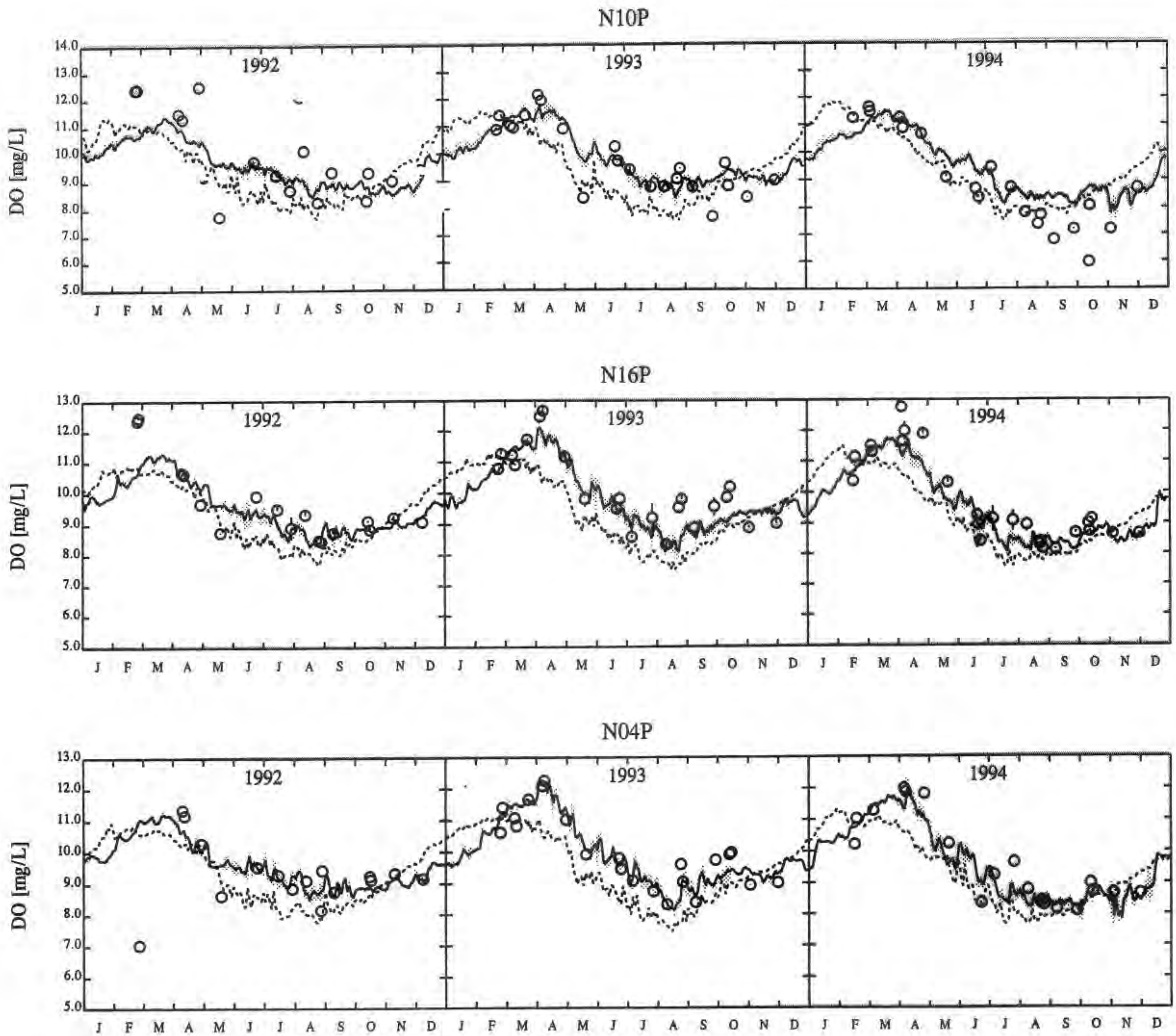
N10P

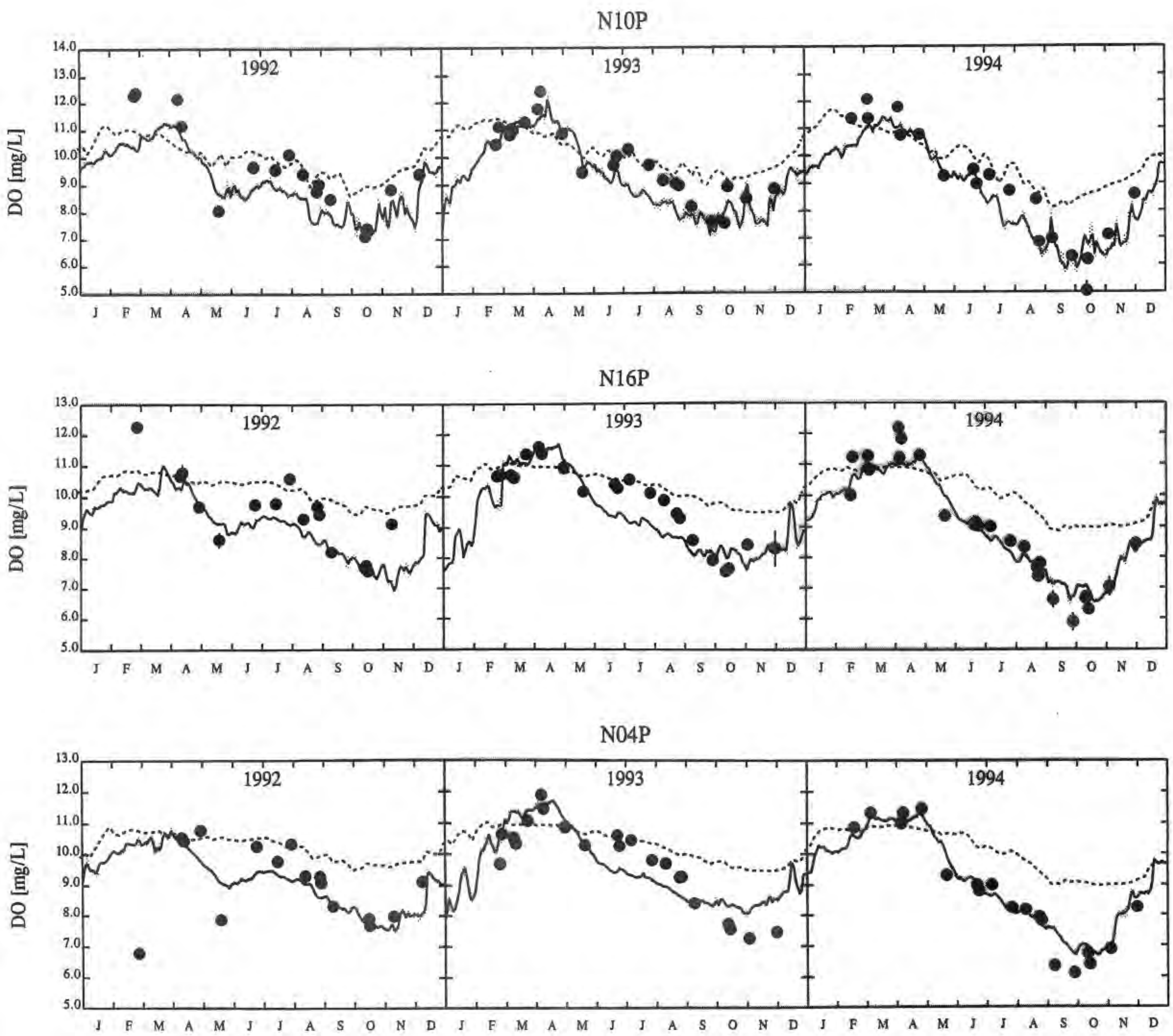


F01P




N10P
N16P
N04P
1992
1993
1994
DIN/DSi [mg/mg]
4.50
3.75
3.00
2.25
1.50
0.75
0.00
J F M A M J J A S O N D


N10P
N16P
N04P
1992
1993
1994
DO [mg/L]
J F M A M J J A S O N D


N10P
N16P
N04P
1992
1993
1994
DO [mg/L]
J F M A M J J A S O N D

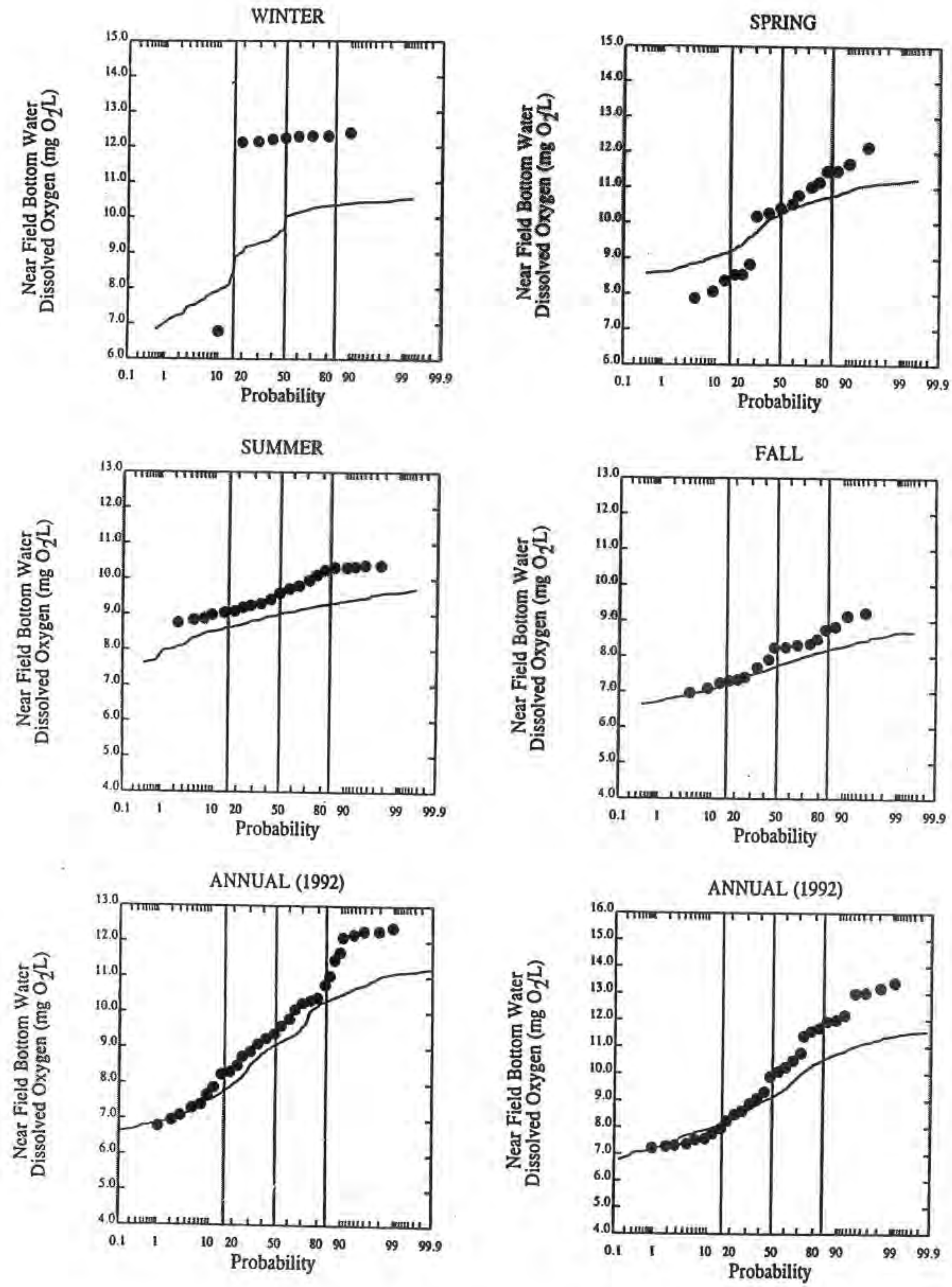


Figure 4-37. Model vs. Data Probability Comparisons for Bottom DO 1992

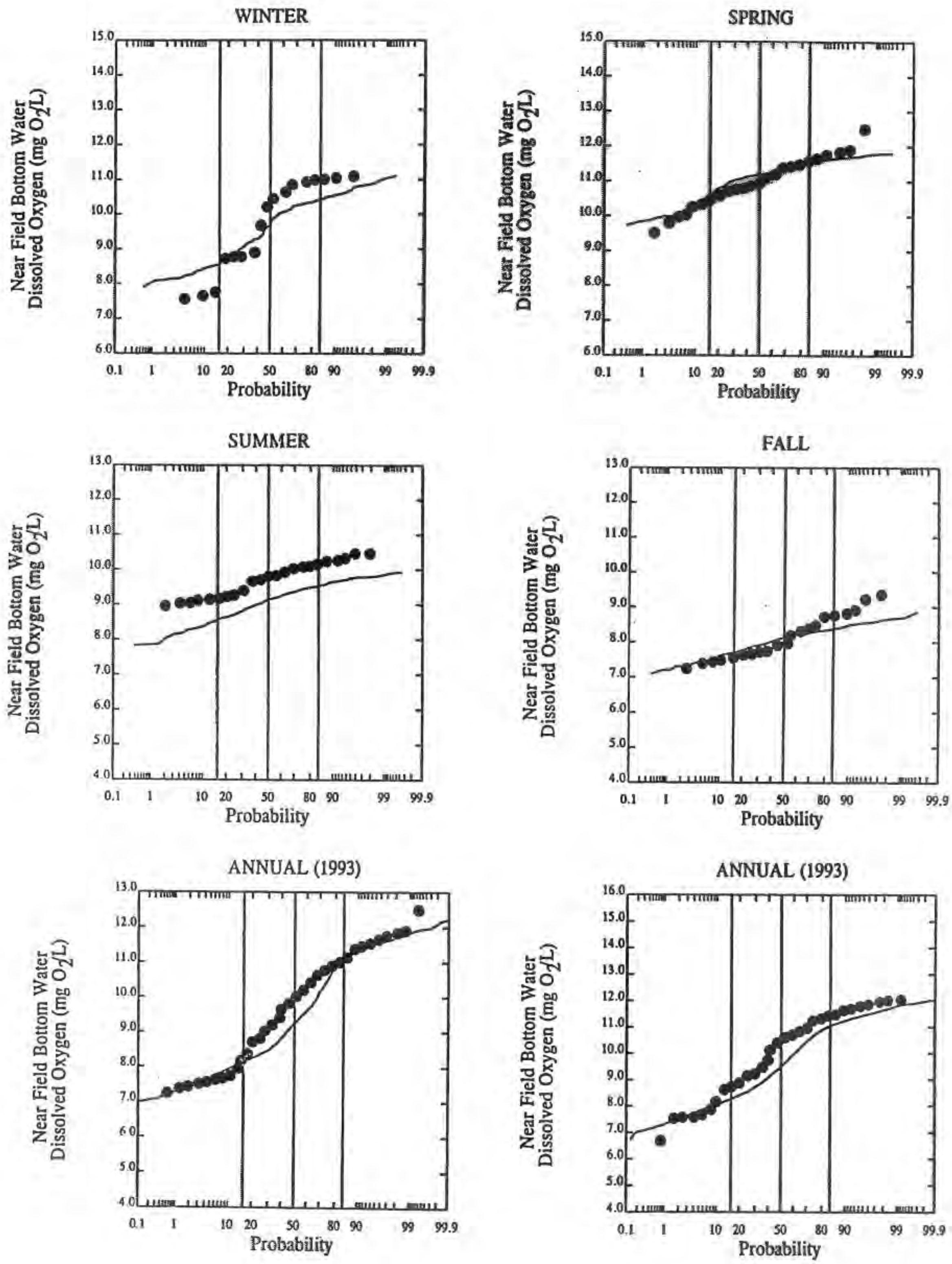


Figure 4-40. Model vs. Data Probability Comparisons for Bottom DO 1993

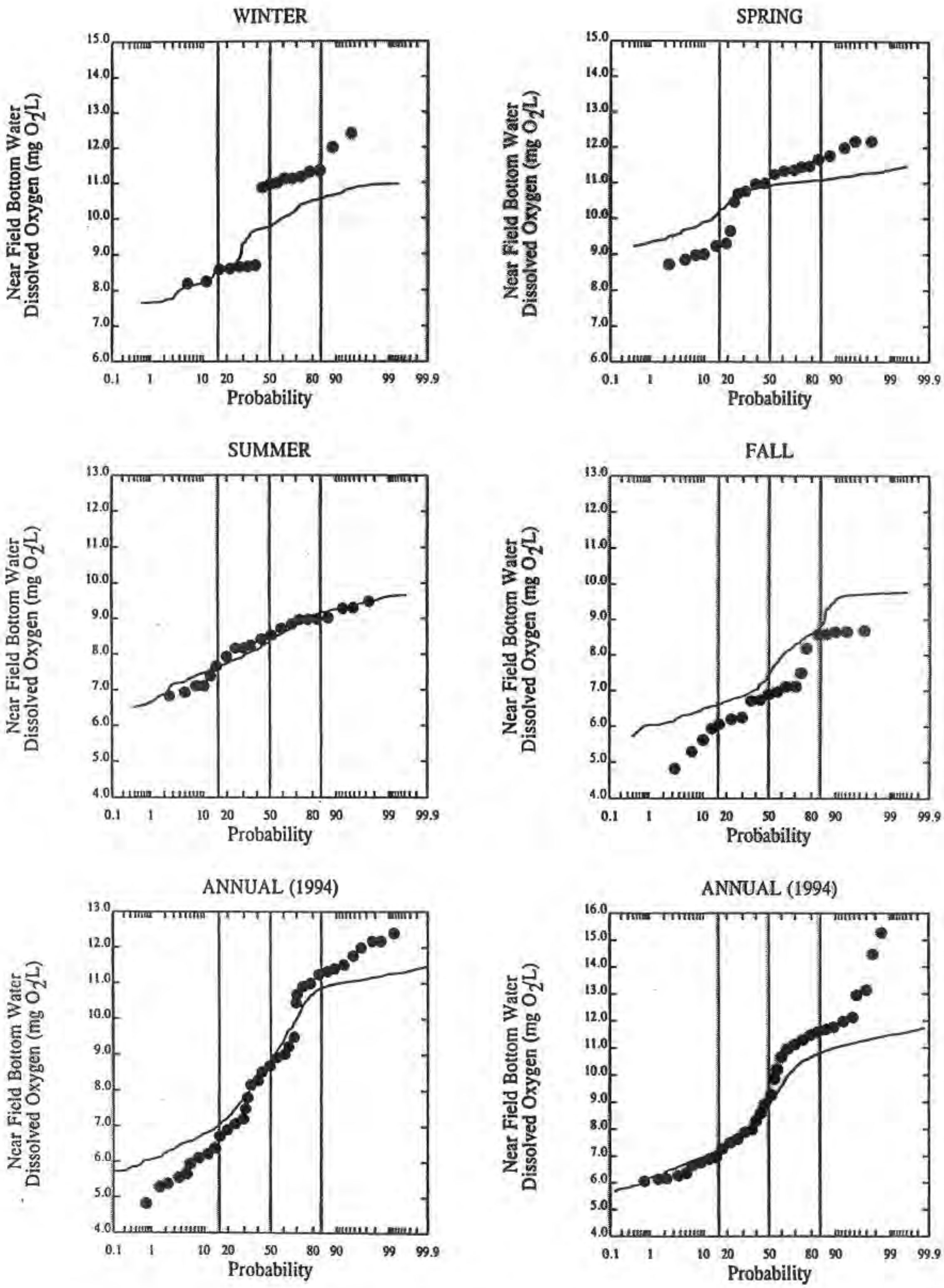


Figure 4-43. Model vs. Data Probability Comparisons for Bottom DO 1994

	Obs	Model	
Median	8.1	7.8	92
10%	7.0	7.0	
	8.0	8.0	93
	7.2	7.2	
	7.0	7.3	94
	5.7	6.1	

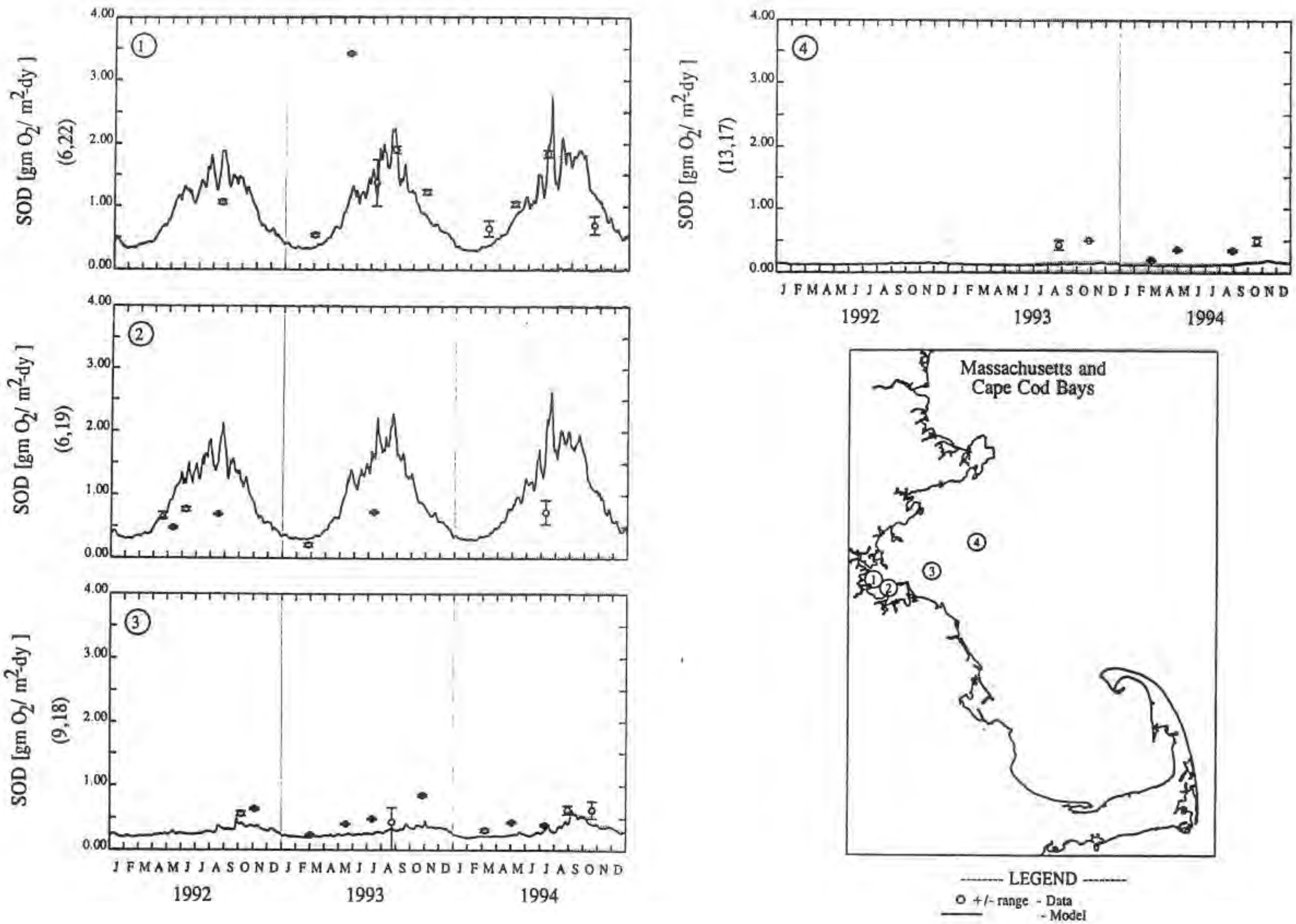


Figure 4-44. Model vs. Data Temporal Comparison for SOD 1992-1994

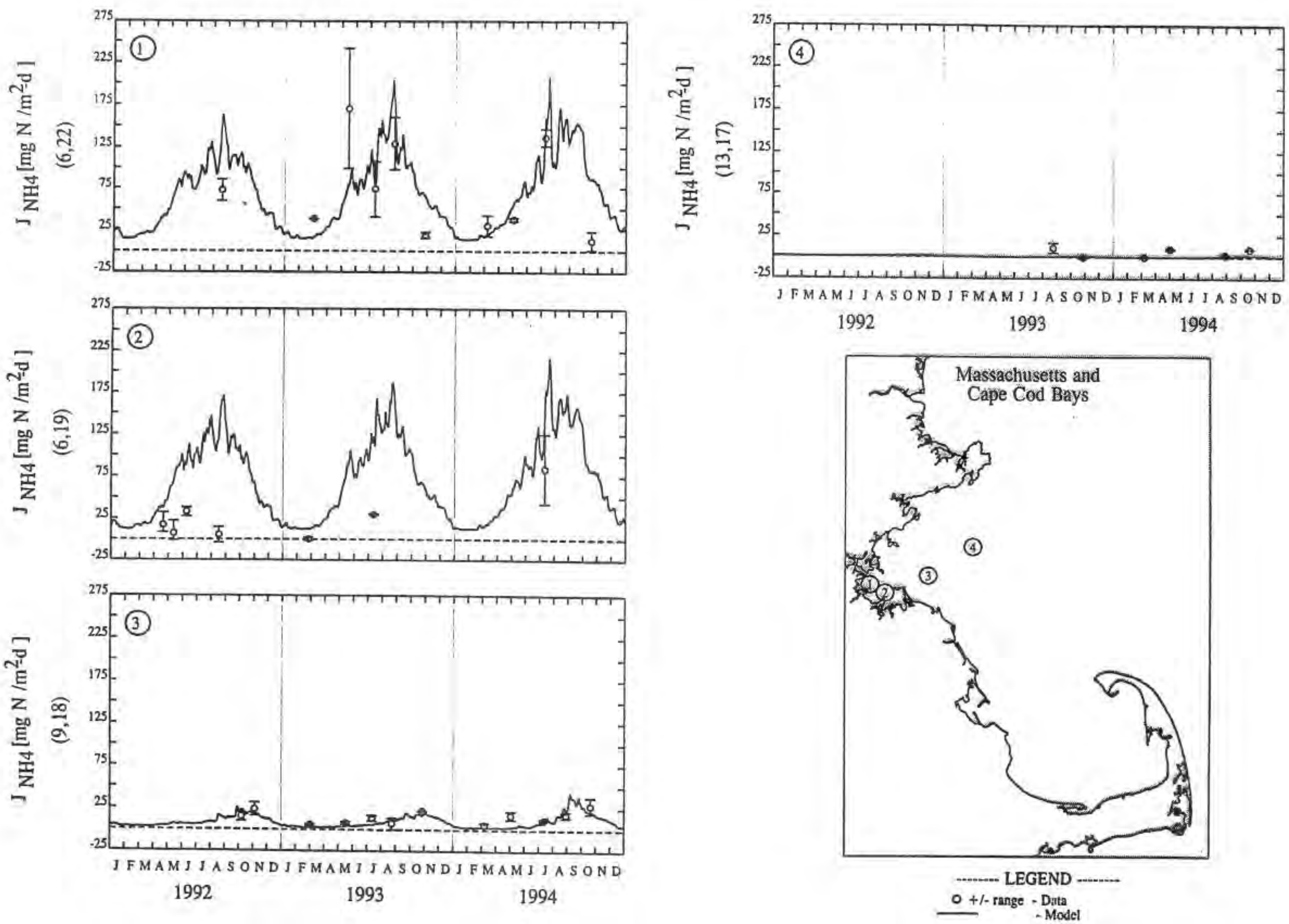


Figure 4-45. Model vs. Data Temporal Comparison for Ammonia Flux 1992-1994

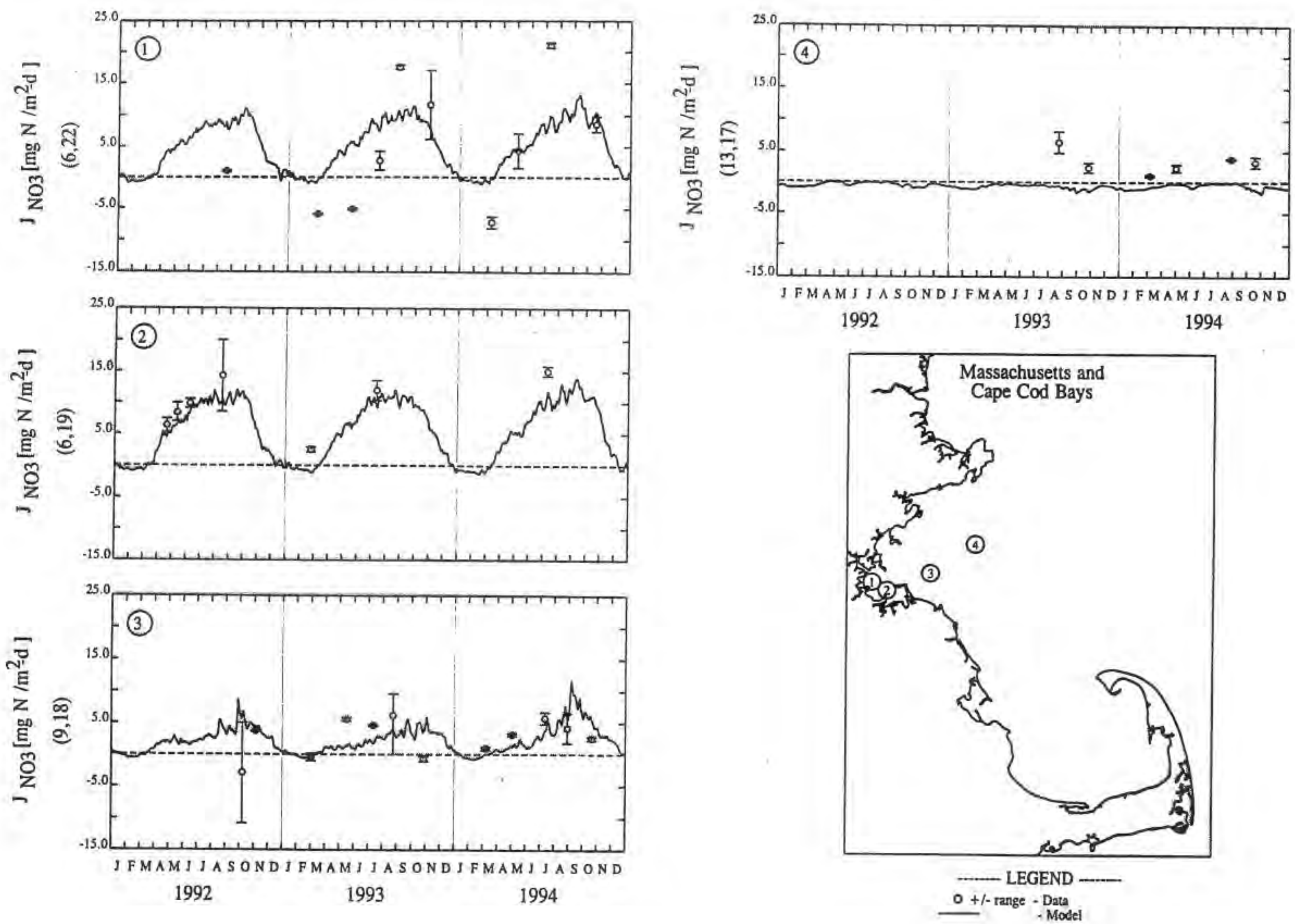


Figure 4-46. Model vs. Data Temporal Comparison for Nitrate Flux 1992-1994

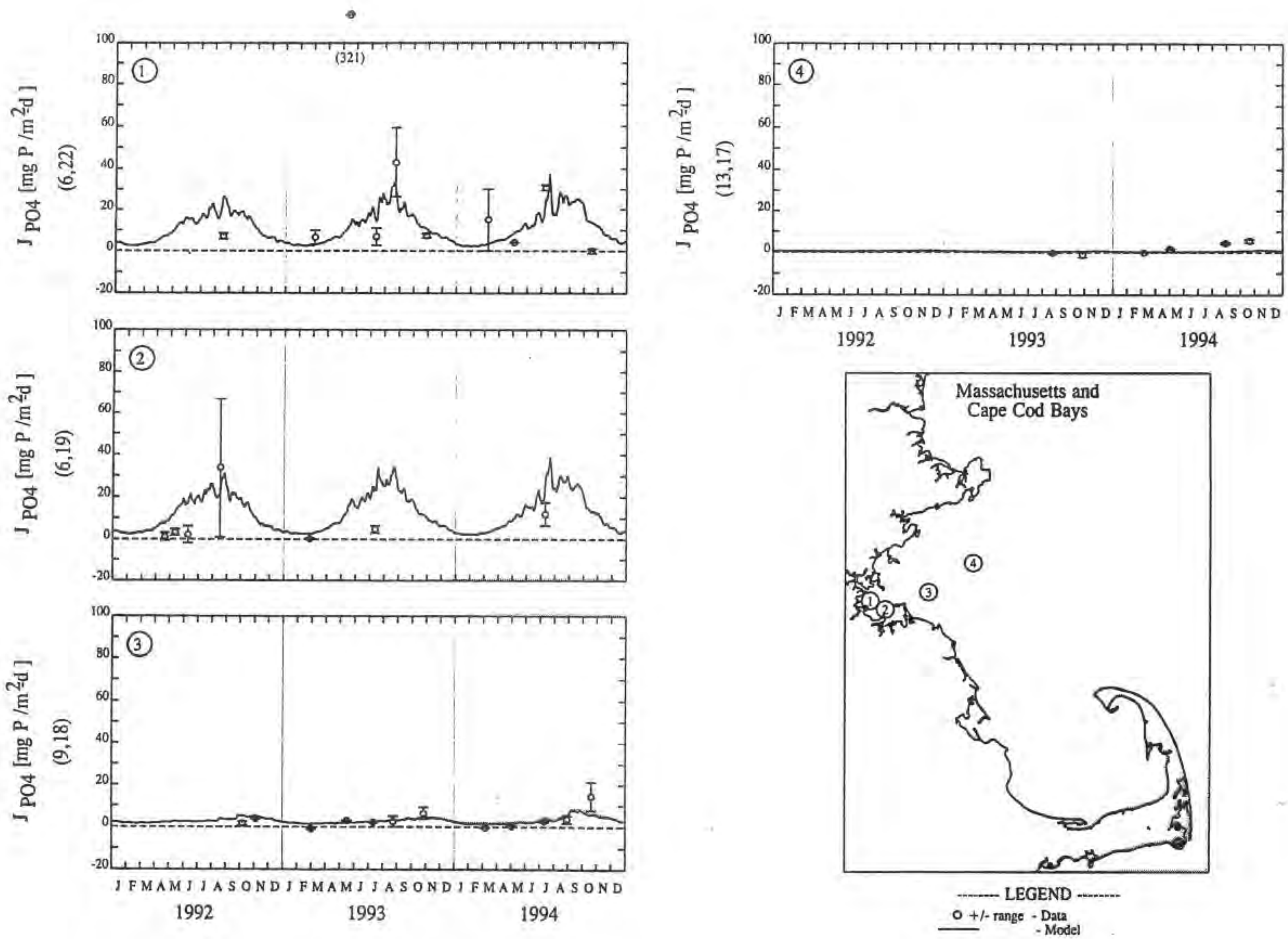


Figure 4-48. Model vs. Data Temporal Comparison for Phosphate Flux 1992-1994

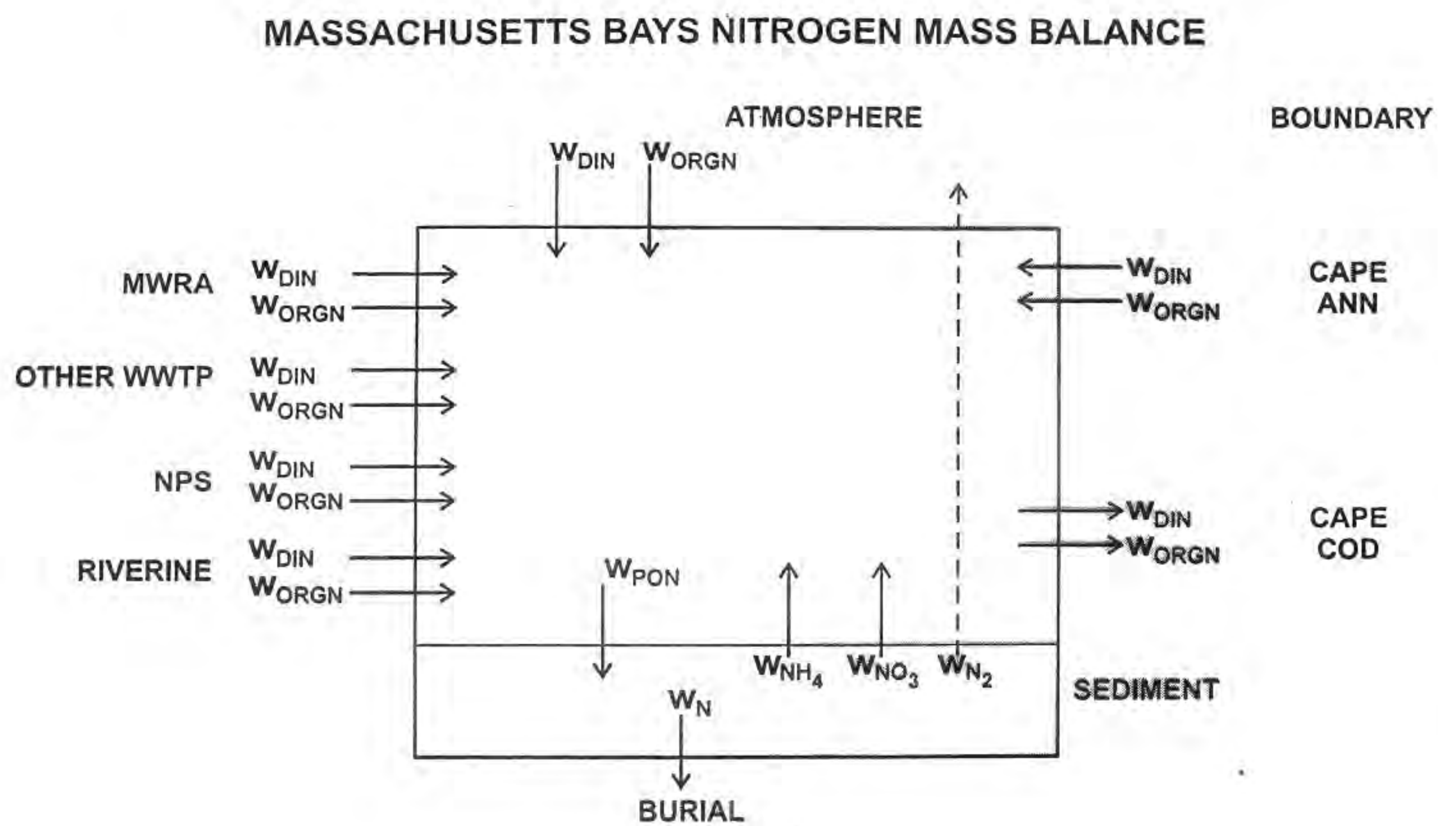
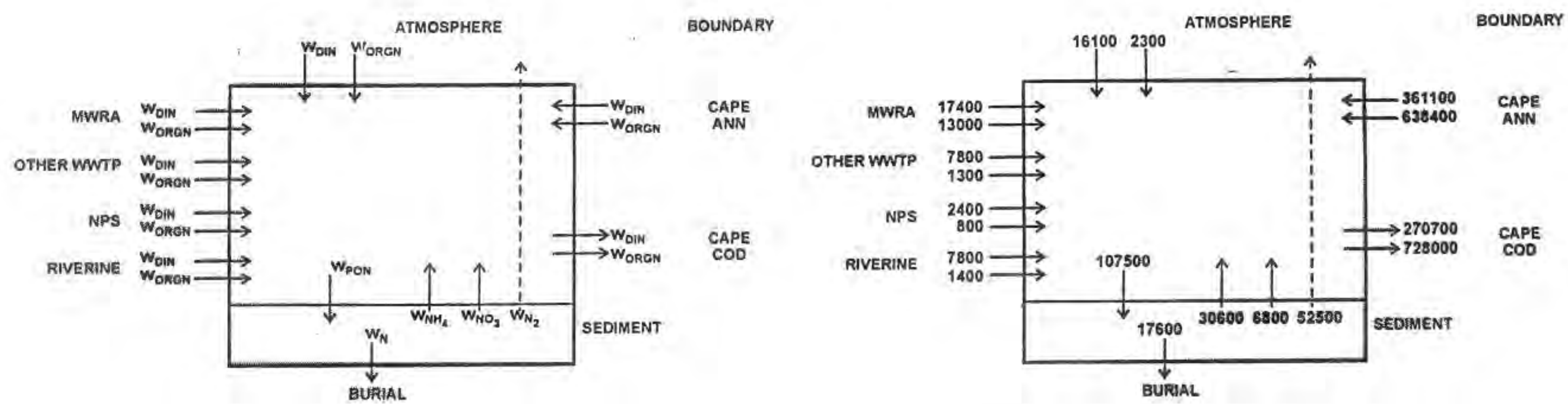


Figure 4-50. Massachusetts Bay Nitrogen Mass Balance

MASSACHUSETTS BAYS NITROGEN MASS BALANCE FOR 1992



(All units are kg/day)

SUMMARY	DIN	ORGN	TN	%TN
MWRA	17400	13000	30400	3
NON-MWRA	34100	18800	52900	5
BOUNDARY	361100	638400	999500	92

Figure 4-51. Massachusetts Bay Nitrogen Mass Balance for 1992

- Not asked for projections
- other tests of calibration. primary productivity
  - respiration by decline in DO

Nitrogen
- Mass Balance

In Cape Ann
Out Cape Cod

Sources

Sink sediment

MWRA 3% TN

~49% reaches sediment denitrified

Model put MWRA in perspective
threshold evaluation

Water Column Monitoring and Nutrient Cycling

1998 Physical Regime *(Dr. Rocky Geyer, WHOI)*

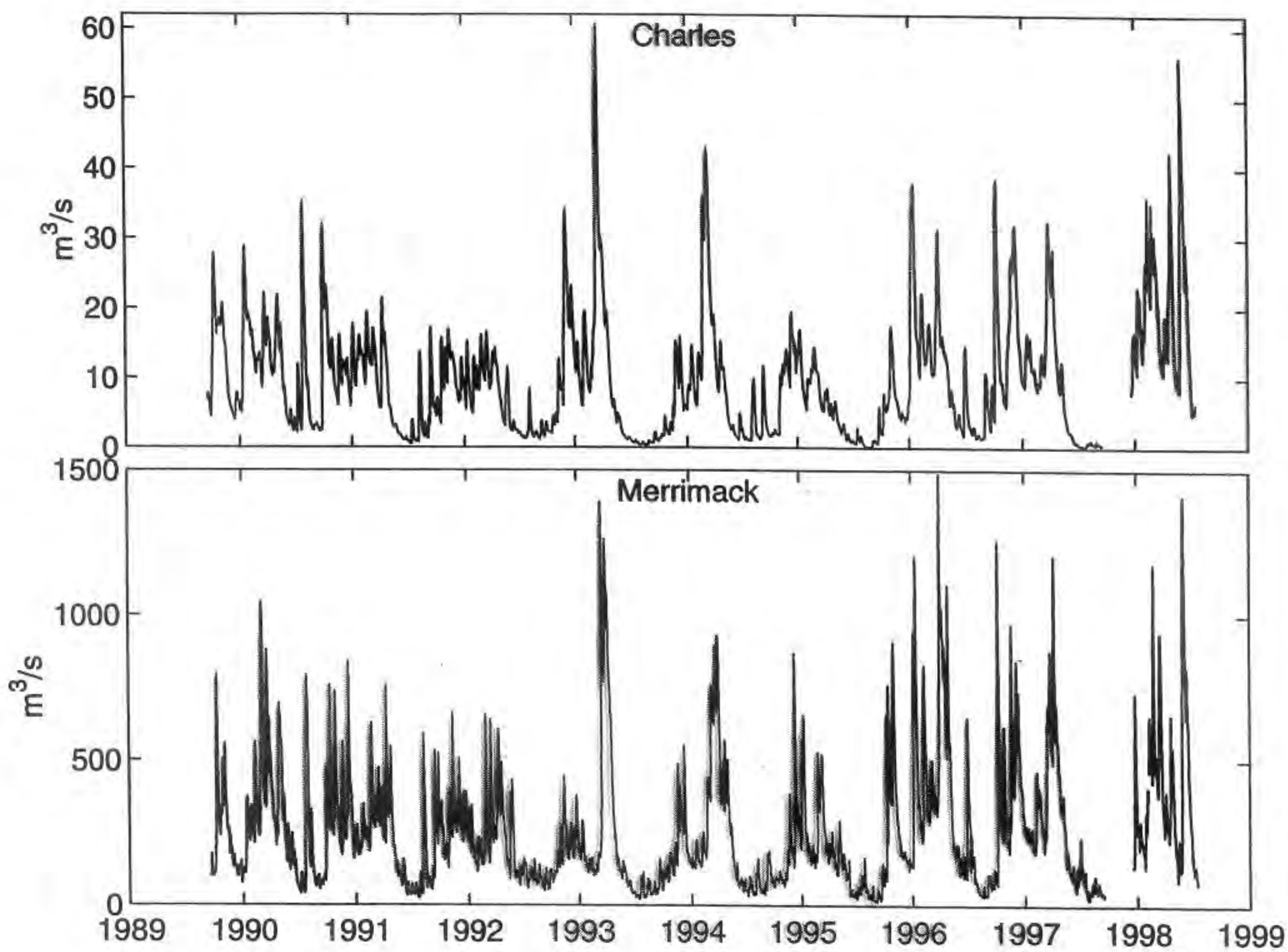
Summary of Physical Oceanography
MWRA Outfall Site
1998

1. Forcing Conditions

- Warm winter
- Very wet spring (particularly June)
- Persistent southerly (upwelling) winds in summer

2. Oceanographic Conditions

- Warm bottom water (early)
- Very low salinity, surface and bottom
- High stratification
- Less warming of bottom water than normal


Charles
Merrimack
m^3/s
m^3/s
0
10
20
30
40
50
60
0
500
1000
1500
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999

Charles River Discharge

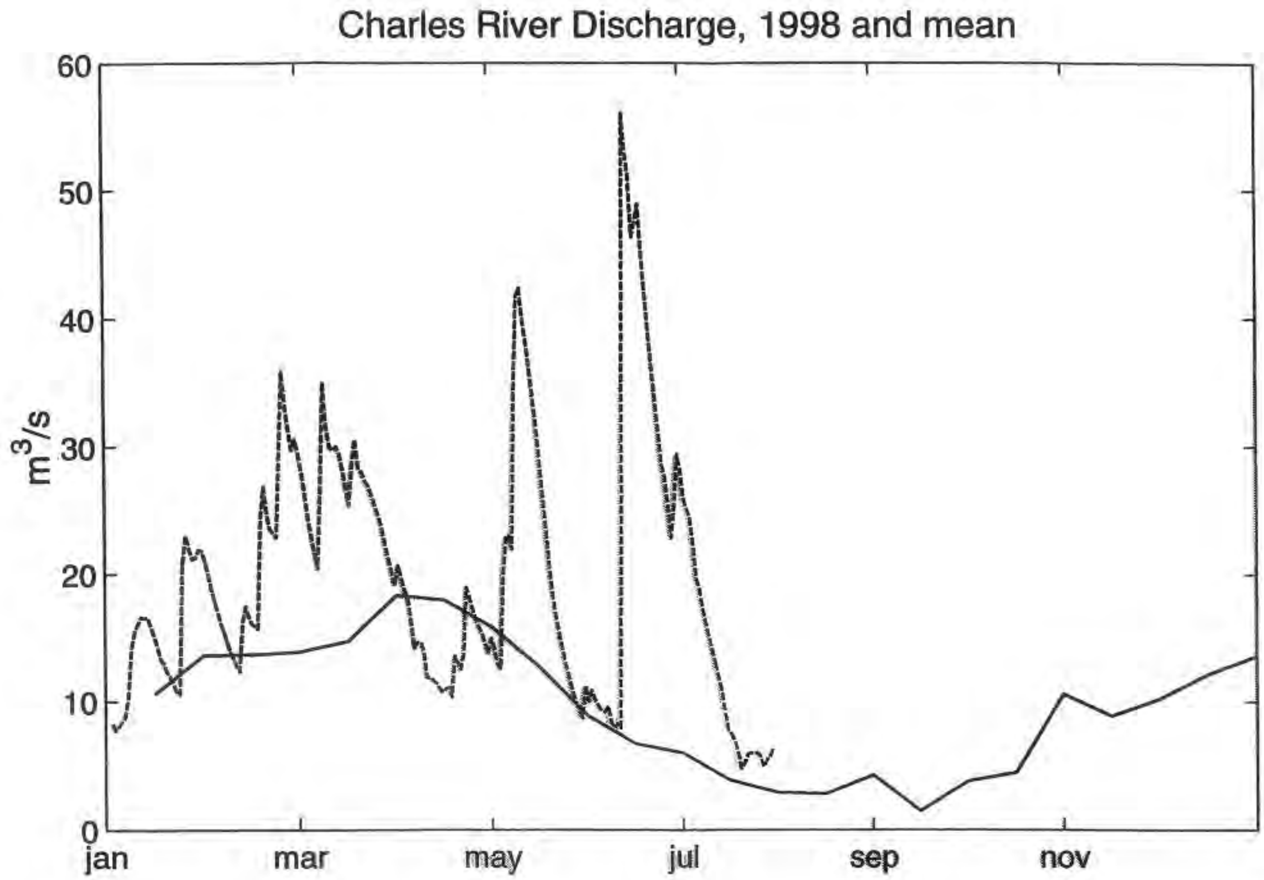
(m^3/s)

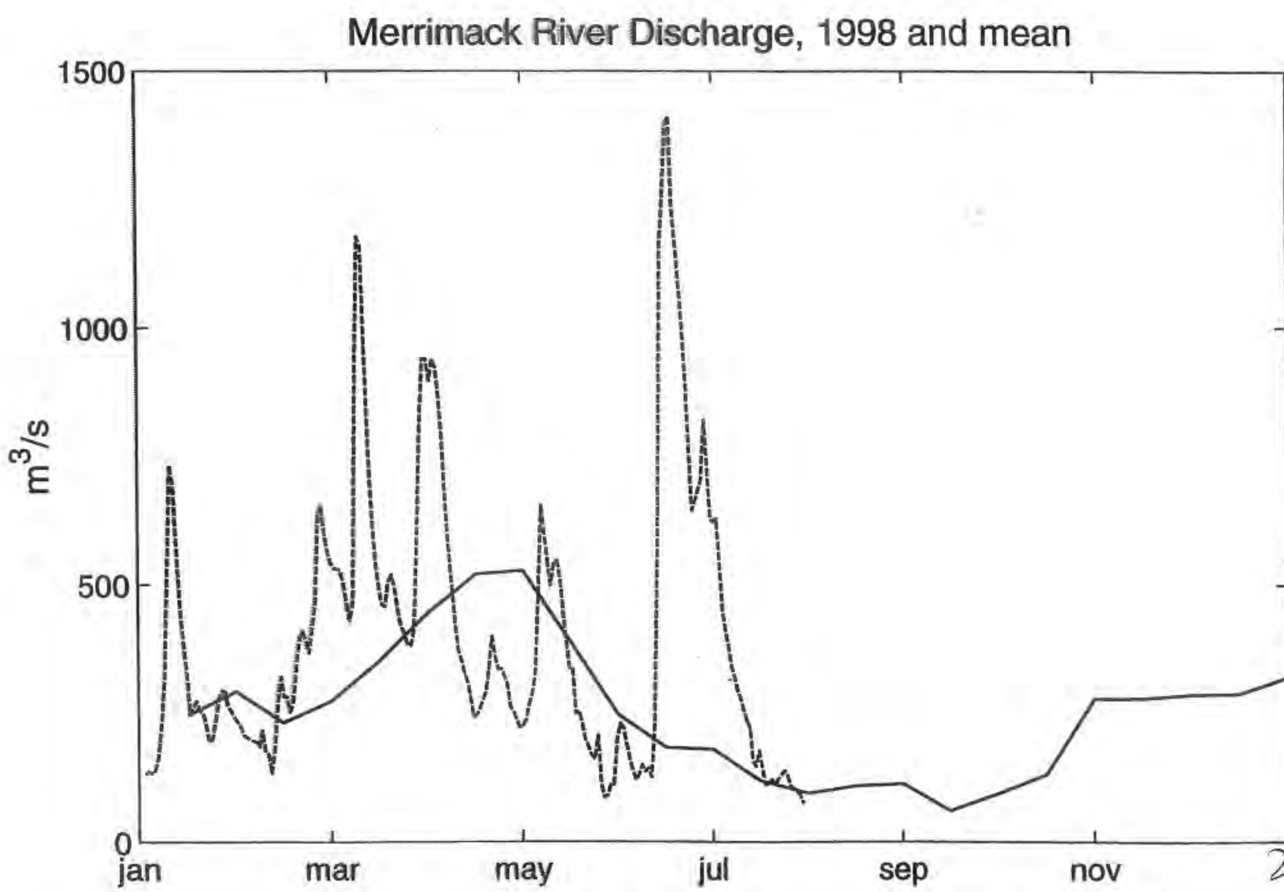
	jan-mar	apr-jun	jul-sep	oct-dec
1990	13	13	7	13
1991	13	7	3	10
1992	10	8	2	9
1993	15	15	1	5
1994	15	11	3	7
1995	11	5	1	7
1996	16	12	4	16
1997	12	13	1	*
1998	**21**	**21**	*	*

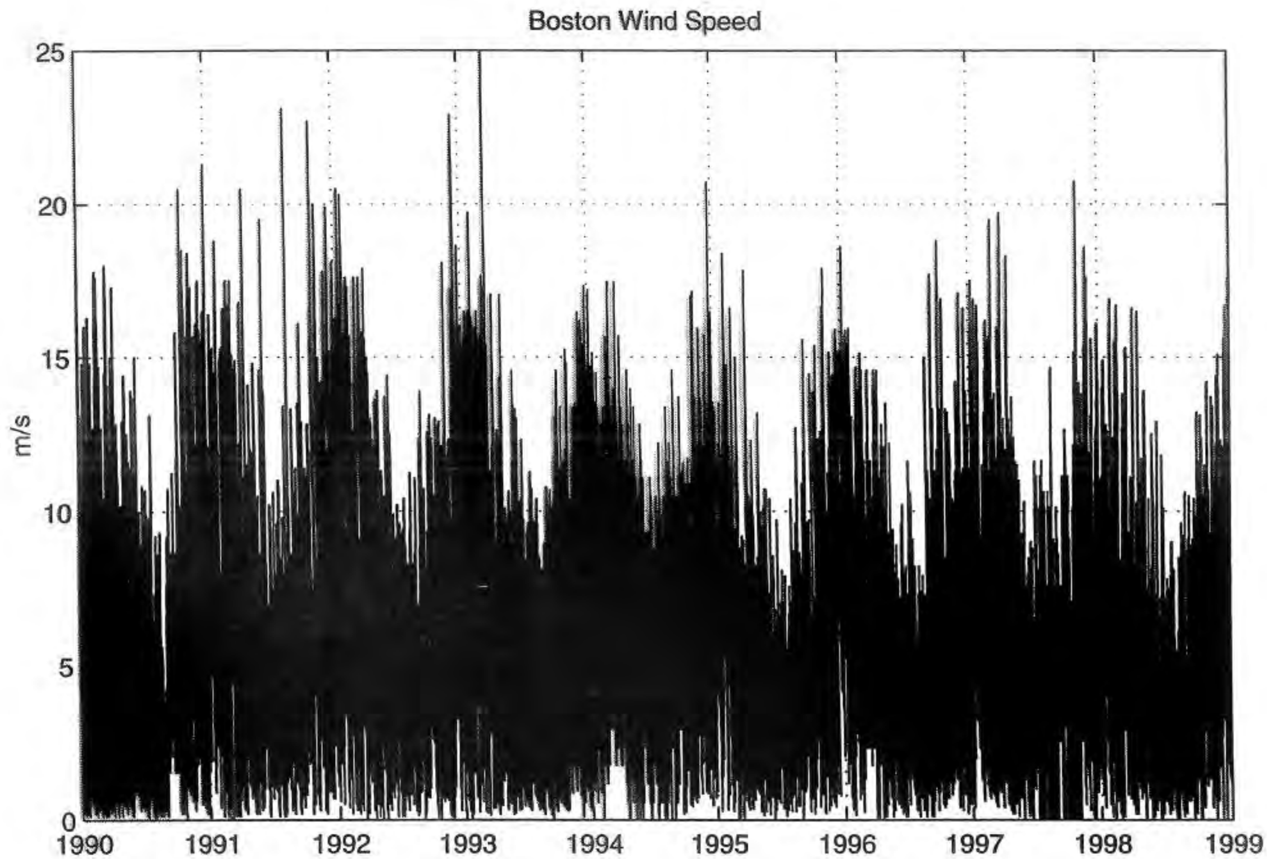
Merrimack River Discharge

(m^3/s)

	jan-mar	apr-jun	jul-sep	oct-dec
1990	333	366	164	331
1991	289	237	117	295
1992	254	266	100	174
1993	200	393	51	198
1994	253	380	74	164
1995	295	154	45	292
1996	409	487	127	401
1997	296	404	70	*
1998	**401**	**451**	*	*


Charles River Discharge, 1998 and mean
60
50
40
30
20
10
0
m^3/s
jan
mar
may
jul
sep
nov


Merrimack River Discharge, 1998 and mean
1500
1000
500
0
m^3/s
jan
mar
may
jul
sep
nov


Boston Wind Speed
25
20
15
10
5
0
m/s
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999

Southerly (upwelling) Wind Stress

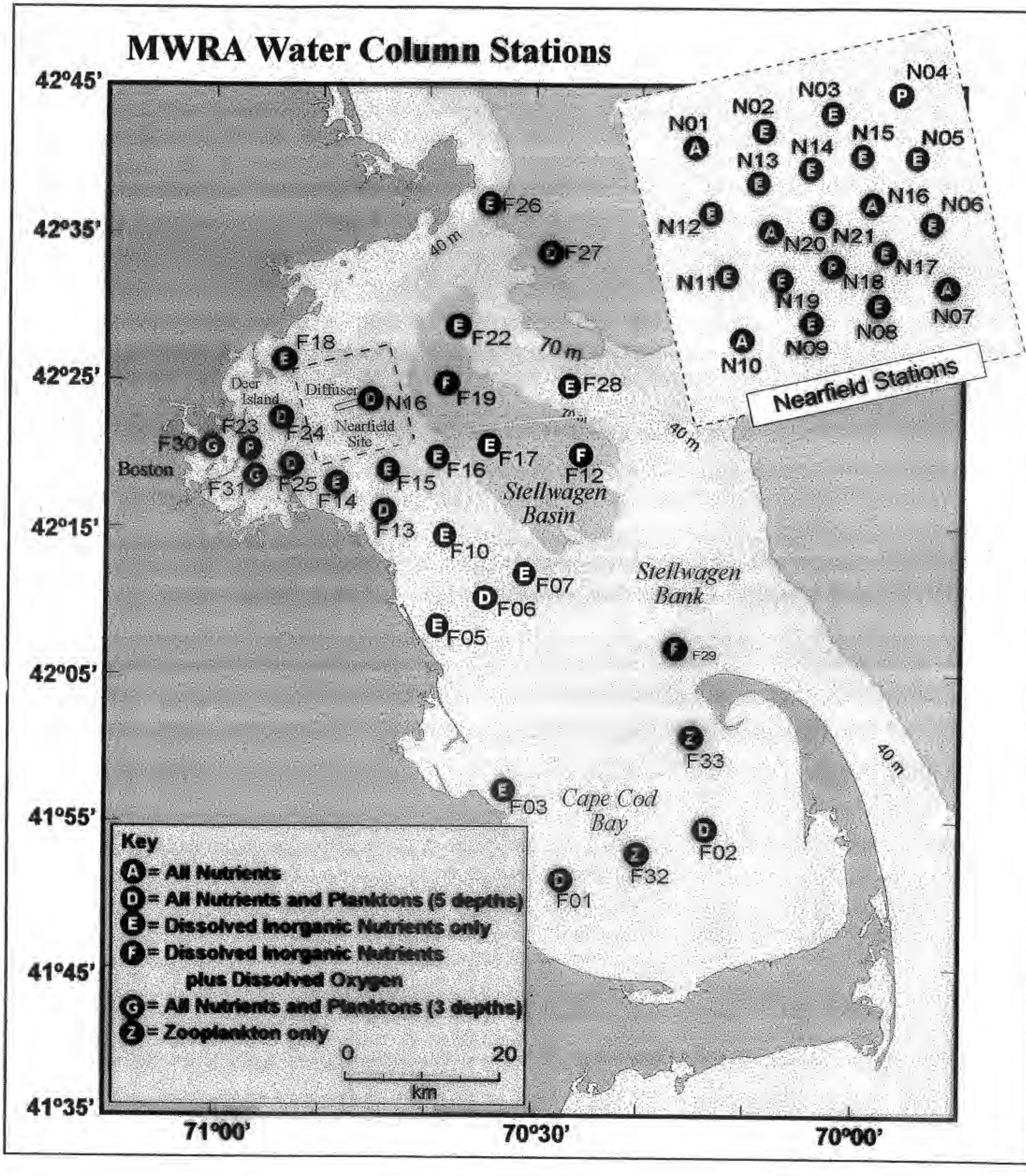
($Pa*10^3$)

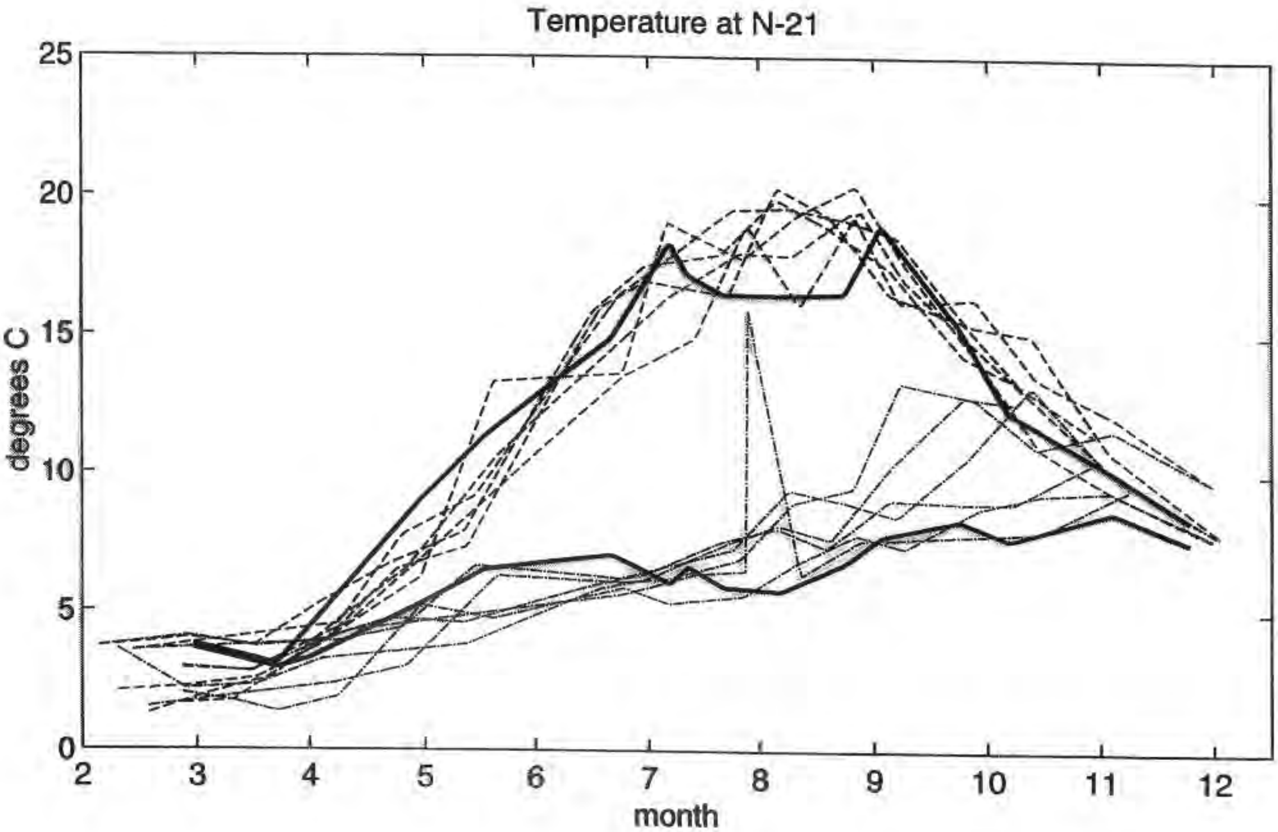
	jan-mar	apr-jun	jul-sep	oct-dec
1990	-0.0	1.4	0.8	0.1
1991	-1.6	-0.2	1.0	-4.2
1992	-3.8	-0.4	1.0	-3.4
1993	-4.5	-0.0	1.3	-1.3
1994	-3.5	1.0	0.4	-1.7
1995	-0.1	0.0	-0.0	-0.9
1996	-2.8	0.5	-0.2	-1.3
1997	-0.1	-0.8	0.5	-2.2
1998	**-4.3**	**-0.8**	**0.9**	**-0.5**
mean	-2.3	0.1	0.6	-1.7

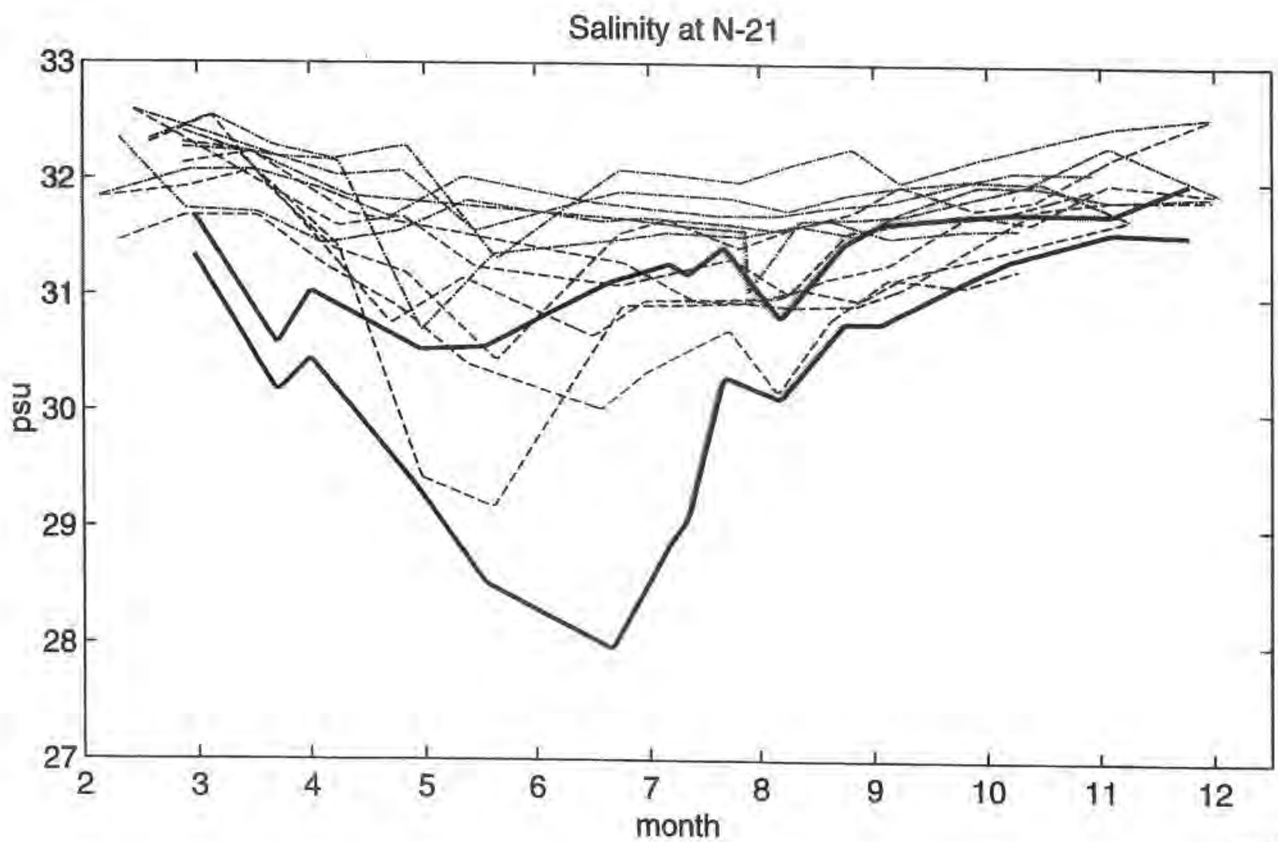
Wind Speed

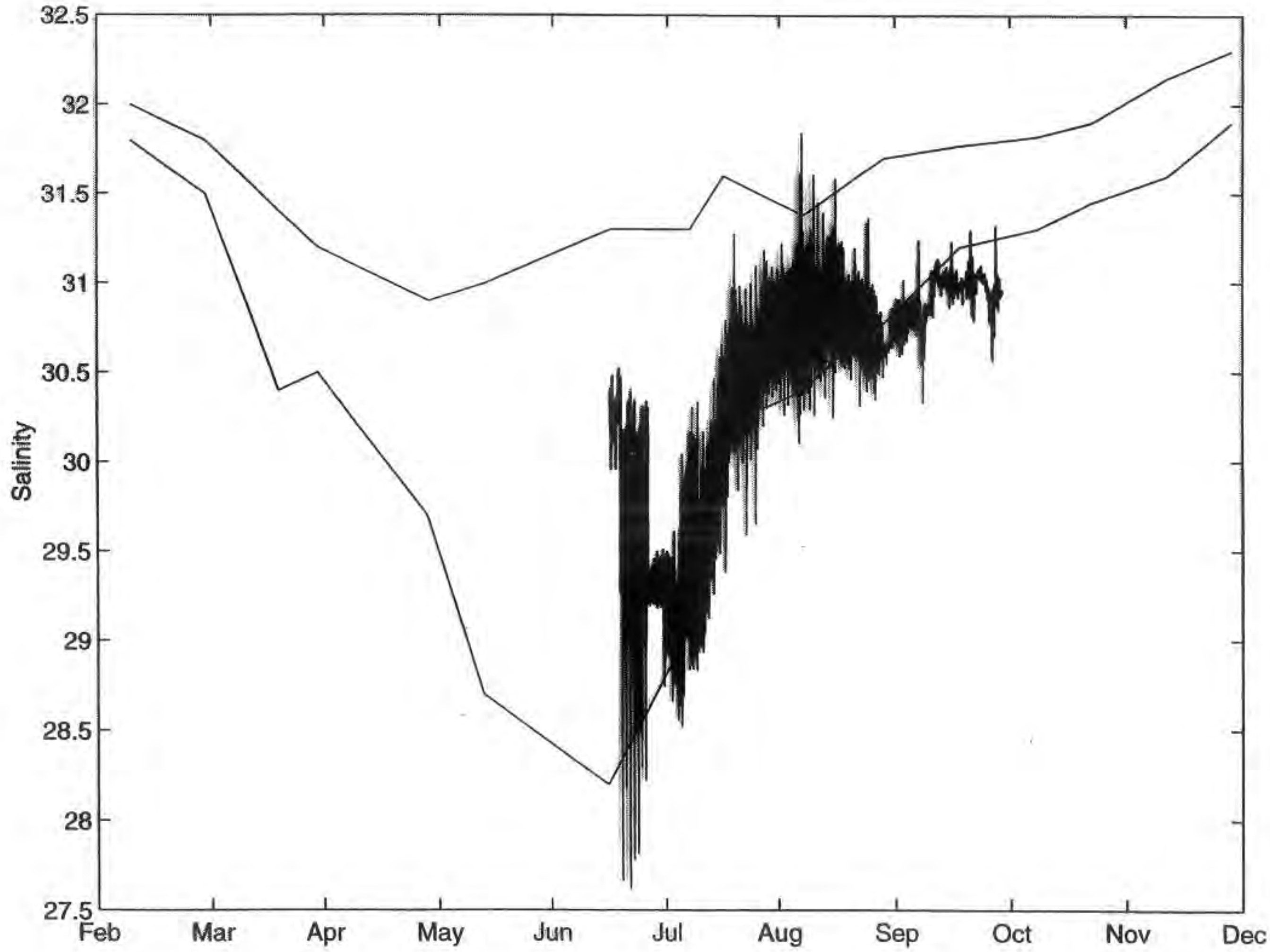
(m/s)

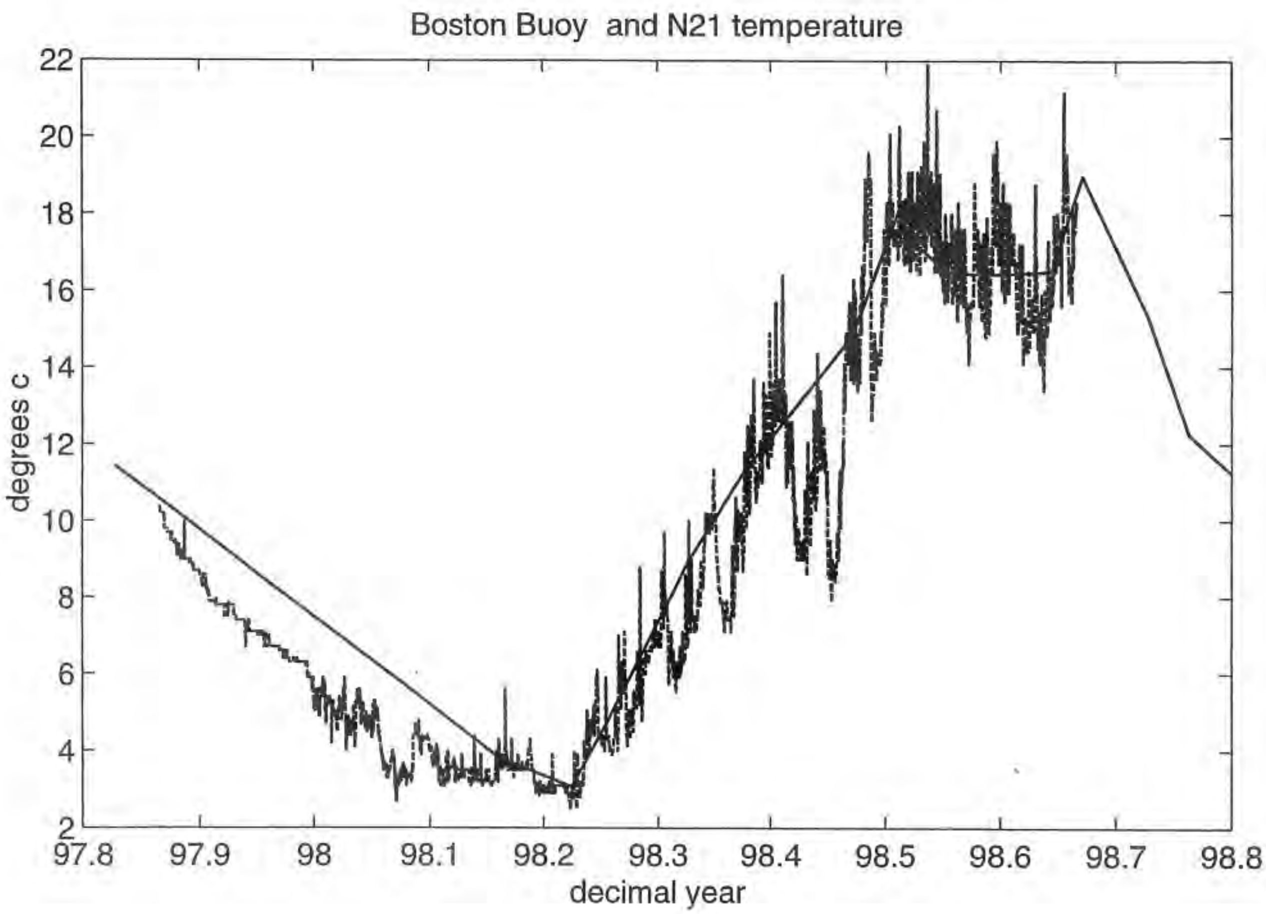
	jan-mar	apr-jun	jul-sep	oct-dec
1990	7.0	5.8	4.4	7.9
1991	7.6	5.8	5.3	7.5
1992	7.9	5.8	5.1	7.0
1993	7.7	5.8	4.9	6.9
1994	7.4	5.9	5.6	6.8
1995	6.6	4.6	4.6	7.2
1996	7.3	5.1	4.5	6.6
1997	7.6	5.3	5.1	6.6
1998	**6.9**	**4.6**	**3.9**	**6.8**
mean	7.3	5.4	4.8	7.0

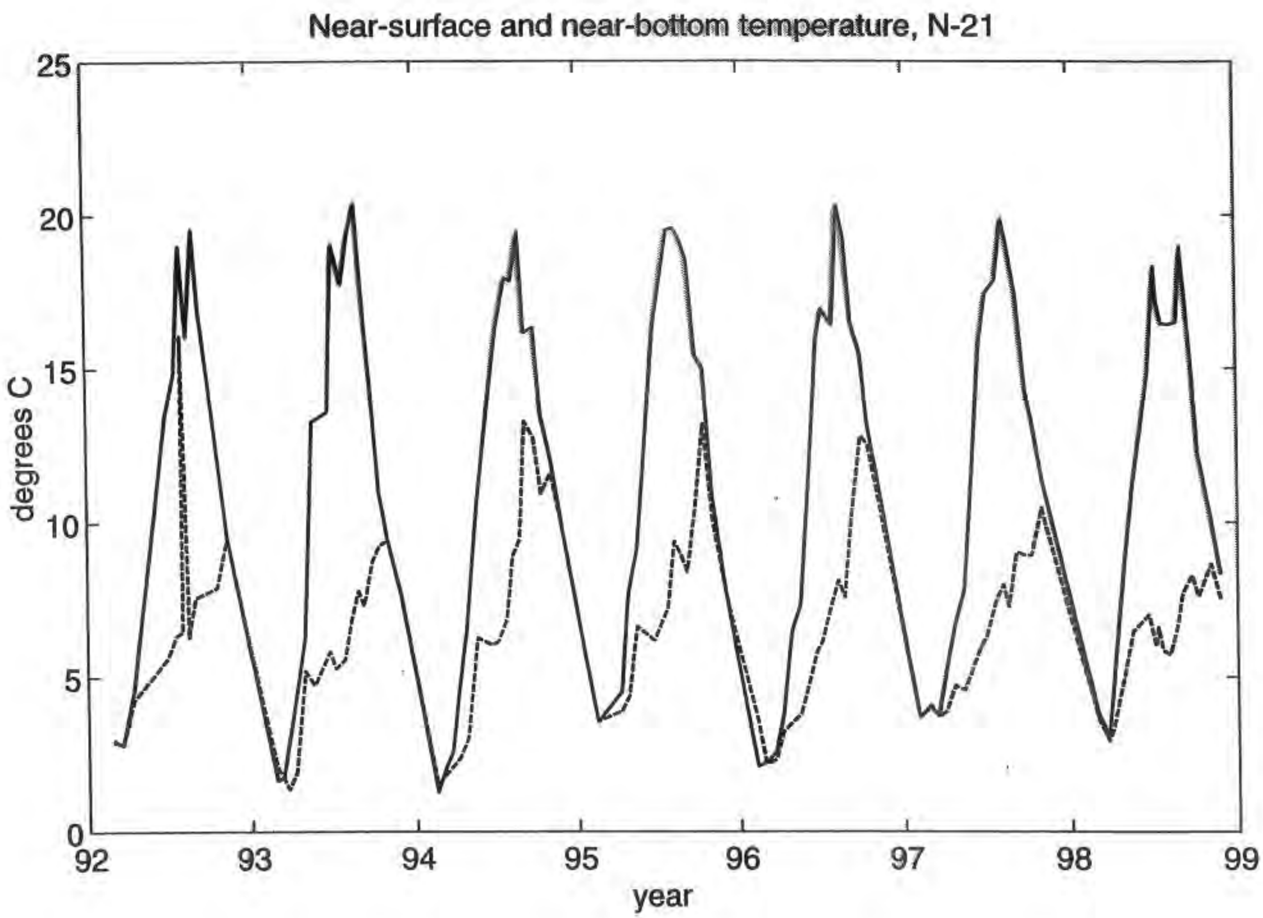

MWRA Water Column Stations
42°45'
42°35'
42°25'
42°15'
42°05'
41°55'
41°45'
41°35'
71°00'
70°30'
70°00'
Nearfield Stations
N01
N02
N03
N04
N05
N06
N07
N08
N09
N10
N11
N12
N13
N14
N15
N16
N17
N18
N19
N20
N21
F01
F02
F03
F05
F06
F07
F10
F12
F13
F14
F15
F16
F17
F18
F19
F22
F23
F24
F25
F26
F27
F28
F29
F30
F31
F32
F33
Deer Island
Diffuser
Nearfield Site
Boston
Stellwagen Basin
Stellwagen Bank
Cape Cod Bay
40 m
70 m
Key
A = All Nutrients
D = All Nutrients and Planktons (5 depths)
E = Dissolved Inorganic Nutrients only
F = Dissolved Inorganic Nutrients plus Dissolved Oxygen
G = All Nutrients and Planktons (3 depths)
Z = Zooplankton only
0
20
km

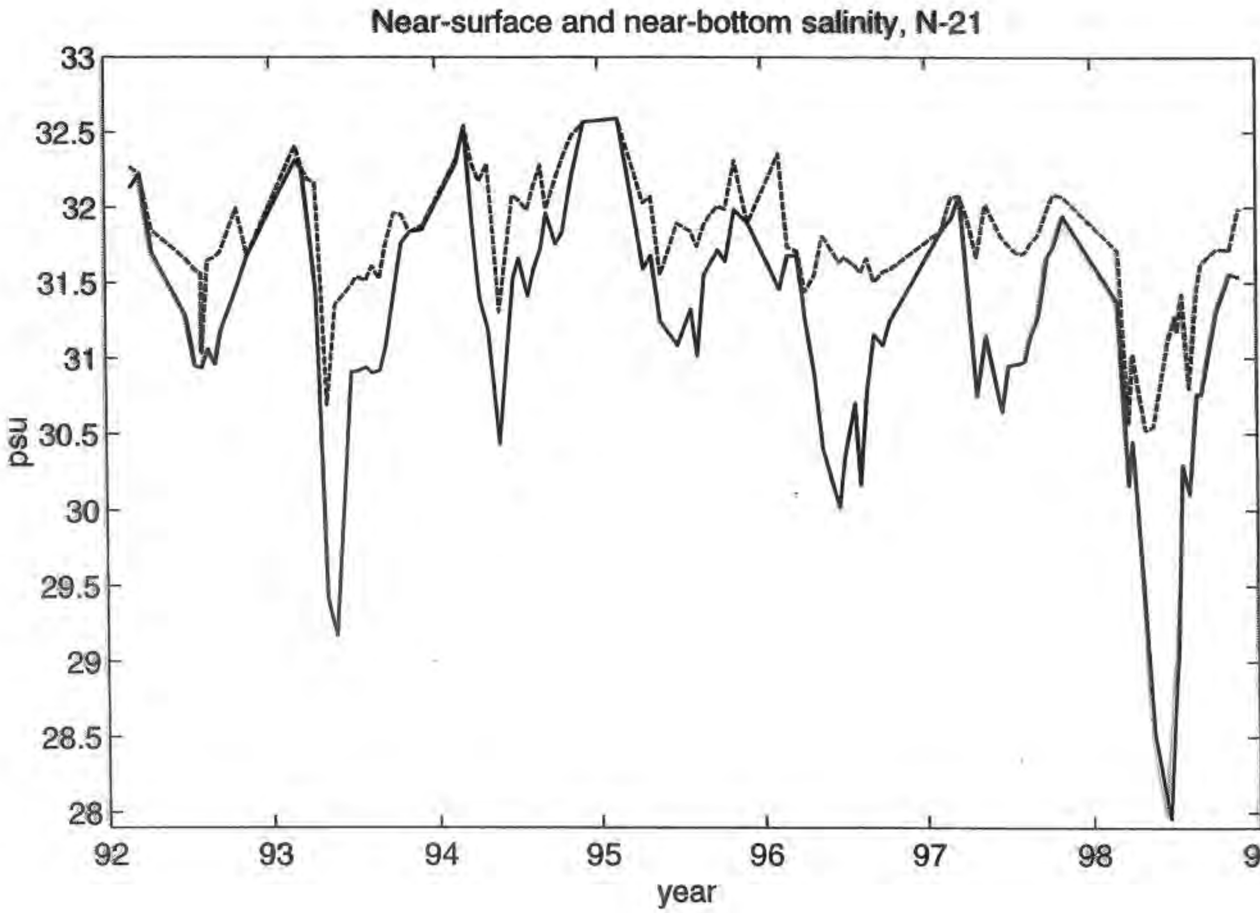

Temperature at N-21
degrees C
25
20
15
10
5
0
2
3
4
5
6
7
8
9
10
11
12
month


Salinity at N-21
psu
33
32
31
30
29
28
27
2
3
4
5
6
7
8
9
10
11
12
month

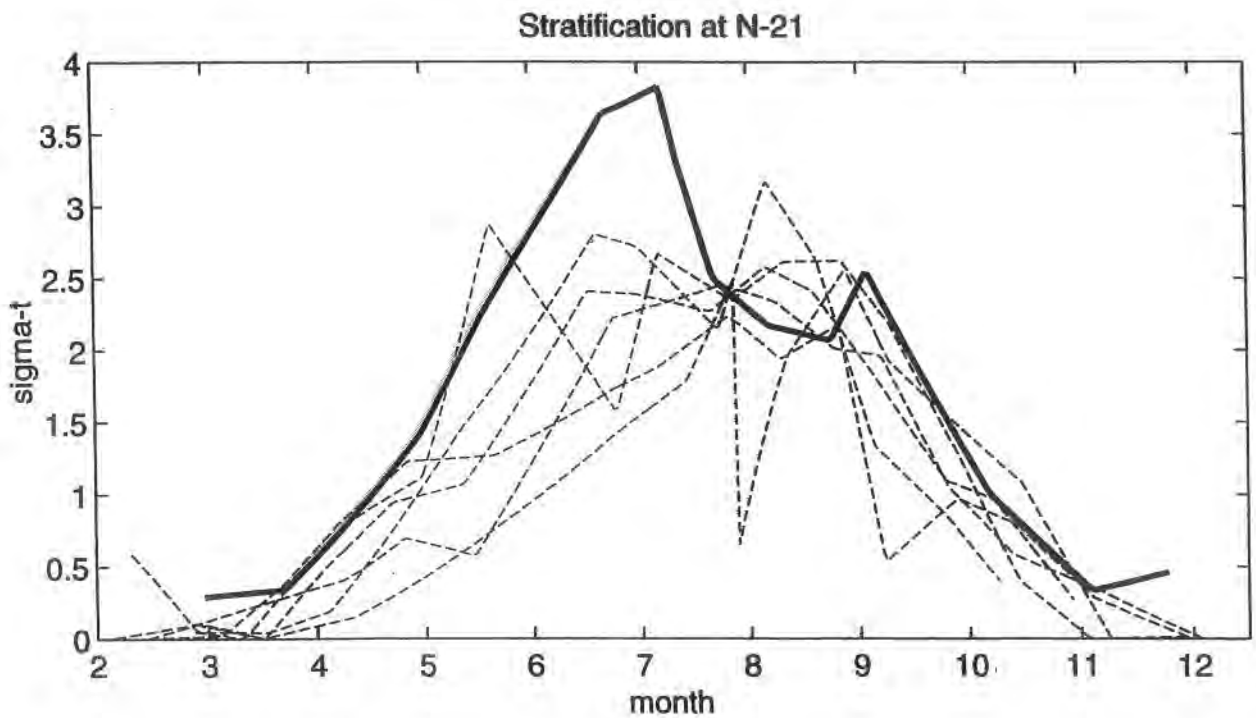

32.5
32
31.5
31
30.5
30
29.5
29
28.5
28
27.5
Salinity
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Boston Buoy and N21 temperature
degrees c
decimal year
22
20
18
16
14
12
10
8
6
4
2
97.8
97.9
98
98.1
98.2
98.3
98.4
98.5
98.6
98.7
98.8


Near-surface and near-bottom temperature, N-21
degrees C
0
5
10
15
20
25
92
93
94
95
96
97
98
99
year



Near-surface and near-bottom salinity, N-21
psu
year
33
32.5
32
31.5
31
30.5
30
29.5
29
28.5
28
92
93
94
95
96
97
98
99

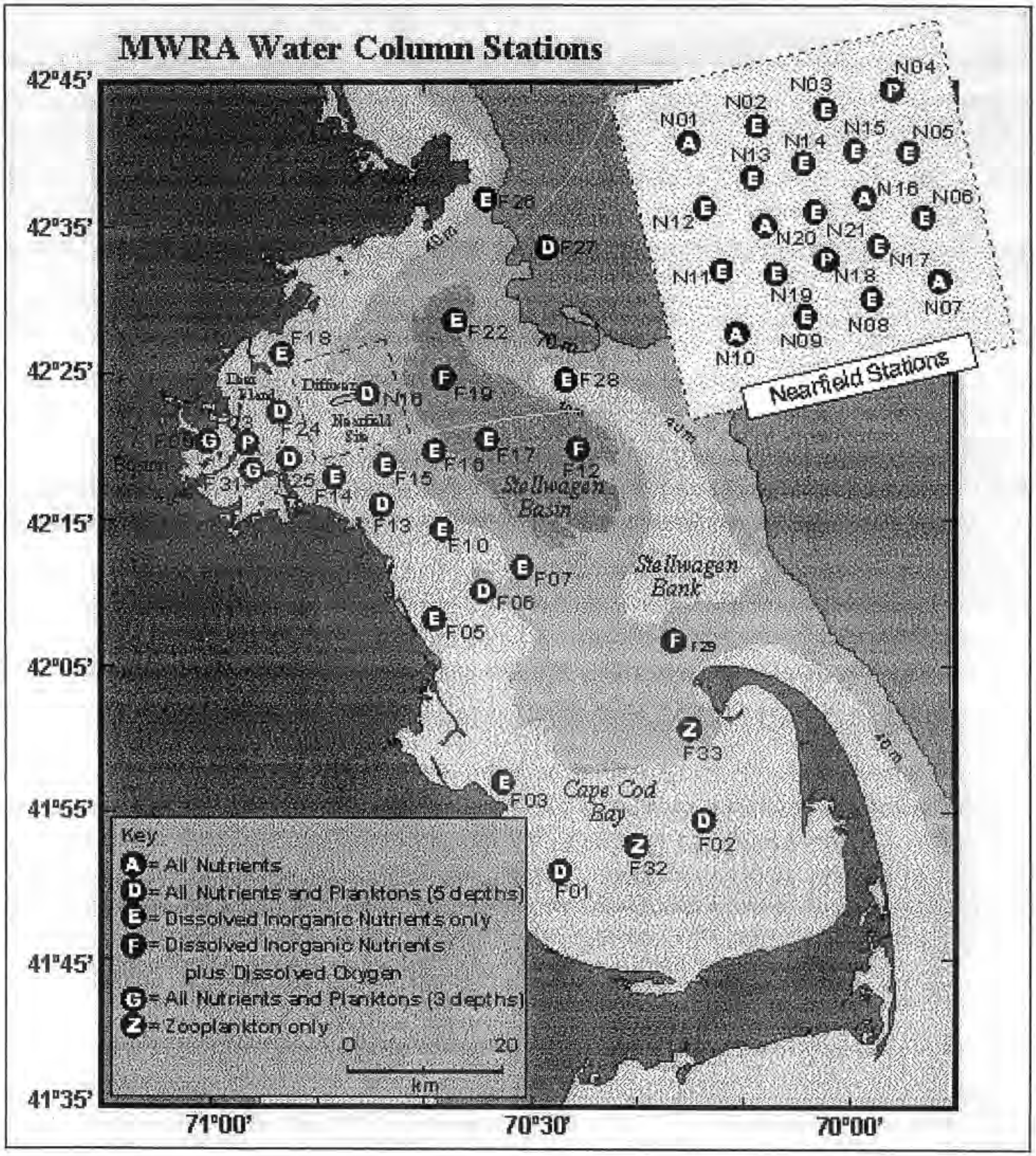

Stratification at N-21
sigma-t
month
0
0.5
1
1.5
2
2.5
3
3.5
4
2
3
4
5
6
7
8
9
10
11
12

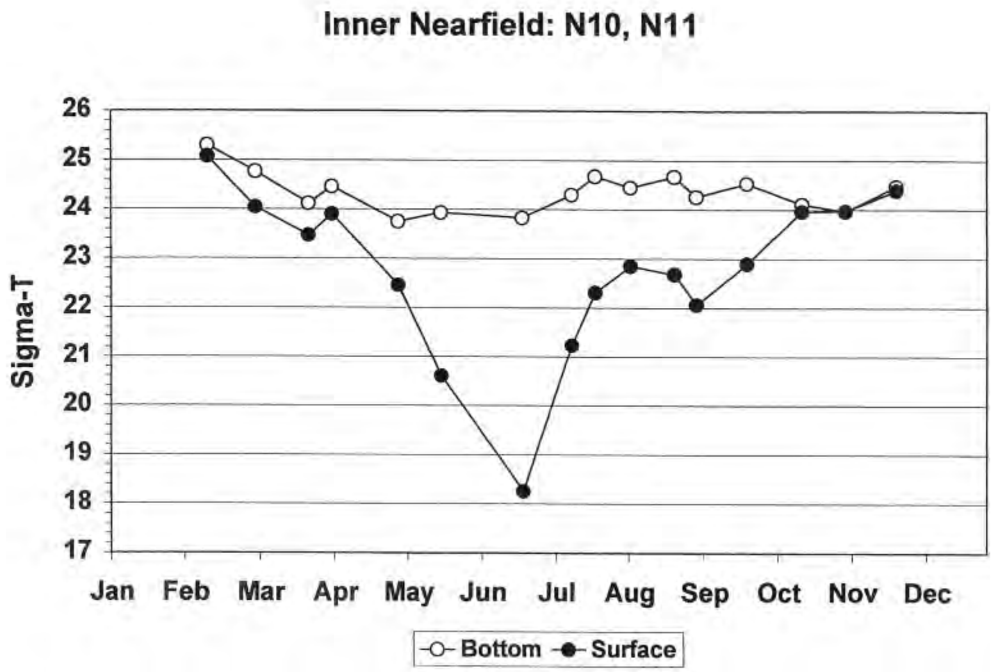
Water Column Monitoring and Nutrient Cycling

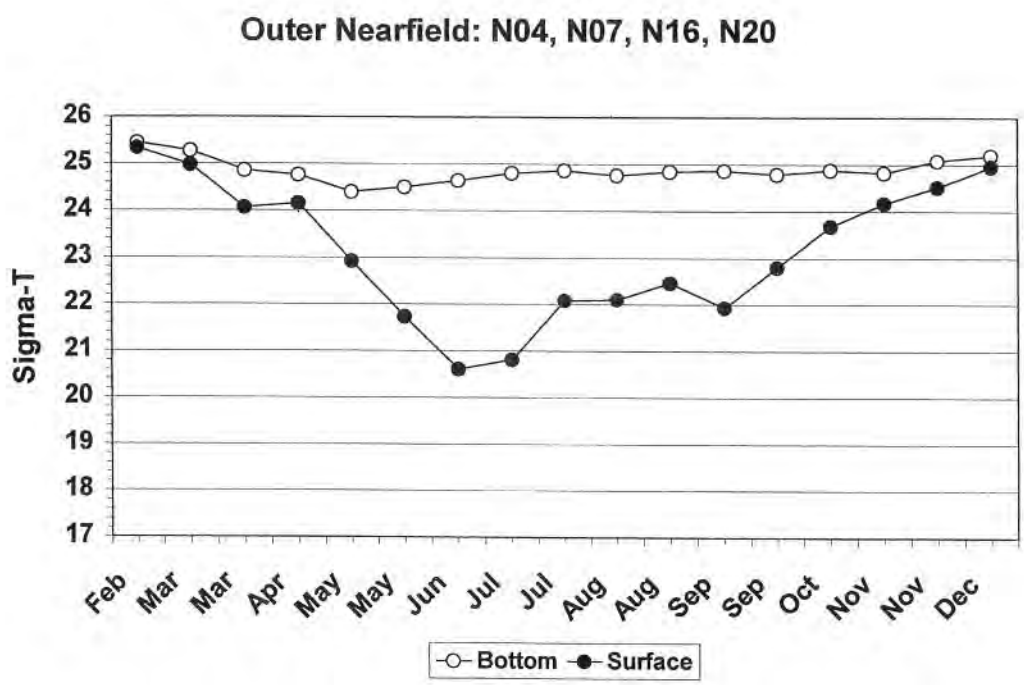
1998 Water Quality Overview *(Mr. Scott Libby, Battelle)*

1998 Nutrient Overview

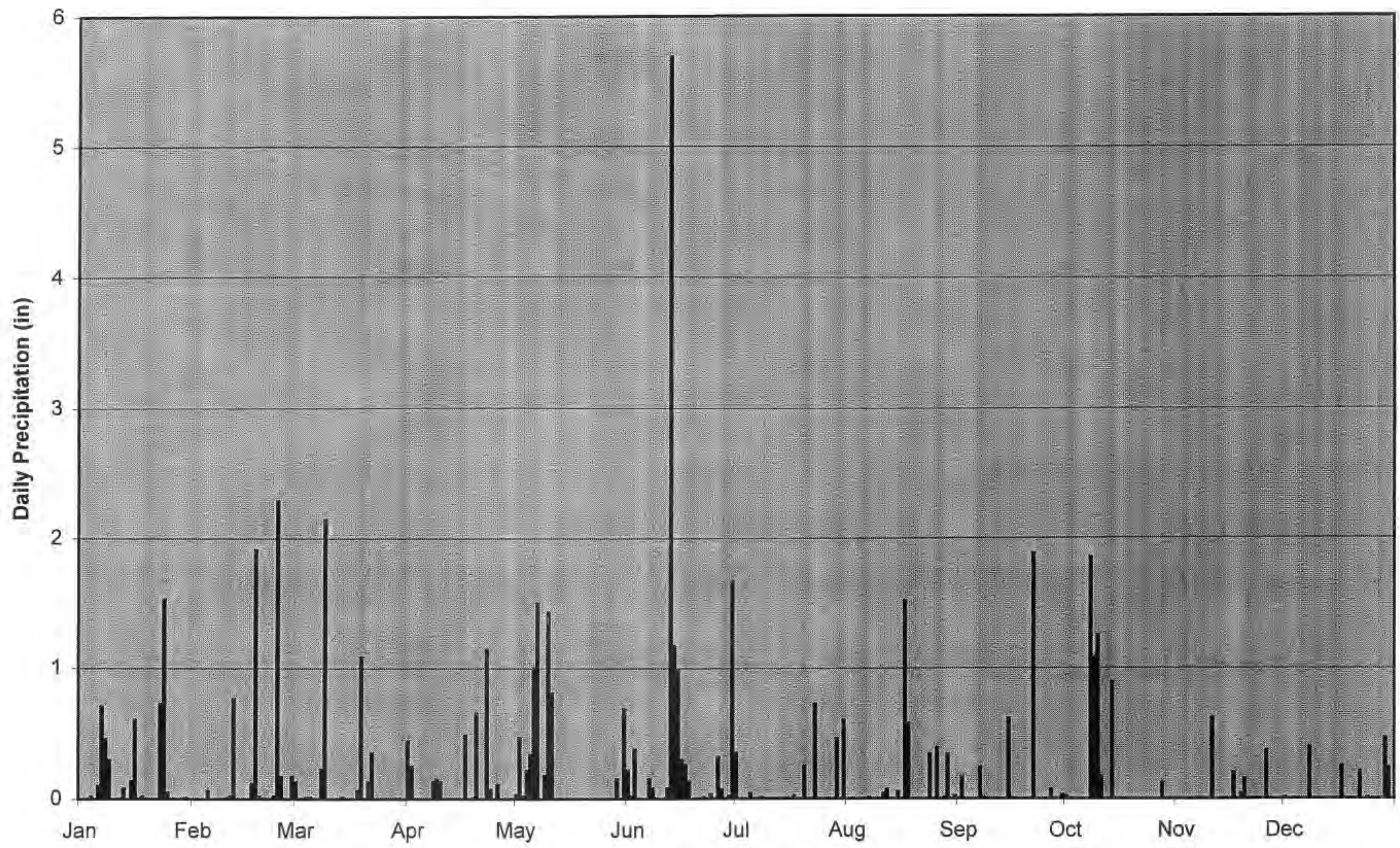
- General Trends - Nutrients, Chla and DO
- 1998 "Events"
- Interannual Comparisons

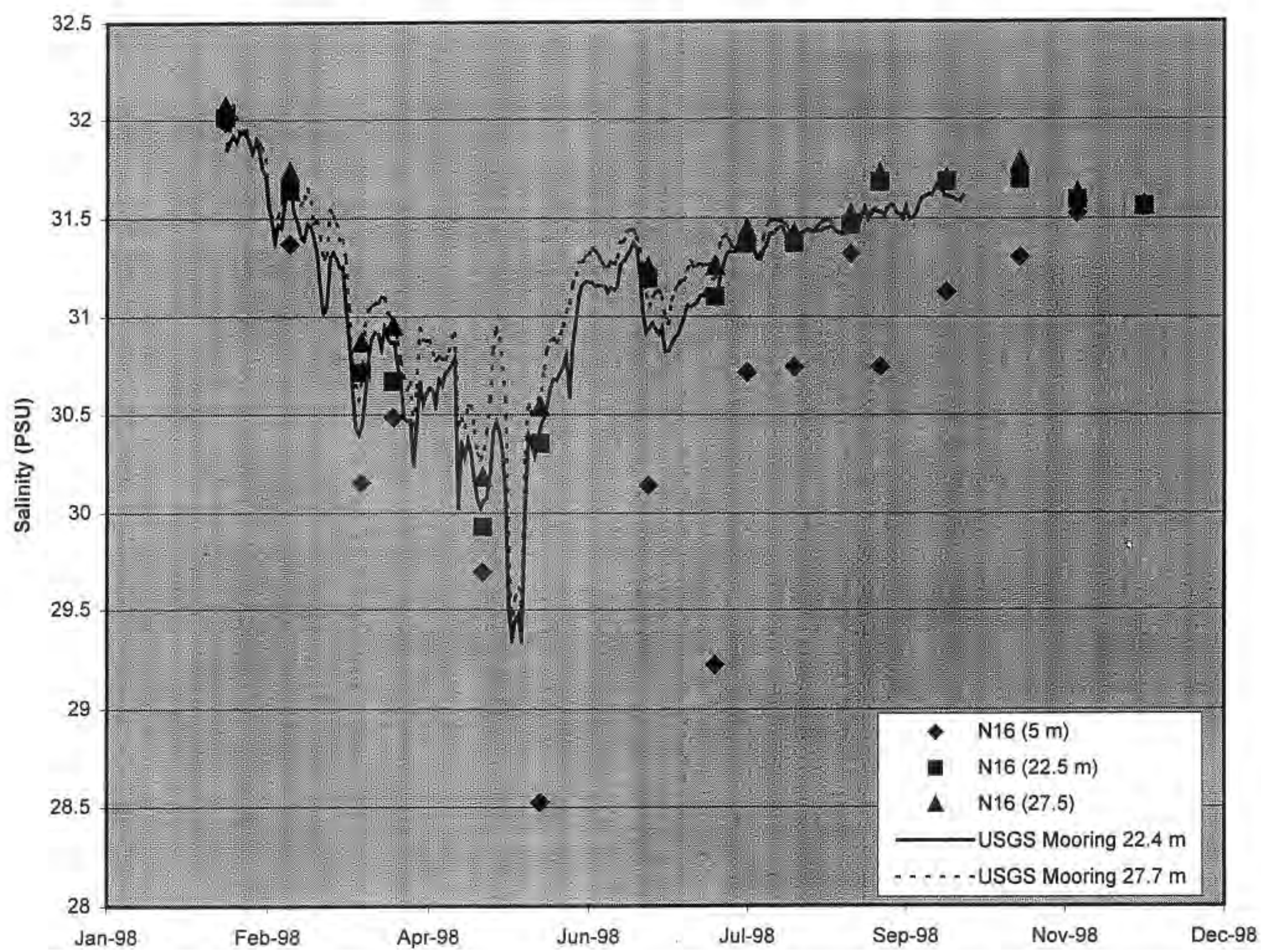

MWRA Water Column Stations
42°45'
42°35'
42°25'
42°15'
42°05'
41°55'
41°45'
41°35'
71°00'
70°30'
70°00'
Nearfield Stations
Stellwagen Basin
Stellwagen Bank
Cape Cod Bay
Key
A = All Nutrients
D = All Nutrients and Planktons (5 depths)
E = Dissolved Inorganic Nutrients only
F = Dissolved Inorganic Nutrients plus Dissolved Oxygen
G = All Nutrients and Planktons (3 depths)
Z = Zooplankton only
0 20
km


Inner Nearfield: N10, N11
Sigma-T
26
25
24
23
22
21
20
19
18
17
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Bottom
Surface


Outer Nearfield: N04, N07, N16, N20
Sigma-T
26
25
24
23
22
21
20
19
18
17
Feb
Mar
Mar
Apr
May
May
Jun
Jul
Jul
Aug
Aug
Sep
Sep
Oct
Nov
Nov
Dec
Bottom
Surface

(c) Boston's Logan Airport Precipitation

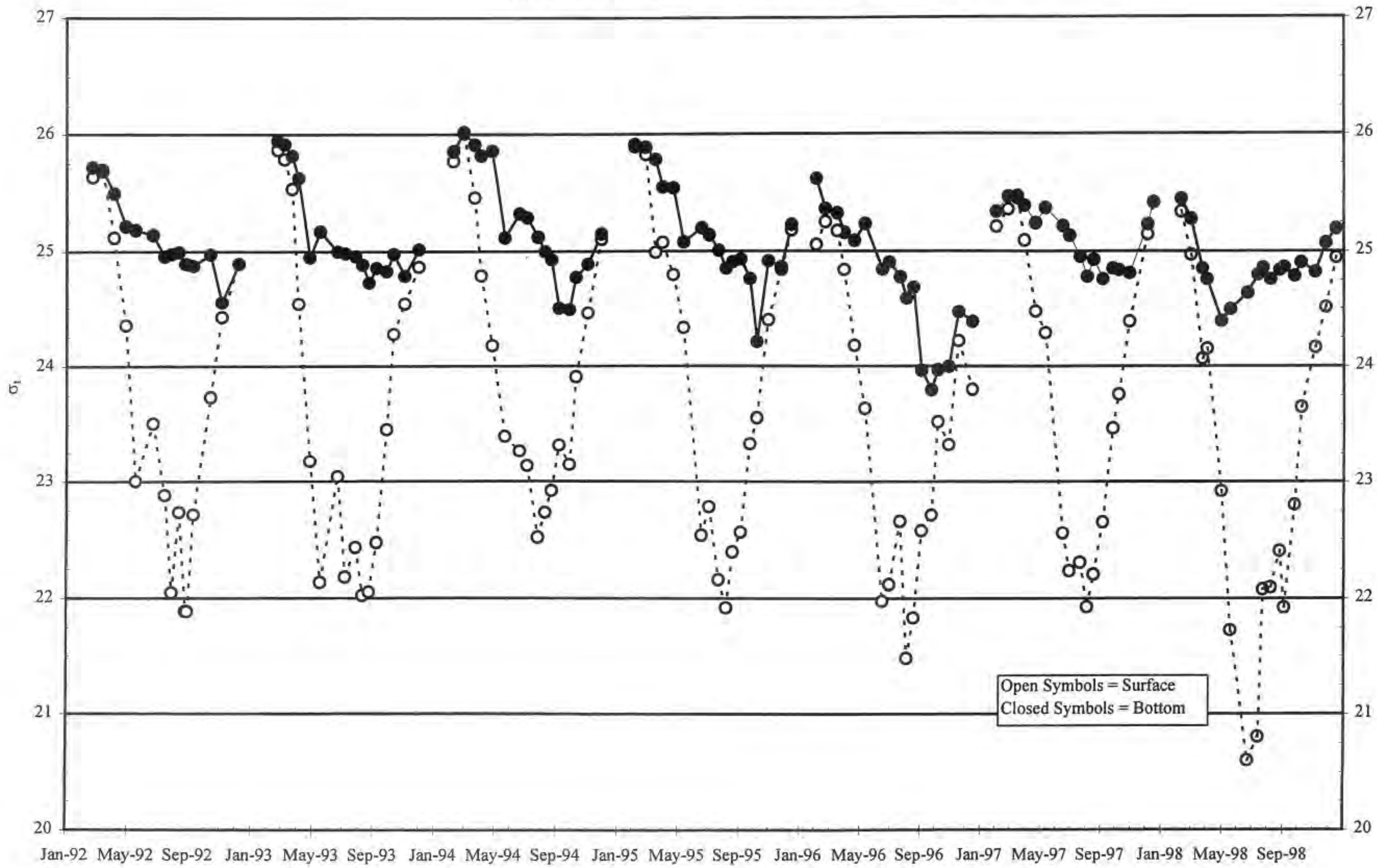




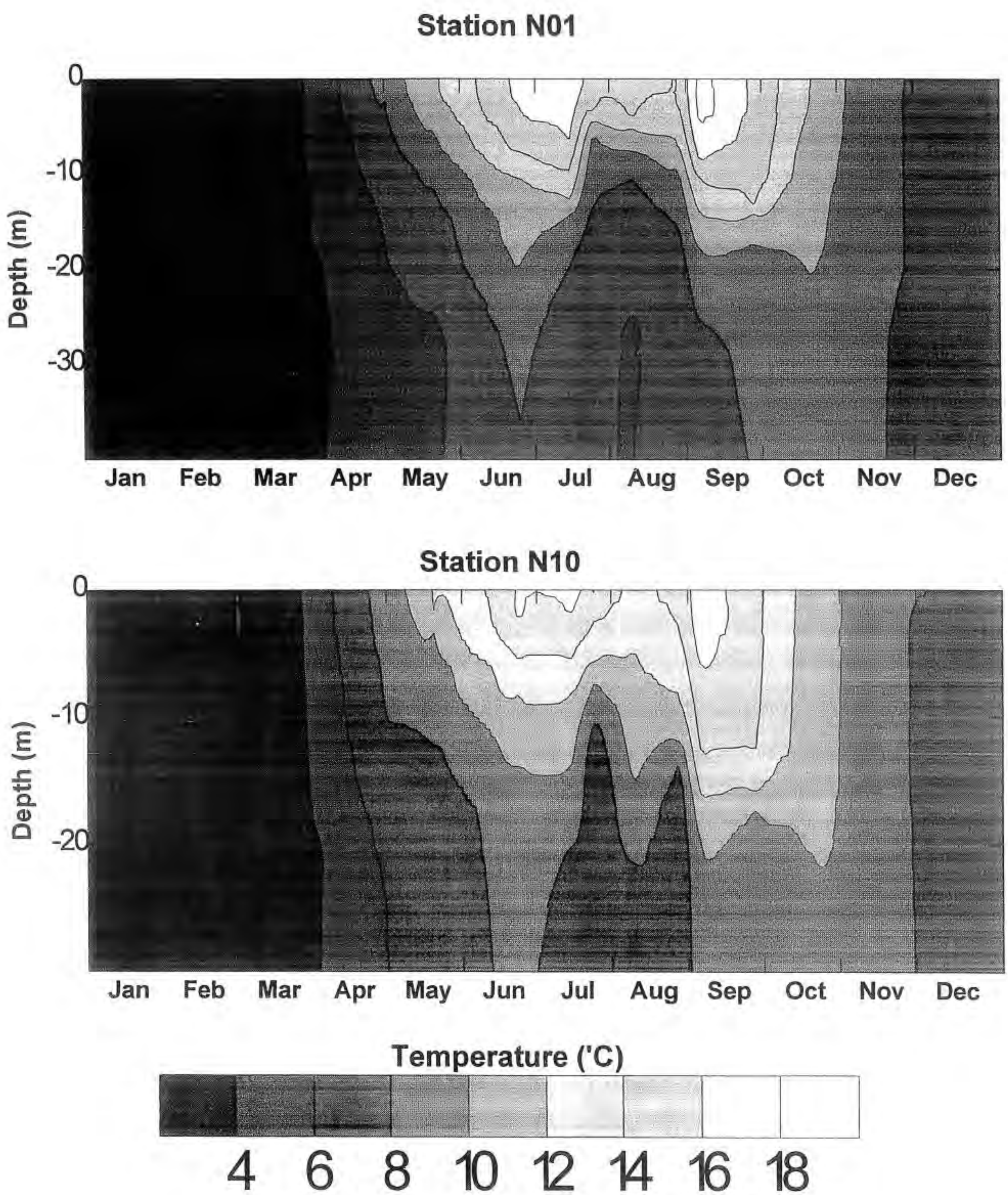
Salinity (PSU)
32.5
32
31.5
31
30.5
30
29.5
29
28.5
28
Jan-98
Feb-98
Apr-98
Jun-98
Jul-98
Sep-98
Nov-98
Dec-98
N16 (5 m)
N16 (22.5 m)
N16 (27.5)
USGS Mooring 22.4 m
USGS Mooring 27.7 m

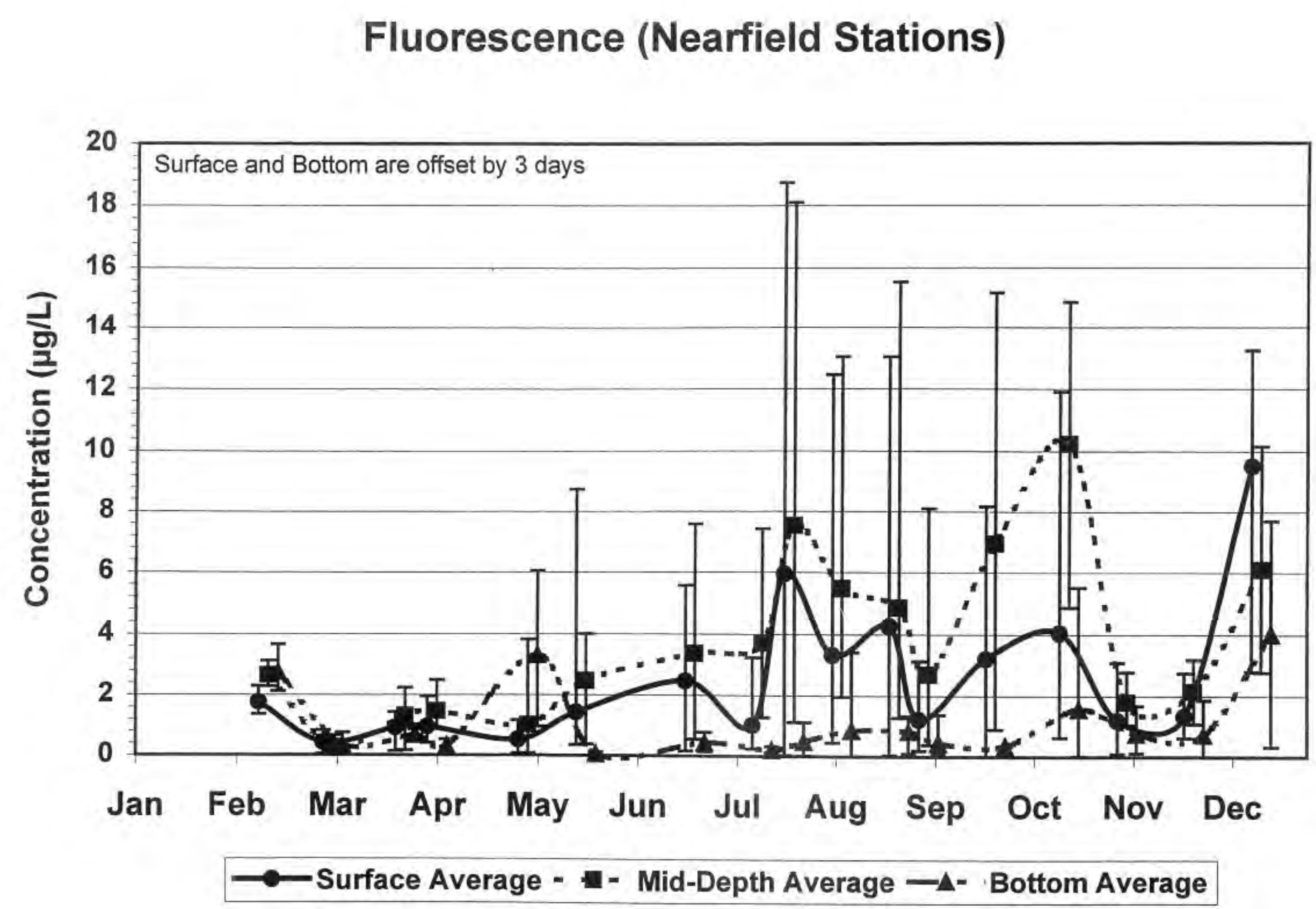
219

(a) Outer Nearfield: N04, N07, N16, N20



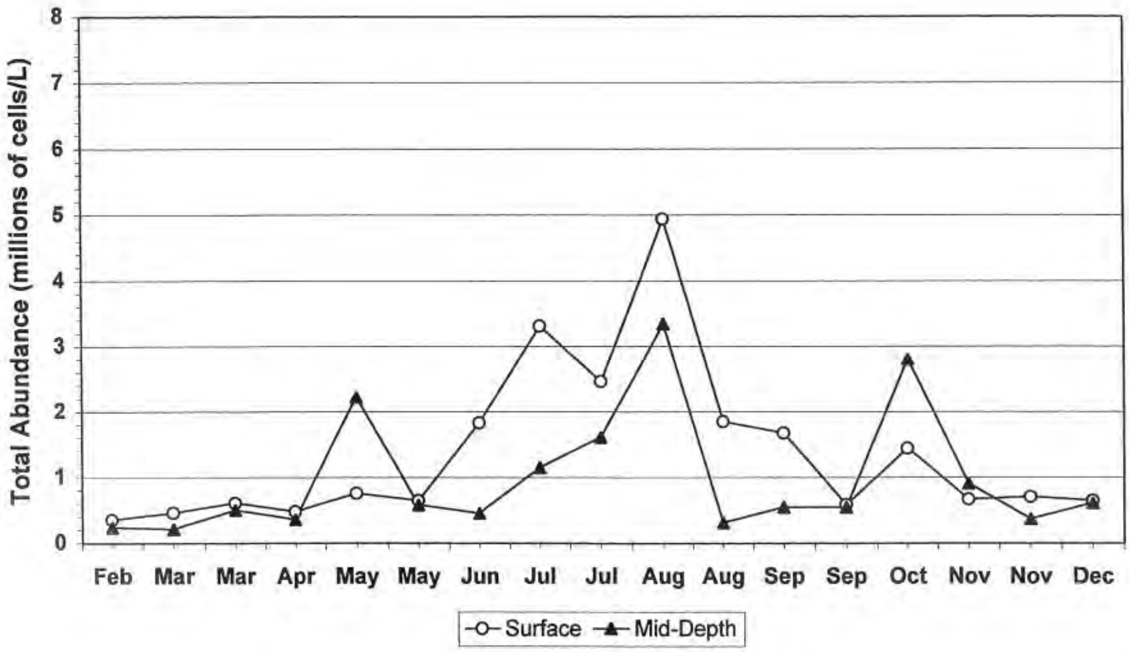
220


Station N01
Depth (m)
0
-10
-20
-30
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Station N10
Depth (m)
0
-10
-20
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Temperature ('C)
4 6 8 10 12 14 16 18

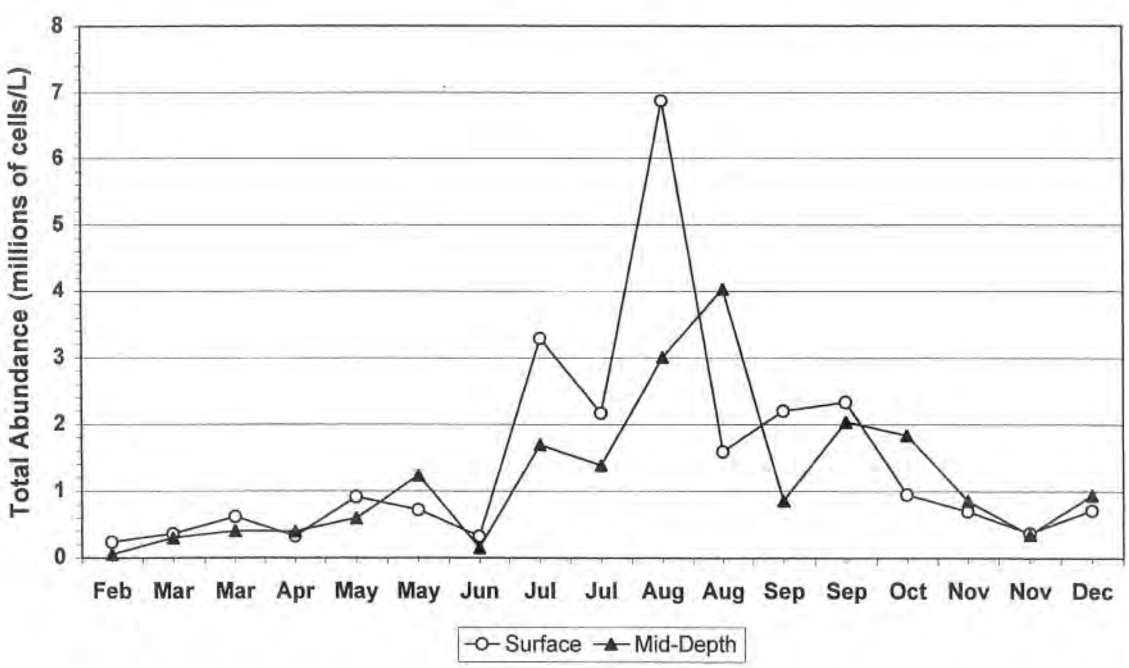


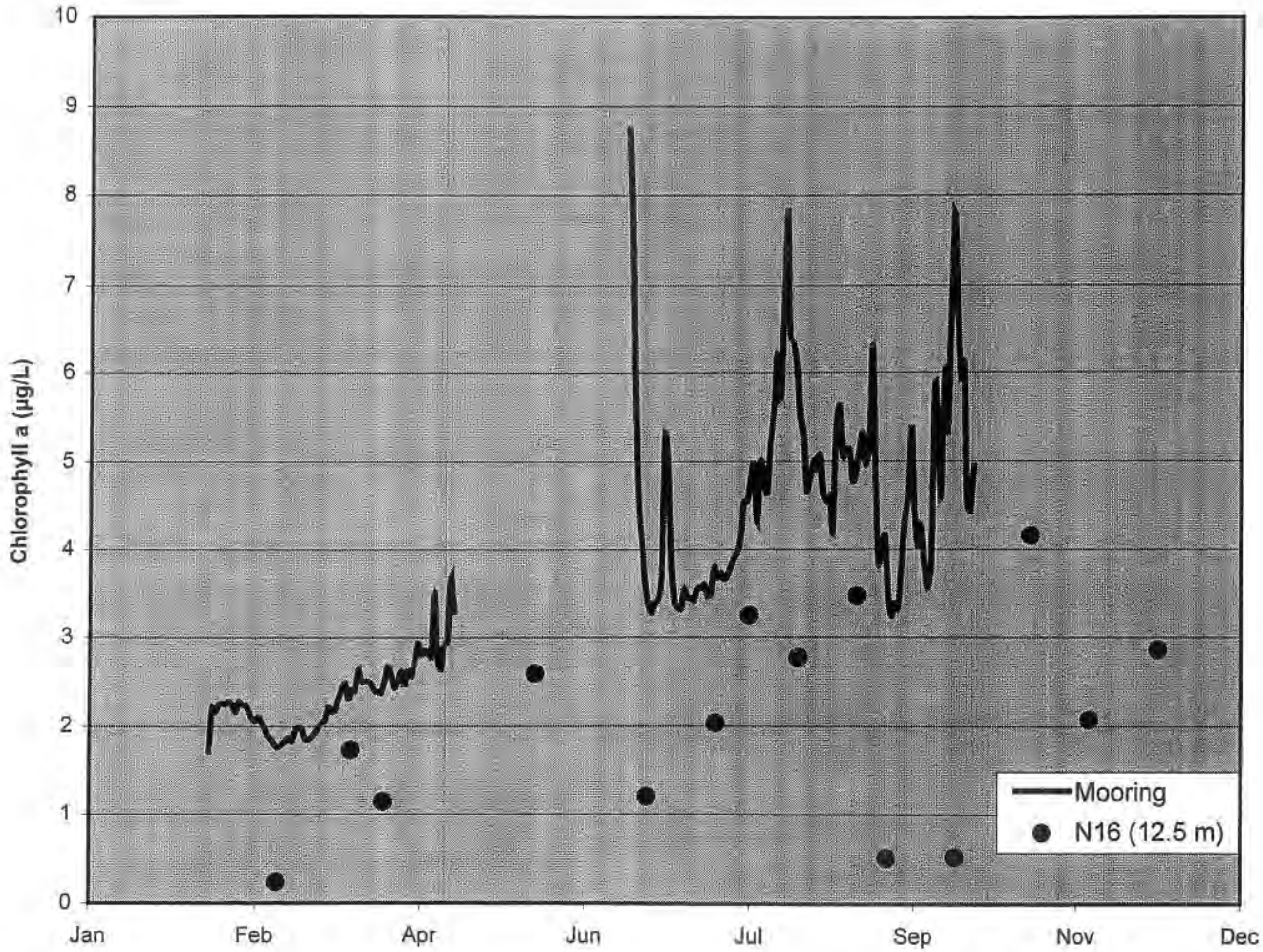
Fluorescence (Nearfield Stations)
Surface and Bottom are offset by 3 days
Concentration (µg/L)
20
18
16
14
12
10
8
6
4
2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Surface Average
Mid-Depth Average
Bottom Average

Station N04

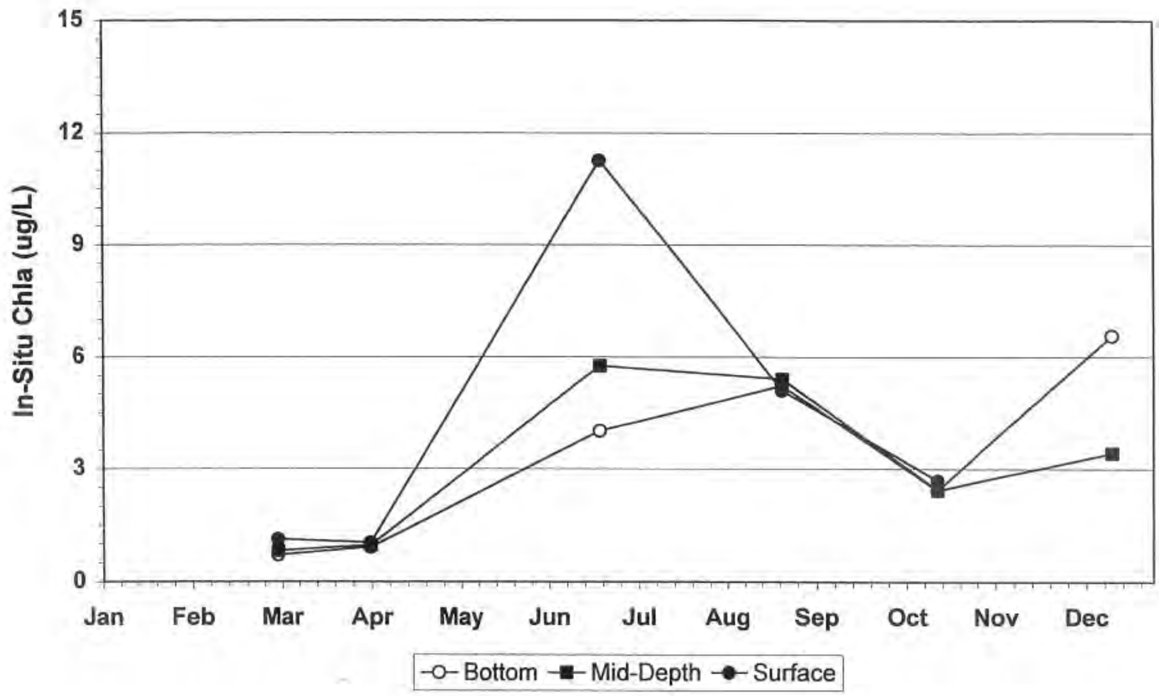


Station N18

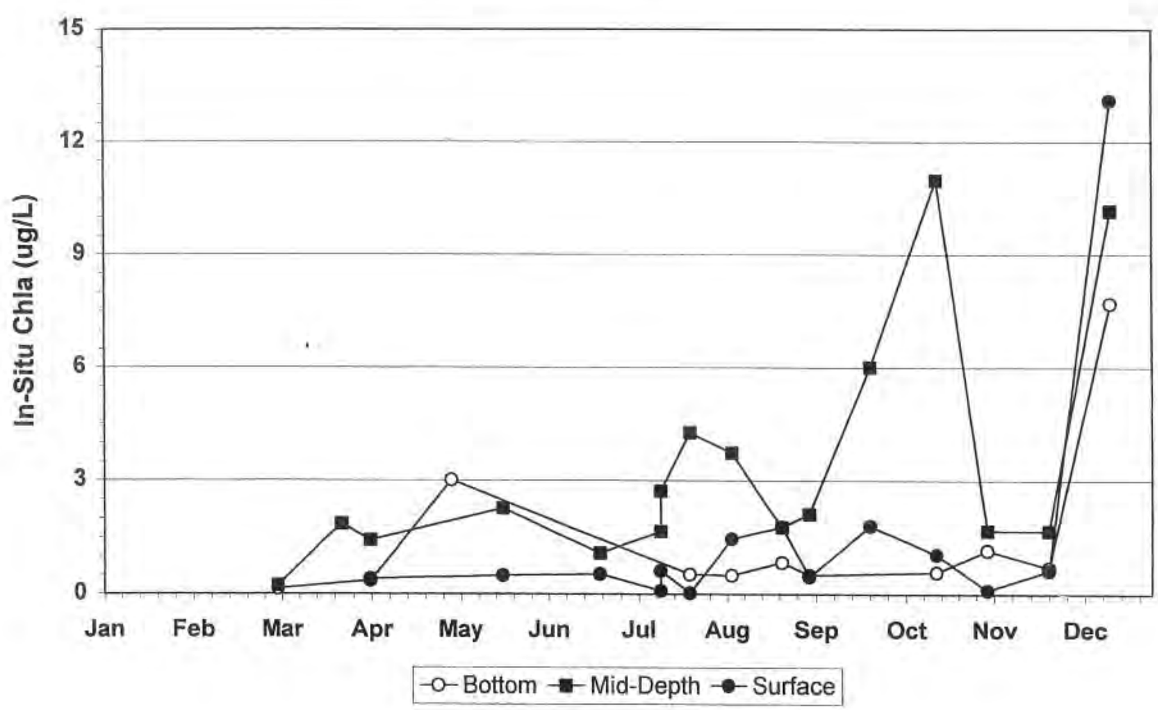



Chlorophyll a (µg/L)
0
1
2
3
4
5
6
7
8
9
10
Jan
Feb
Apr
Jun
Jul
Sep
Nov
Dec
Mooring
N16 (12.5 m)

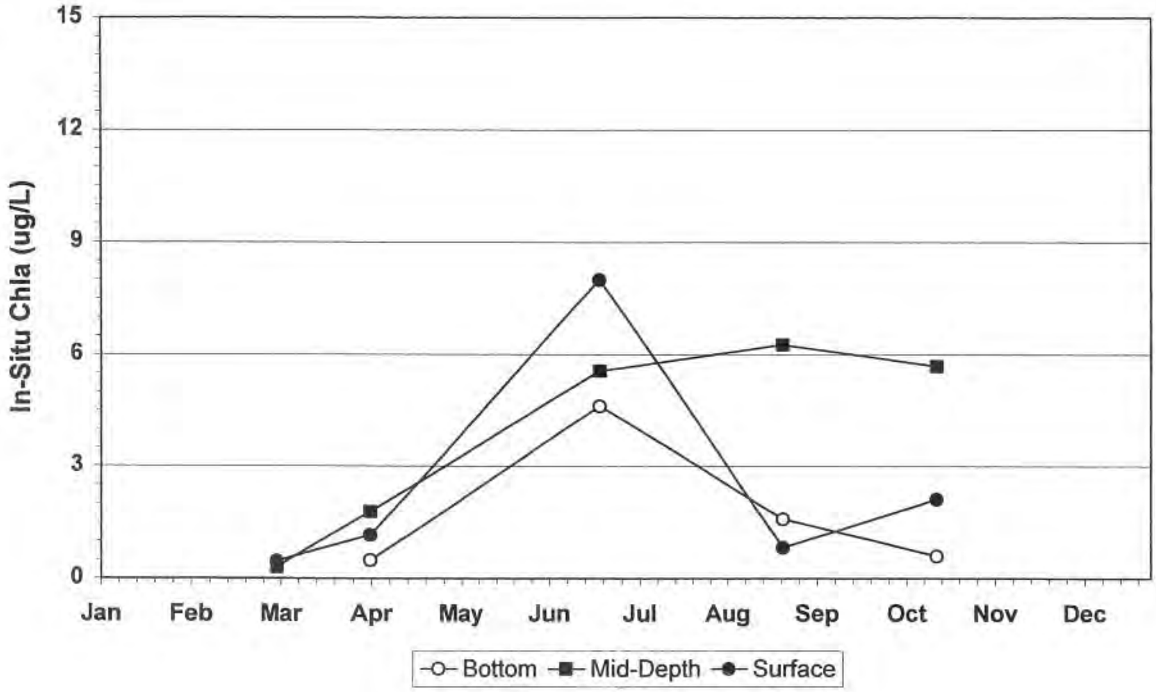
Station F23



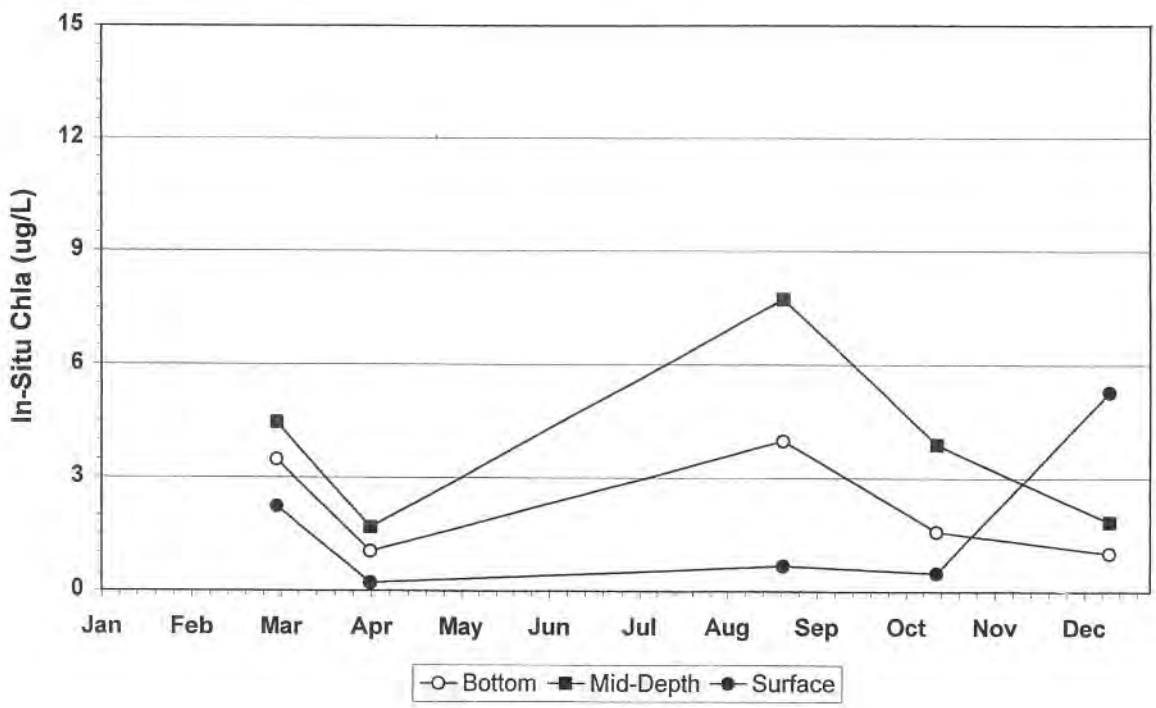
Station N18

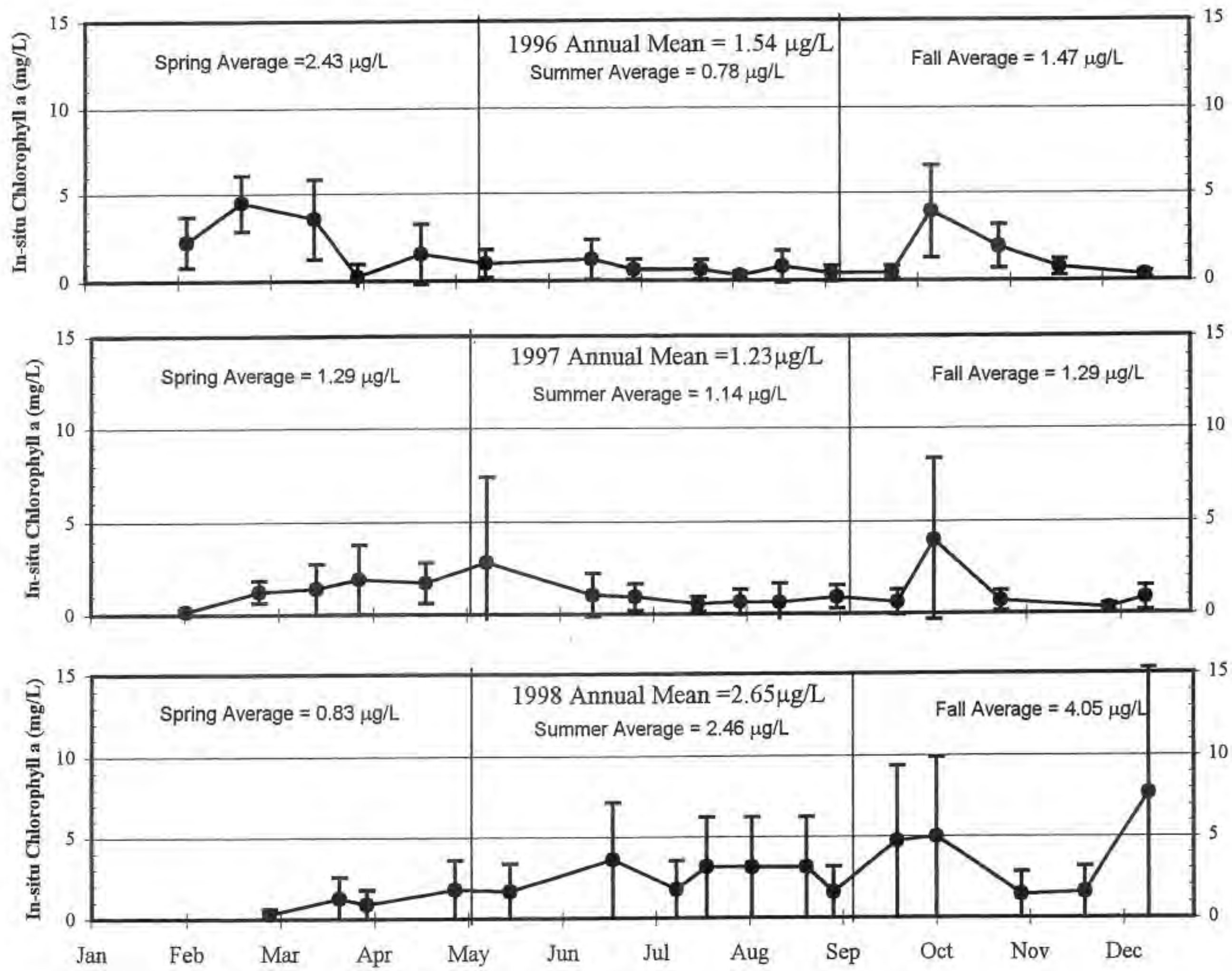


Station F13

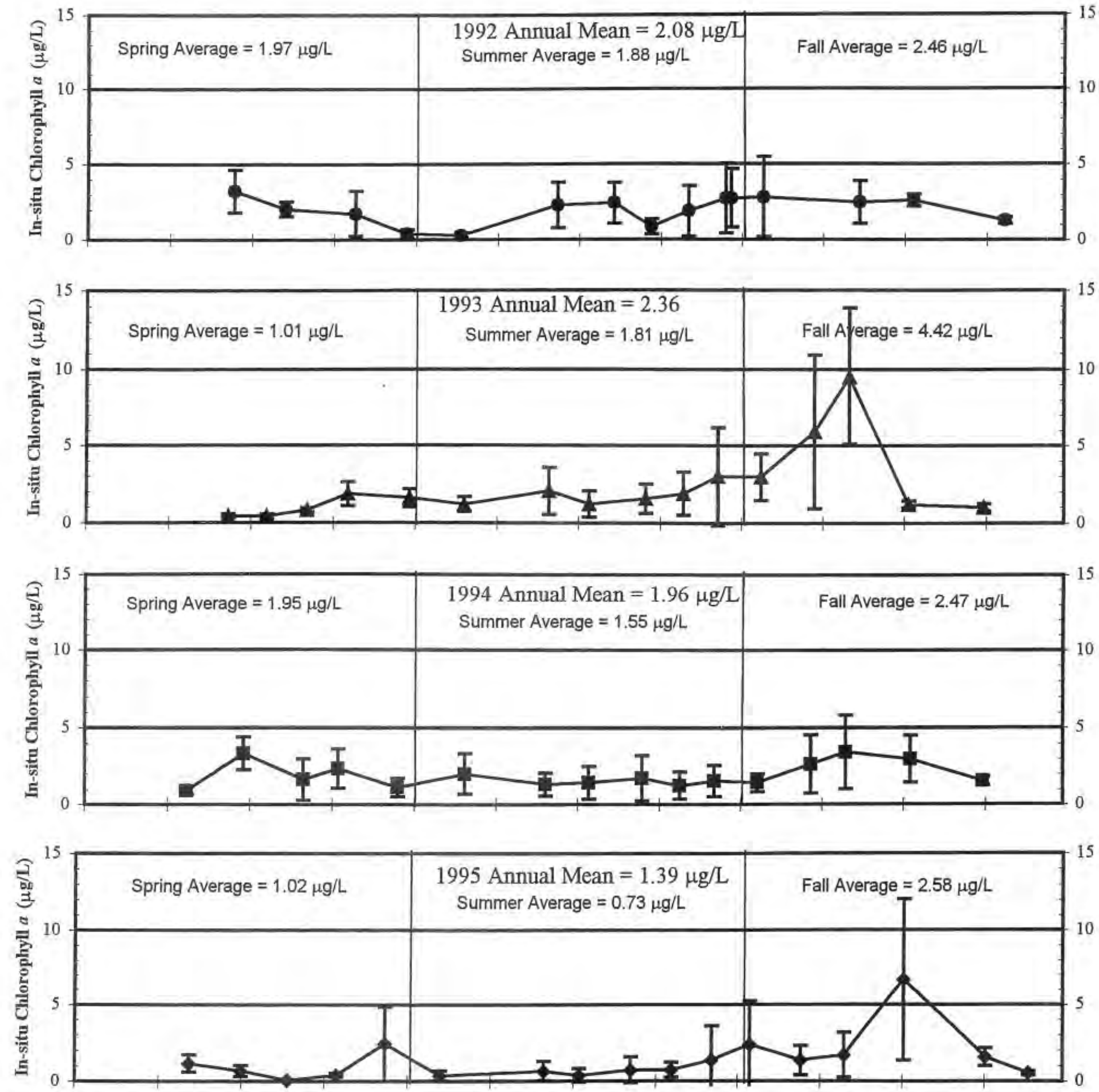


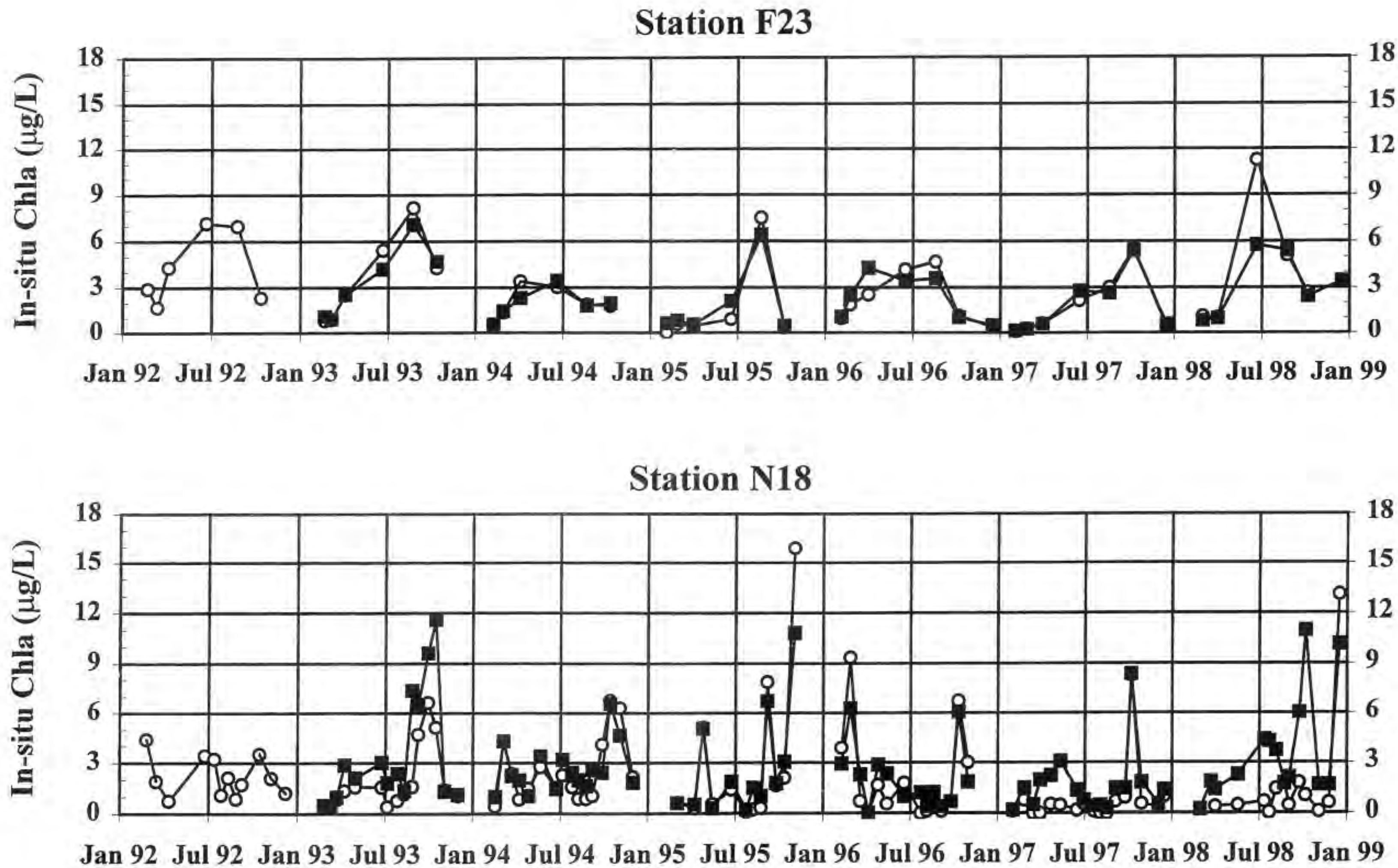
Station F02




1996 Annual Mean = 1.54 µg/L
Spring Average =2.43 µg/L
Summer Average = 0.78 µg/L
Fall Average = 1.47 µg/L
1997 Annual Mean =1.23µg/L
Spring Average = 1.29 µg/L
Summer Average = 1.14 µg/L
Fall Average = 1.29 µg/L
1998 Annual Mean =2.65µg/L
Spring Average = 0.83 µg/L
Summer Average = 2.46 µg/L
Fall Average = 4.05 µg/L
In-situ Chlorophyll a (mg/L)
0
5
10
15
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

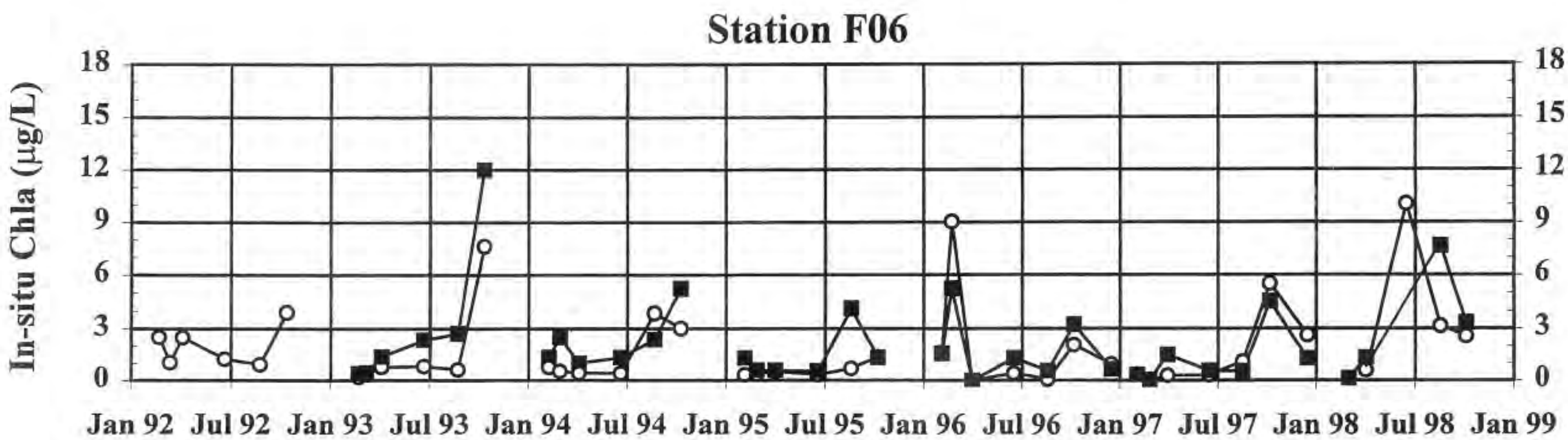
227

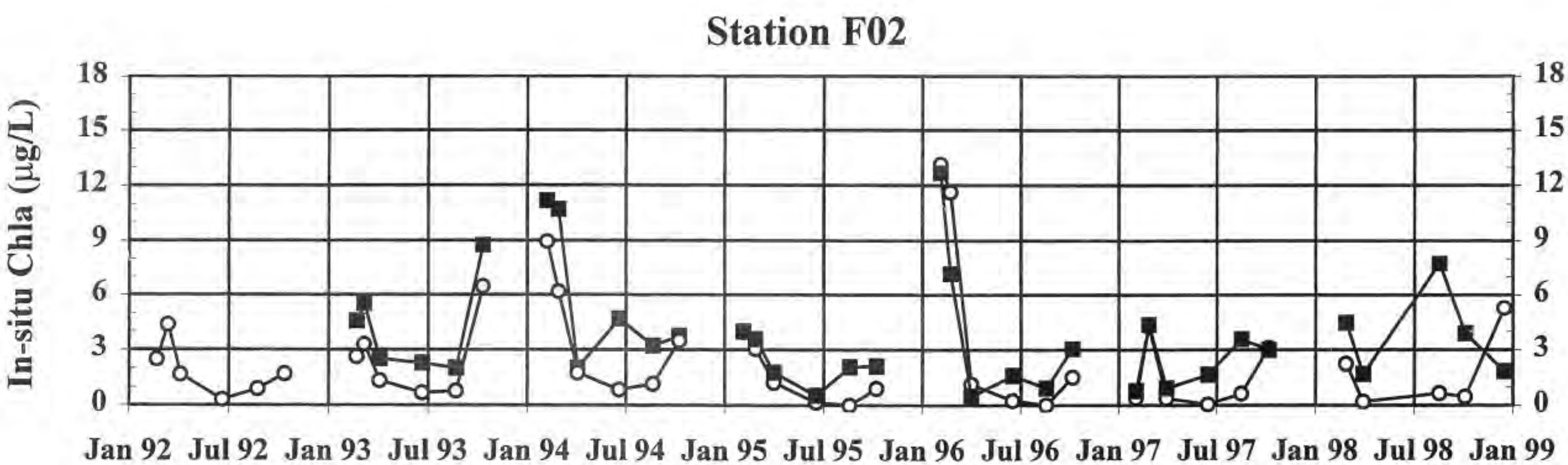

In-situ Chlorophyll a (µg/L)
1992 Annual Mean = 2.08 µg/L
Spring Average = 1.97 µg/L
Summer Average = 1.88 µg/L
Fall Average = 2.46 µg/L
1993 Annual Mean = 2.36
Spring Average = 1.01 µg/L
Summer Average = 1.81 µg/L
Fall Average = 4.42 µg/L
1994 Annual Mean = 1.96 µg/L
Spring Average = 1.95 µg/L
Summer Average = 1.55 µg/L
Fall Average = 2.47 µg/L
1995 Annual Mean = 1.39 µg/L
Spring Average = 1.02 µg/L
Summer Average = 0.73 µg/L
Fall Average = 2.58 µg/L
0
5
10
15



Interannual In-situ Fluorescence

Circles = Surface (A); Squares = Mid-Depth (C)

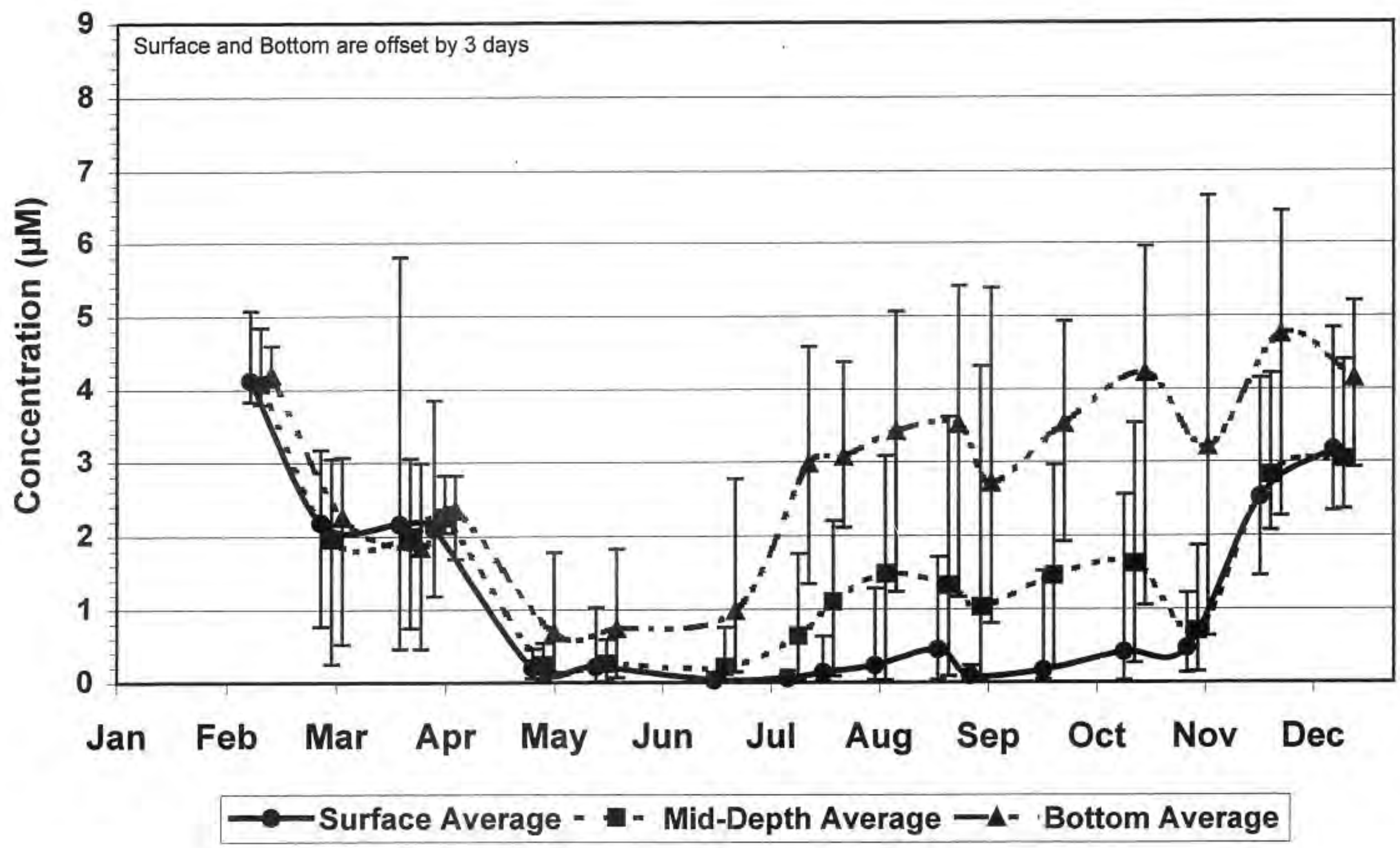


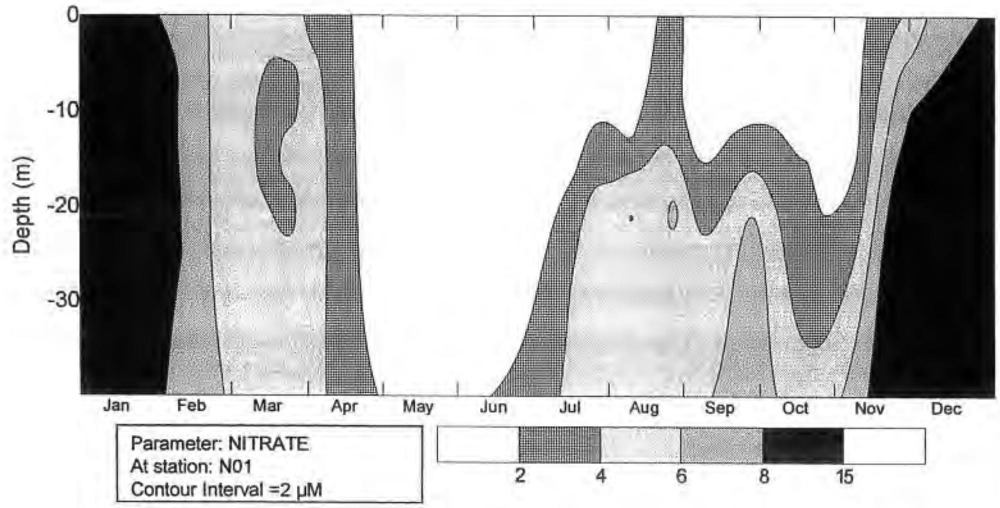


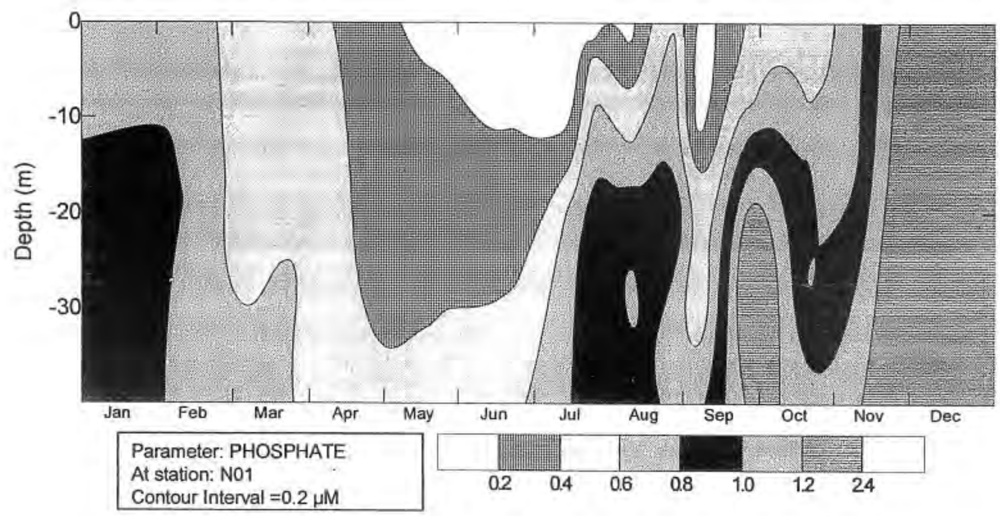
Interannual In-situ Fluorescence

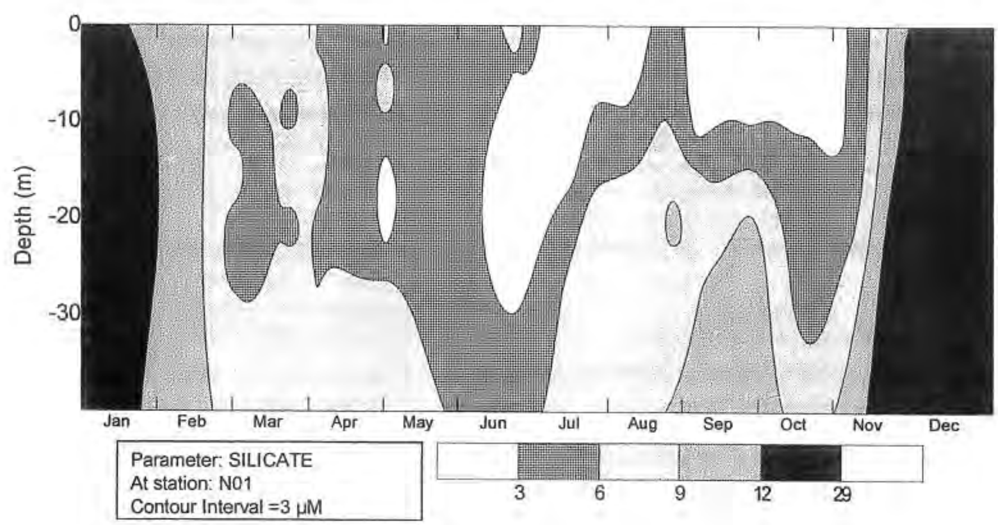
Circles = Surface (A); Squares = Mid-Depth (C)

Nitrate + Nitrite (Nearfield Stations)

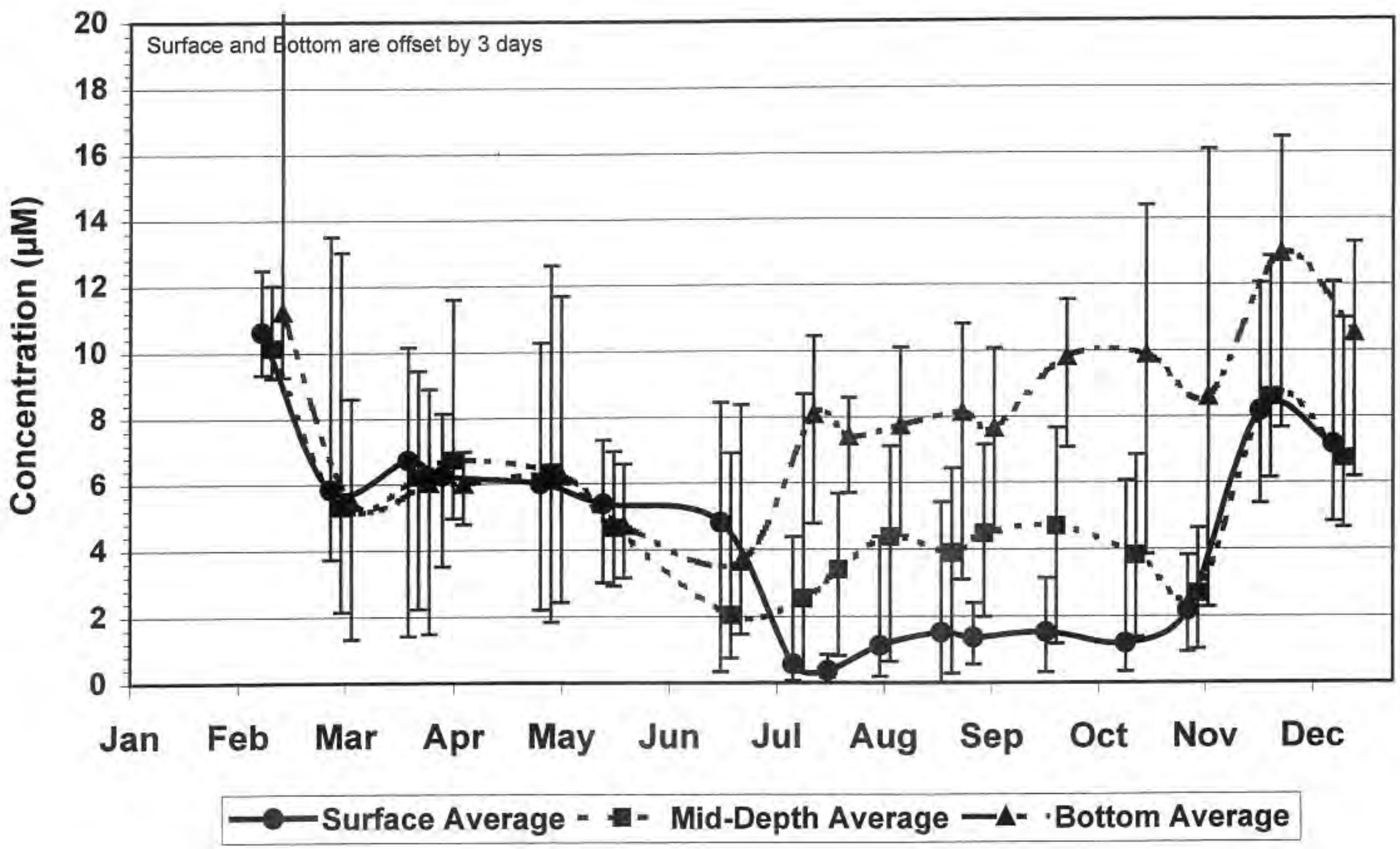



0
-10
-20
-30
Depth (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Parameter: NITRATE
At station: N01
Contour Interval =2 µM
2
4
6
8
15

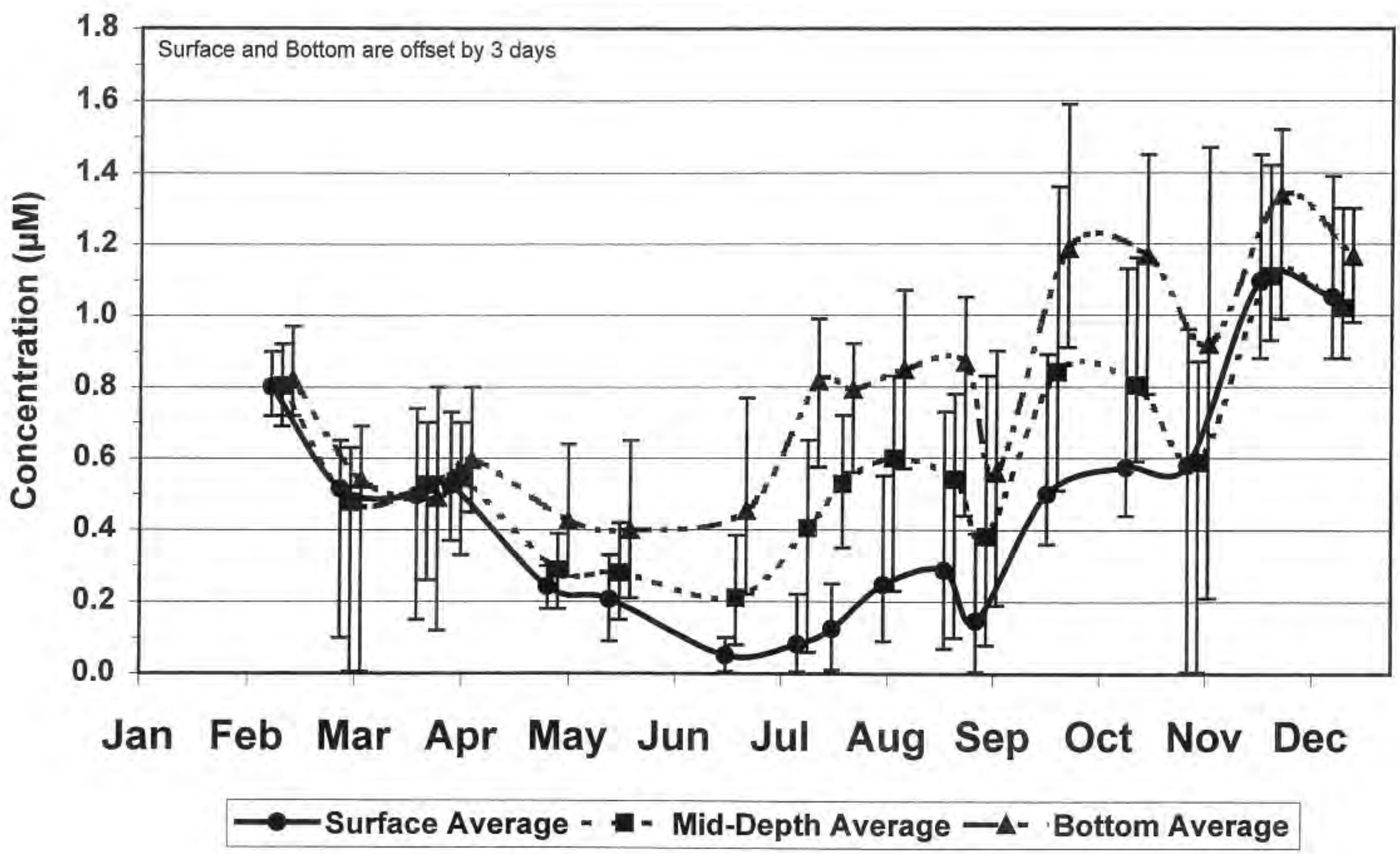

0
-10
-20
-30
Depth (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Parameter: PHOSPHATE
At station: N01
Contour Interval =0.2 µM
0.2
0.4
0.6
0.8
1.0
1.2
2.4


0
-10
-20
-30
Depth (m)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Parameter: SILICATE
At station: N01
Contour Interval =3 µM
3
6
9
12
29

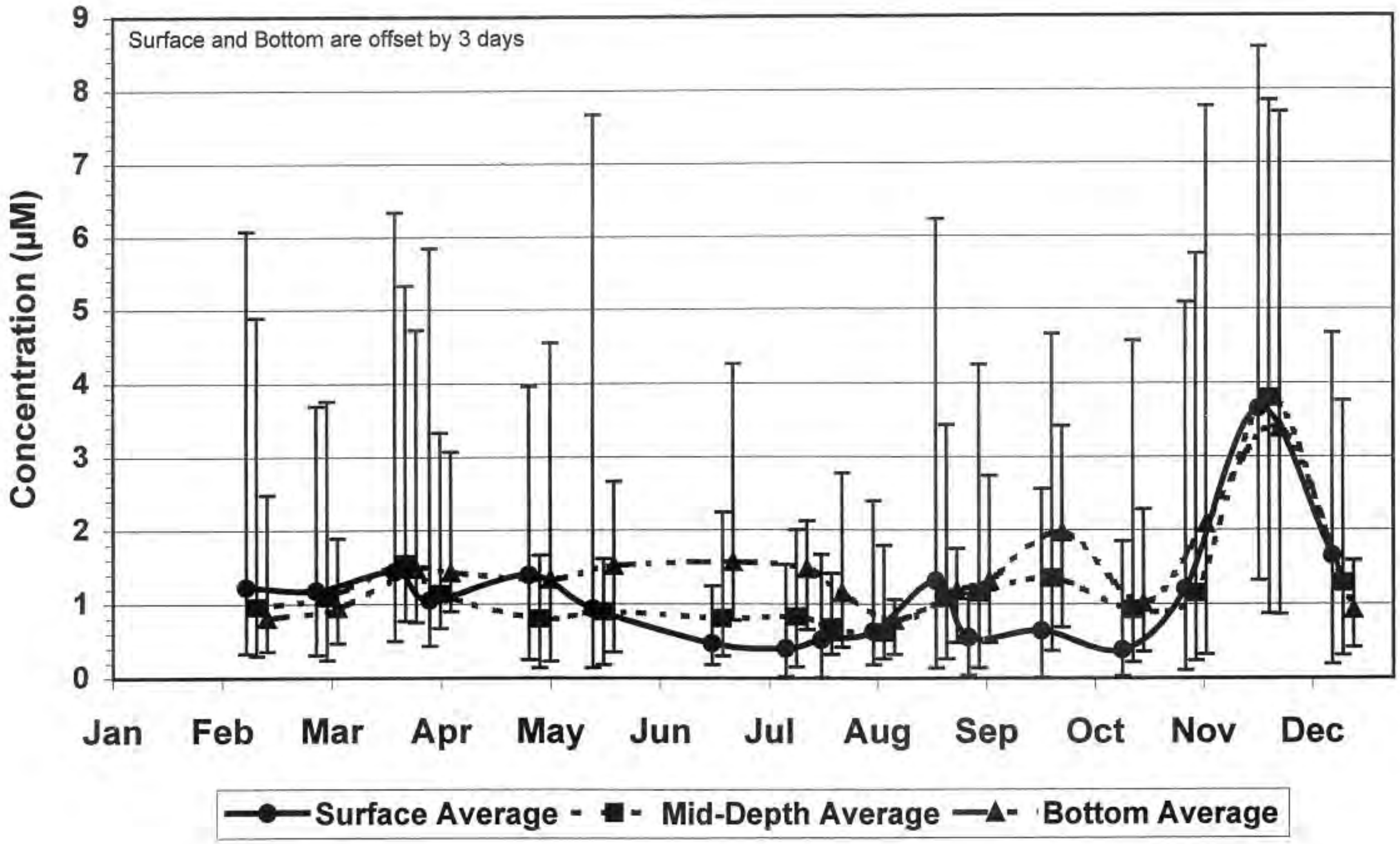
Silicate (Nearfield Stations)

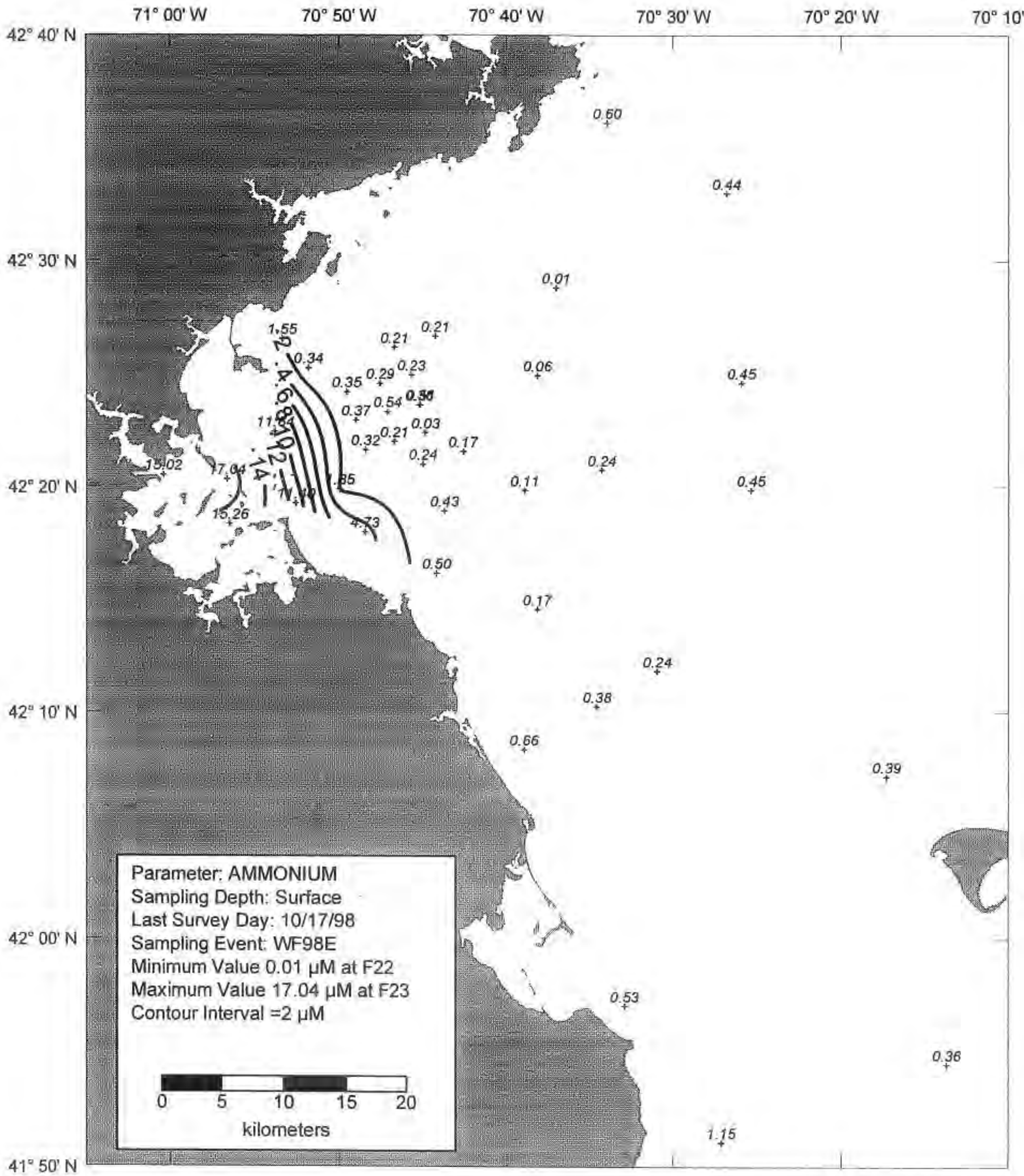


Phosphate (Nearfield Stations)

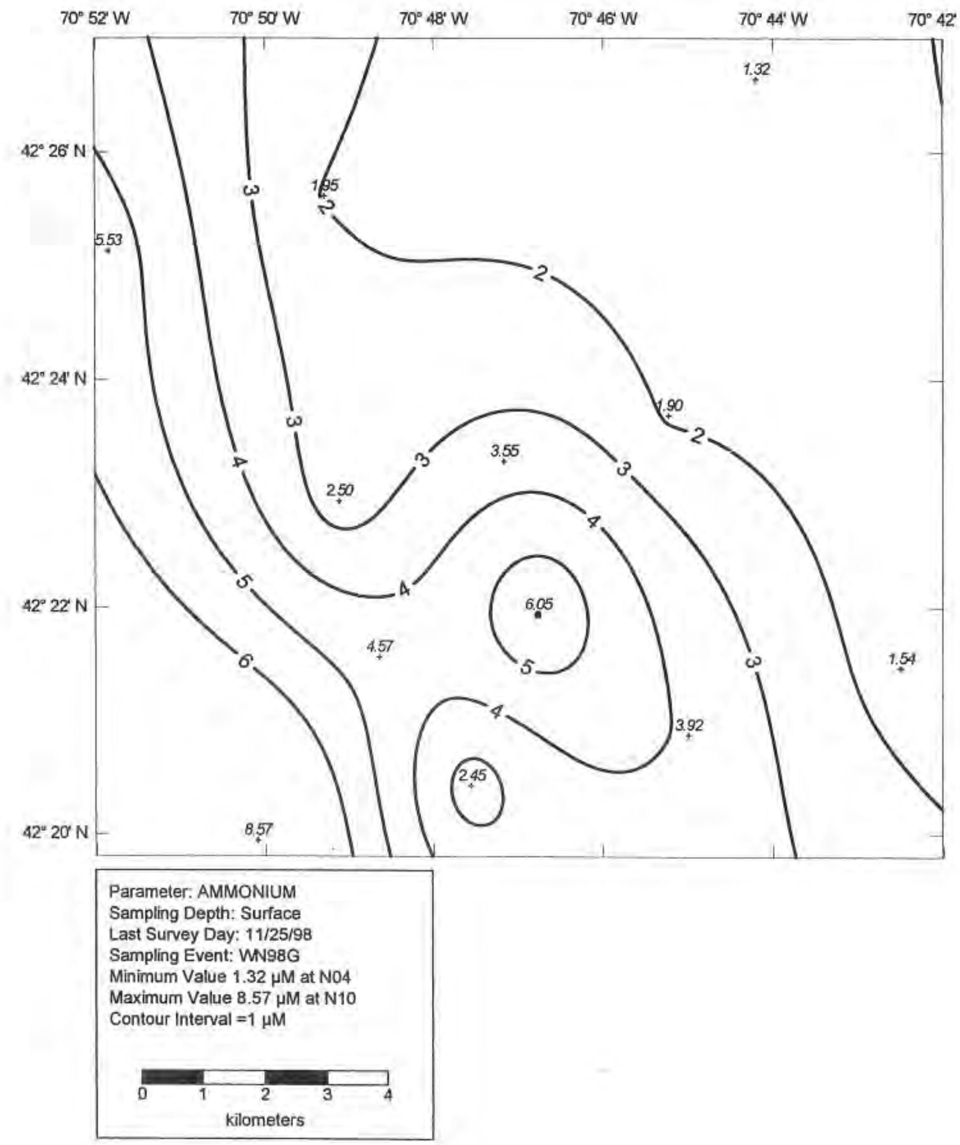


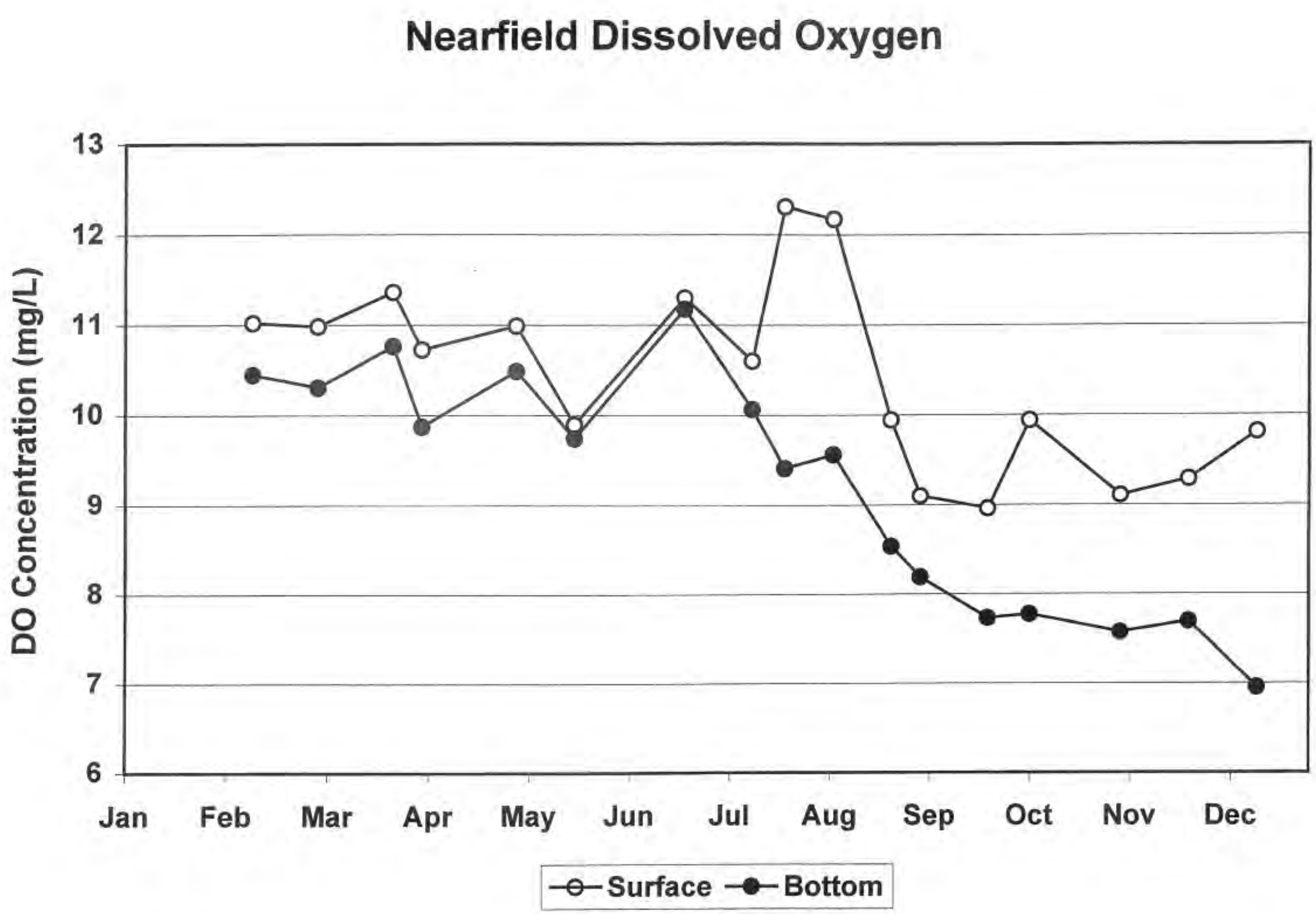
Ammonium (Nearfield Stations)



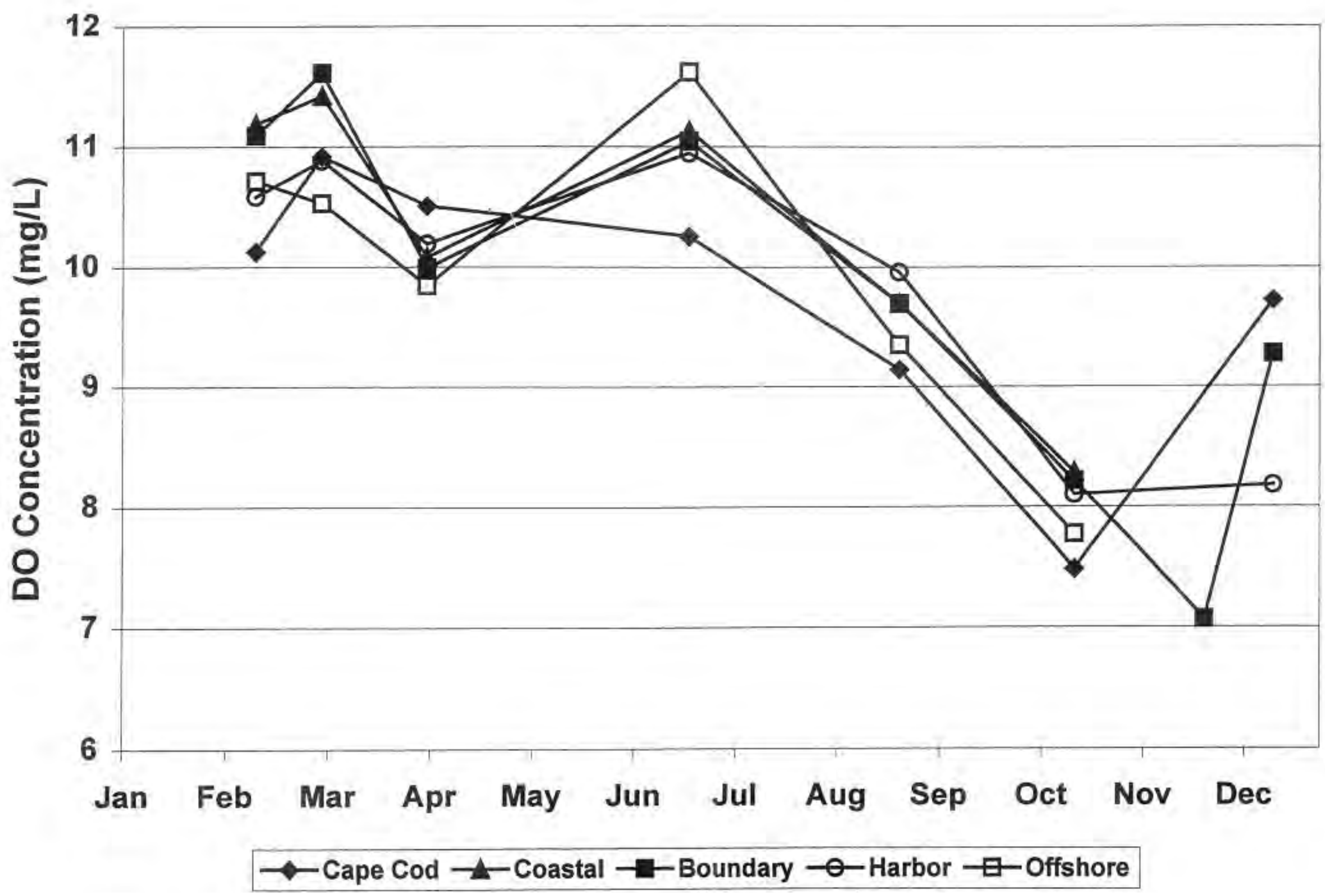


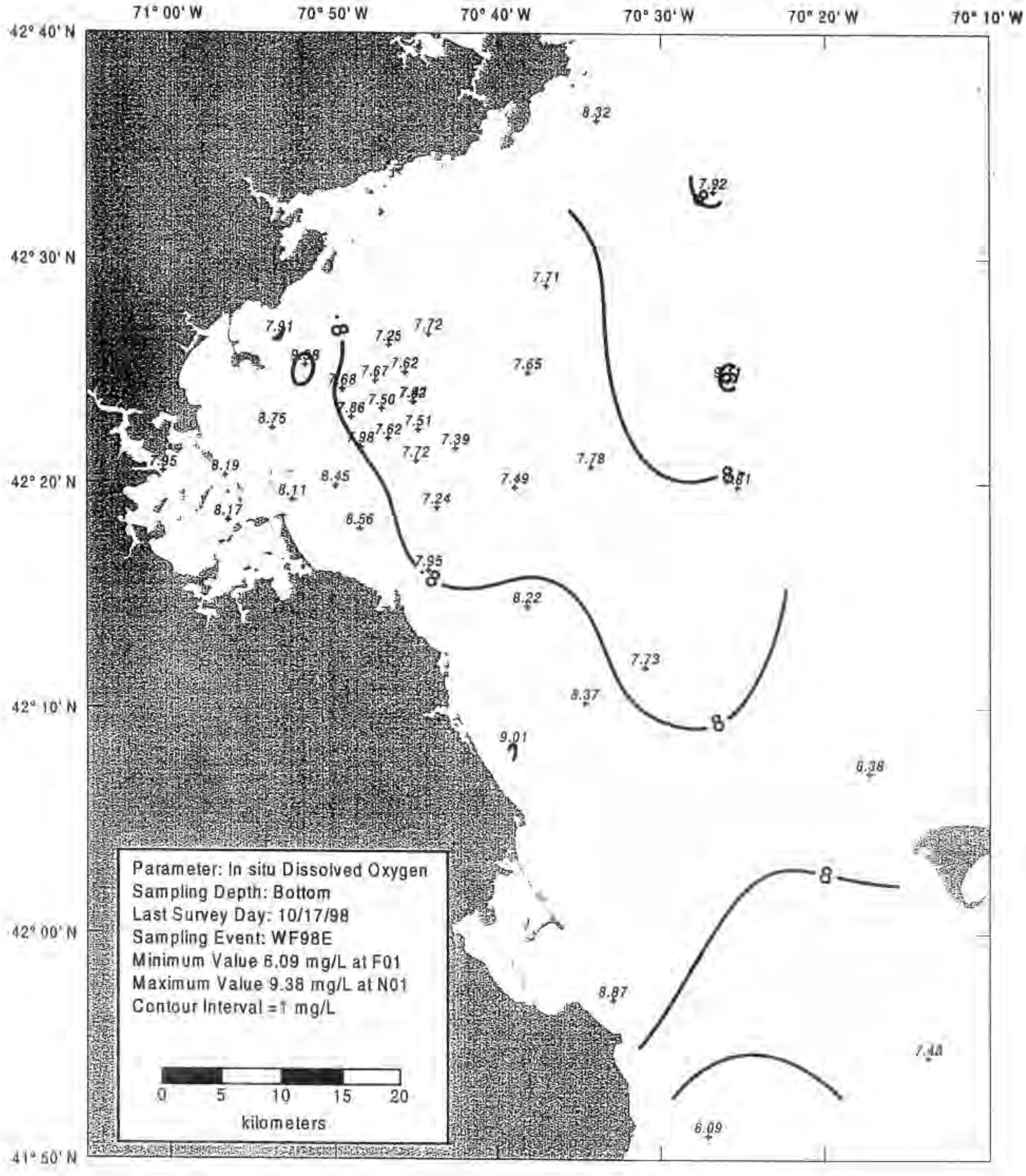
71° 00' W
70° 50' W
70° 40' W
70° 30' W
70° 20' W
70° 10'
42° 40' N
42° 30' N
42° 20' N
42° 10' N
42° 00' N
41° 50' N
Parameter: AMMONIUM
Sampling Depth: Surface
Last Survey Day: 10/17/98
Sampling Event: WF98E
Minimum Value 0.01 µM at F22
Maximum Value 17.04 µM at F23
Contour Interval =2 µM
0 5 10 15 20
kilometers


70° 52' W
70° 50' W
70° 48' W
70° 46' W
70° 44' W
70° 42'
42° 26' N
42° 24' N
42° 22' N
42° 20' N
1.32
1.95
5.53
1.90
3.55
2.50
6.05
4.57
1.54
3.92
2.45
8.57
Parameter: AMMONIUM
Sampling Depth: Surface
Last Survey Day: 11/25/98
Sampling Event: WN98G
Minimum Value 1.32 µM at N04
Maximum Value 8.57 µM at N10
Contour Interval =1 µM
0 1 2 3 4
kilometers


Nearfield Dissolved Oxygen
DO Concentration (mg/L)
13
12
11
10
9
8
7
6
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Surface
Bottom

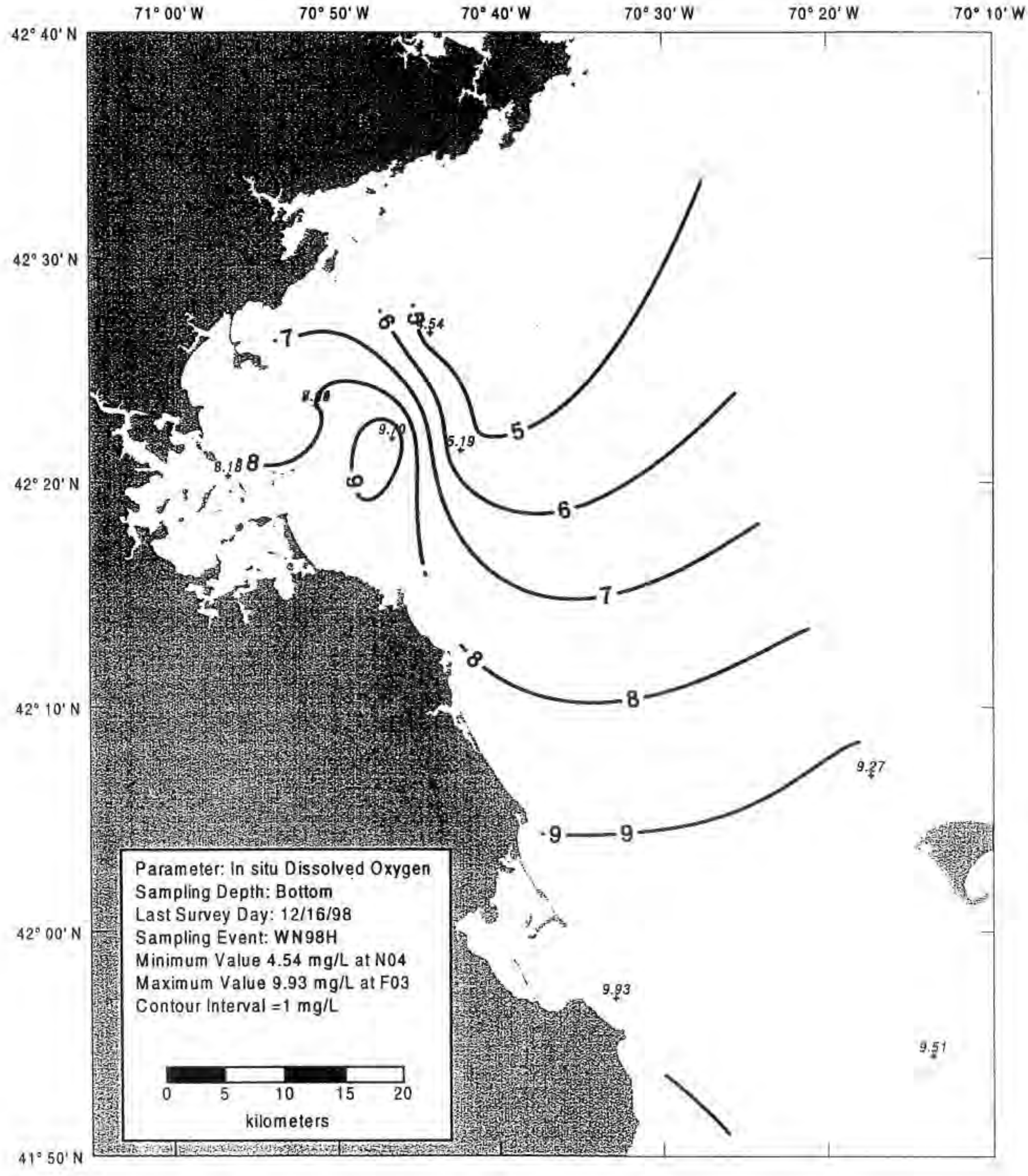
Bottom Water Dissolved Oxygen



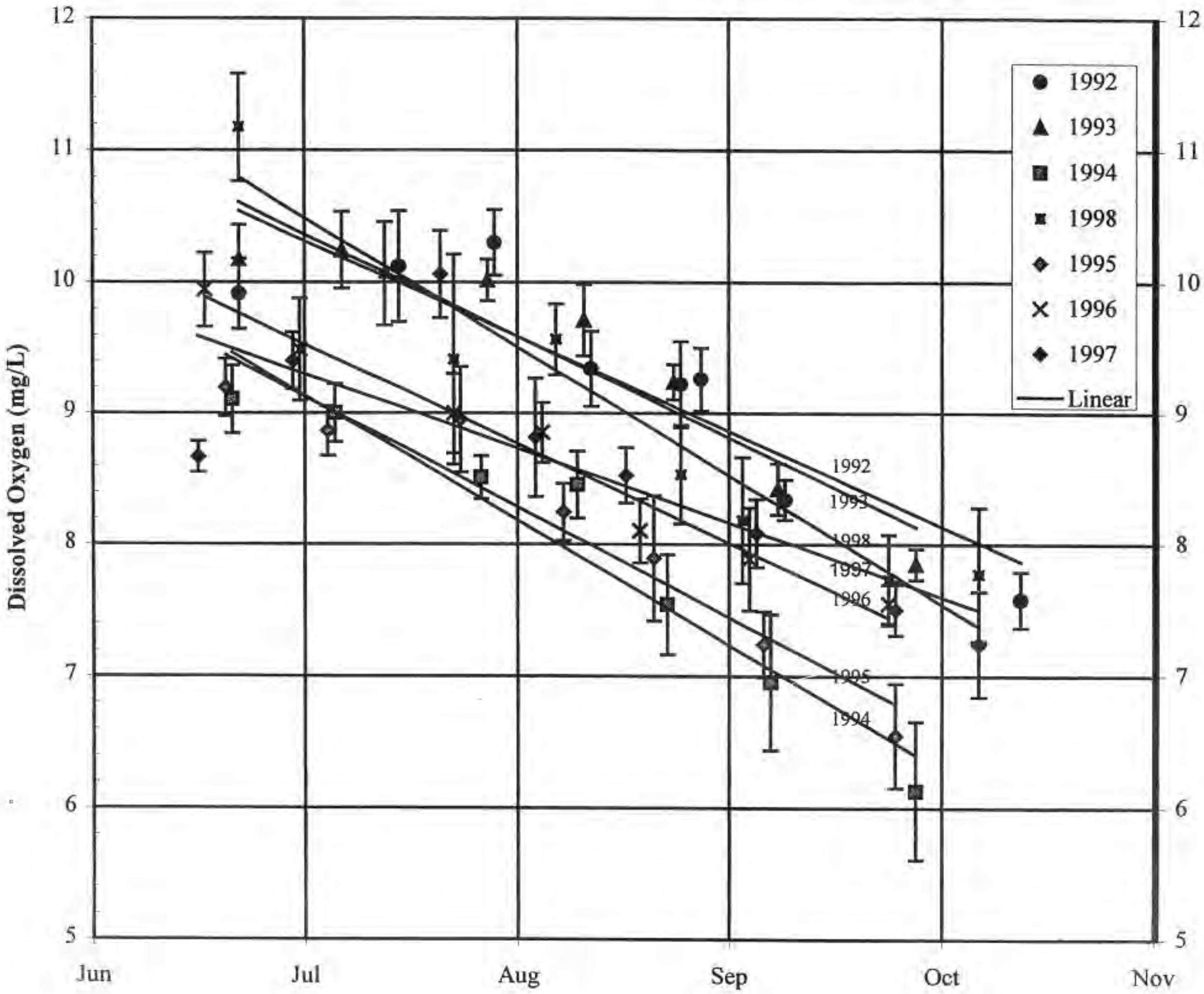


71° 00' W
70° 50' W
70° 40' W
70° 30' W
70° 20' W
70° 10' W
42° 40' N
42° 30' N
42° 20' N
42° 10' N
42° 00' N
41° 50' N
Parameter: In situ Dissolved Oxygen
Sampling Depth: Bottom
Last Survey Day: 10/17/98
Sampling Event: WF98E
Minimum Value 6.09 mg/L at F01
Maximum Value 9.38 mg/L at N01
Contour Interval = 1 mg/L
0
5
10
15
20
kilometers

240

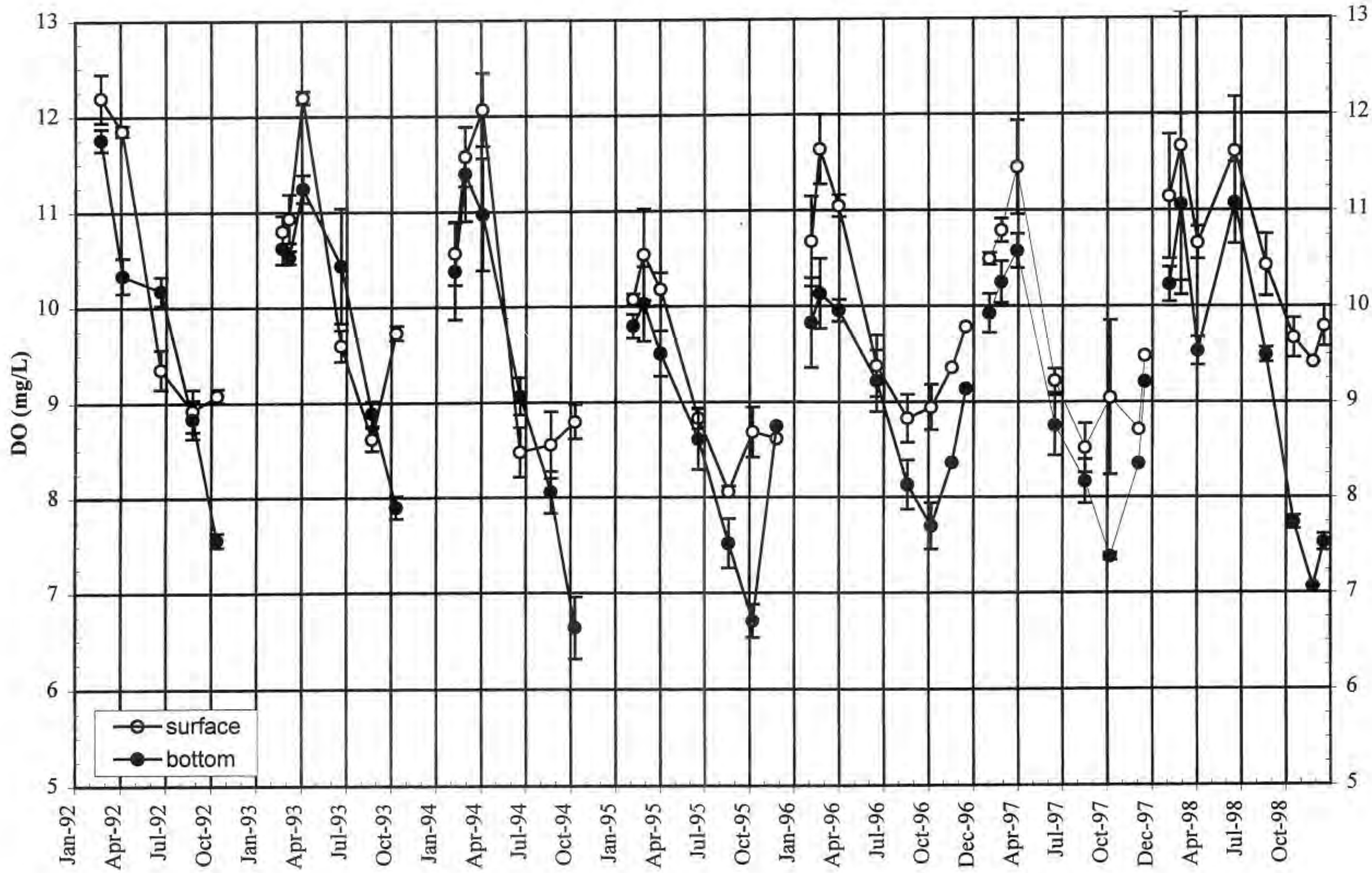


71° 00' W
70° 50' W
70° 40' W
70° 30' W
70° 20' W
70° 10' W
42° 40' N
42° 30' N
42° 20' N
42° 10' N
42° 00' N
41° 50' N
Parameter: In situ Dissolved Oxygen
Sampling Depth: Bottom
Last Survey Day: 12/16/98
Sampling Event: WN98H
Minimum Value 4.54 mg/L at N04
Maximum Value 9.93 mg/L at F03
Contour Interval =1 mg/L
0 5 10 15 20
kilometers
5
6
7
8
9
8.18
5.19
9.27
9.93
9.51

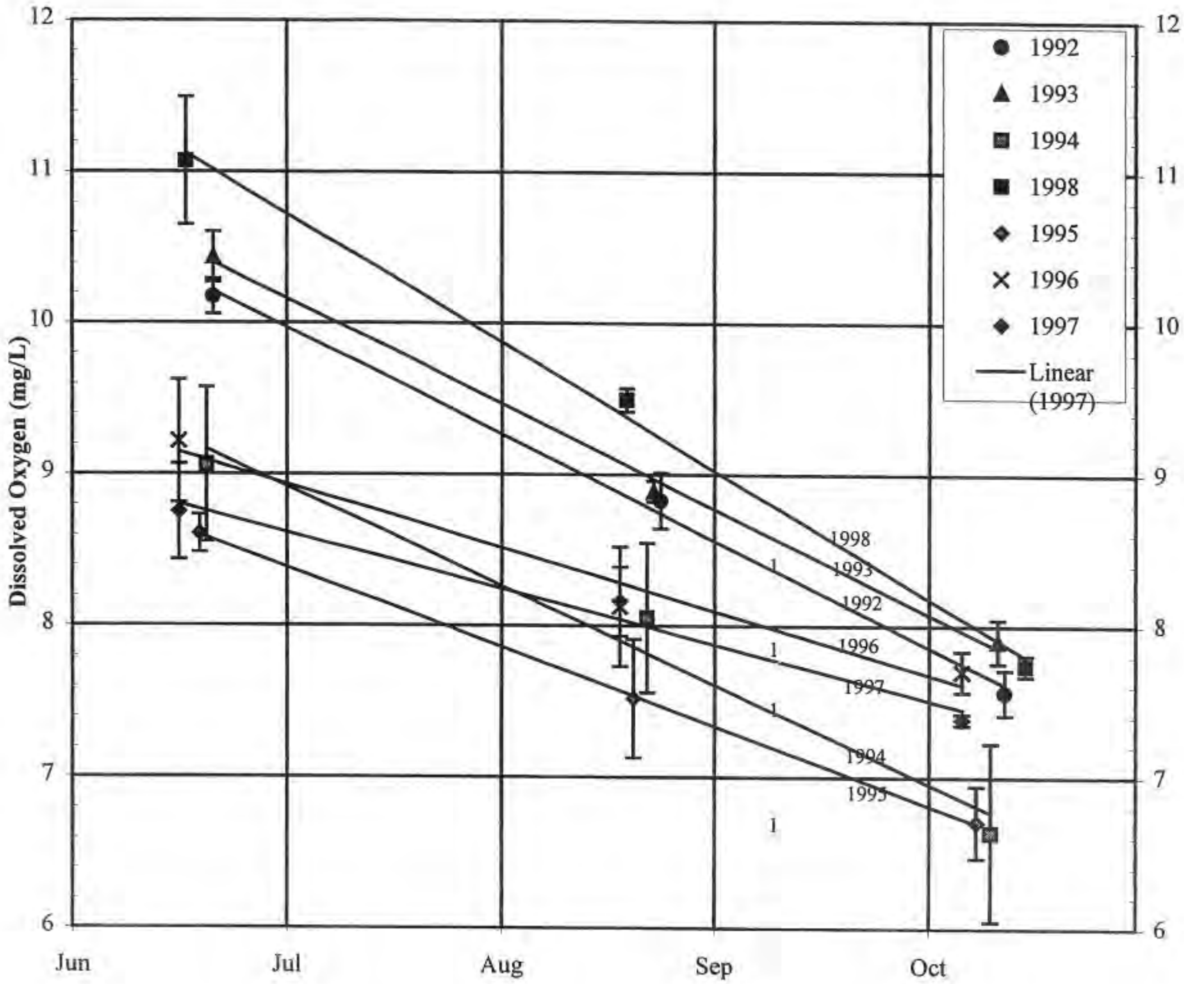


Year	Slope (mg/L/day)	Intercept* (mg/L)	R^2
1992	-0.024	11.0	0.808
1993	-0.025	11.1	0.885
1994	-0.031	10.1	0.929
1995	-0.027	9.9	0.932
1996	-0.025	10.3	0.978
1997	-0.020	9.8	0.632
1998	-0.032	11.5	0.938

Nearfield Dissolved Oxygen Concentrations in Bottom Waters
Mean of all nearfield stations.



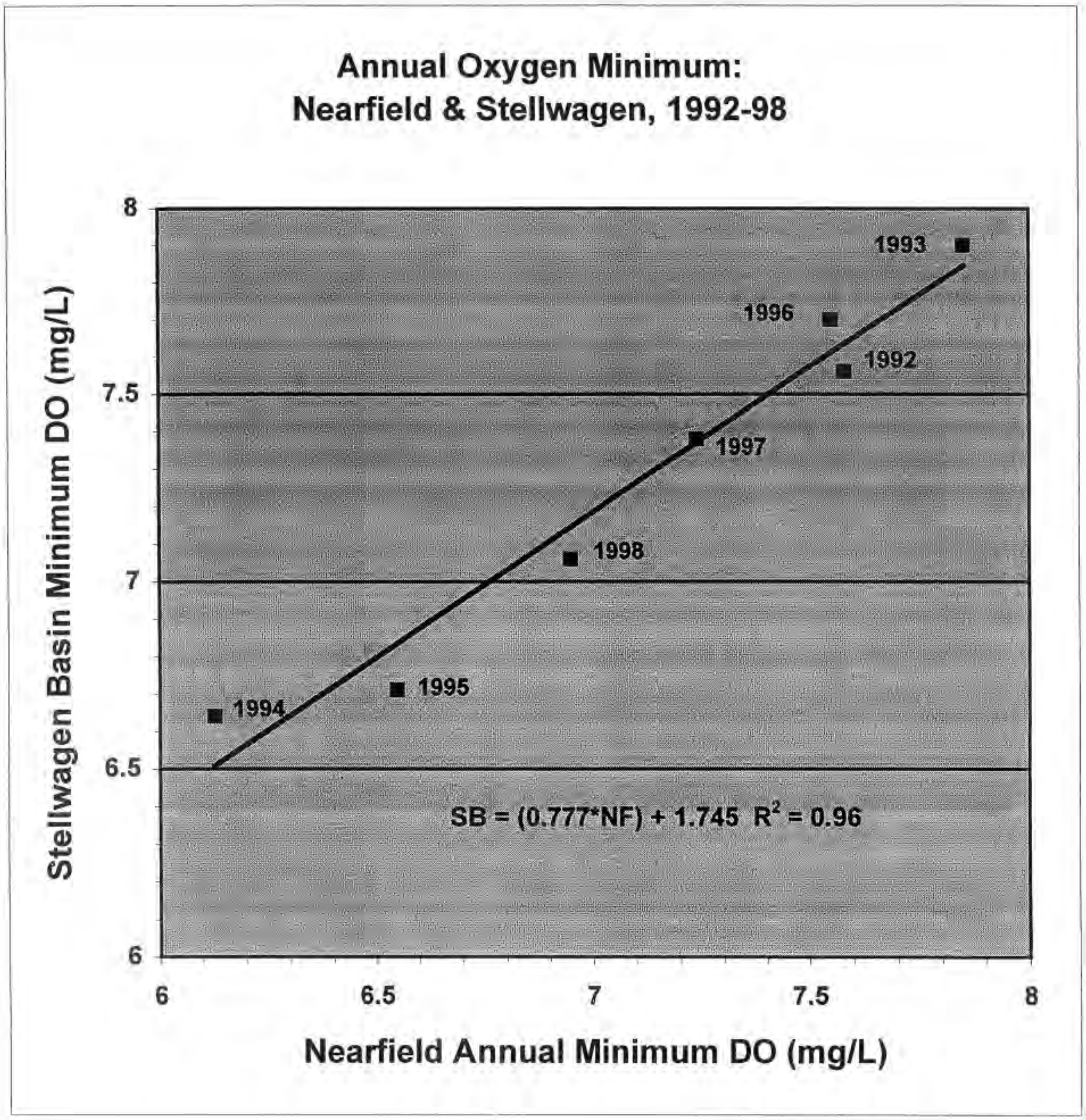
Interannual Stellwagen Basin Dissolved Oxygen Cycle
Surface and Bottom Waters



Year	Slope (mg/L/day)	Intercept* (mg/L)
1992	-0.023	10.7
1993	-0.023	10.9
1994	-0.021	9.6
1995	-0.017	8.9
1996	-0.014	9.4
1997	-0.012	9.0
1998	-0.028	11.6
* Predicted DO on June 1st based on: DO = Slope * Date + Intercept		

Stellwagen Basin Dissolved Oxygen Concentrations in Bottom Waters

Symbols indicate the mean of 4 Stellwagen stations (F12, F17, F19, F22)

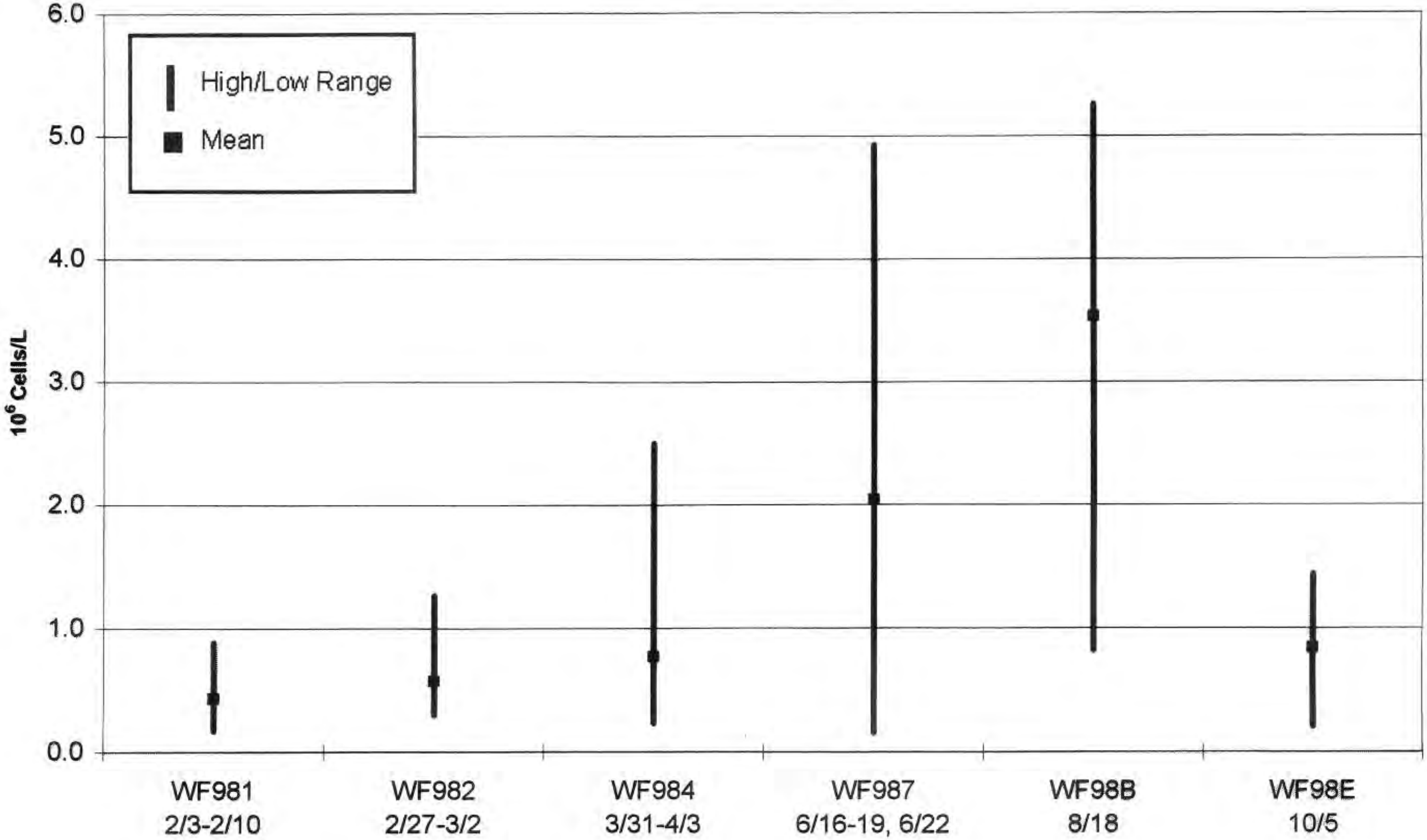


Annual Oxygen Minimum:
Nearfield & Stellwagen, 1992-98
Stellwagen Basin Minimum DO (mg/L)
Nearfield Annual Minimum DO (mg/L)
1993
1996
1992
1997
1998
1995
1994
SB = (0.777*NF) + 1.745 R² = 0.96
8
7.5
7
6.5
6

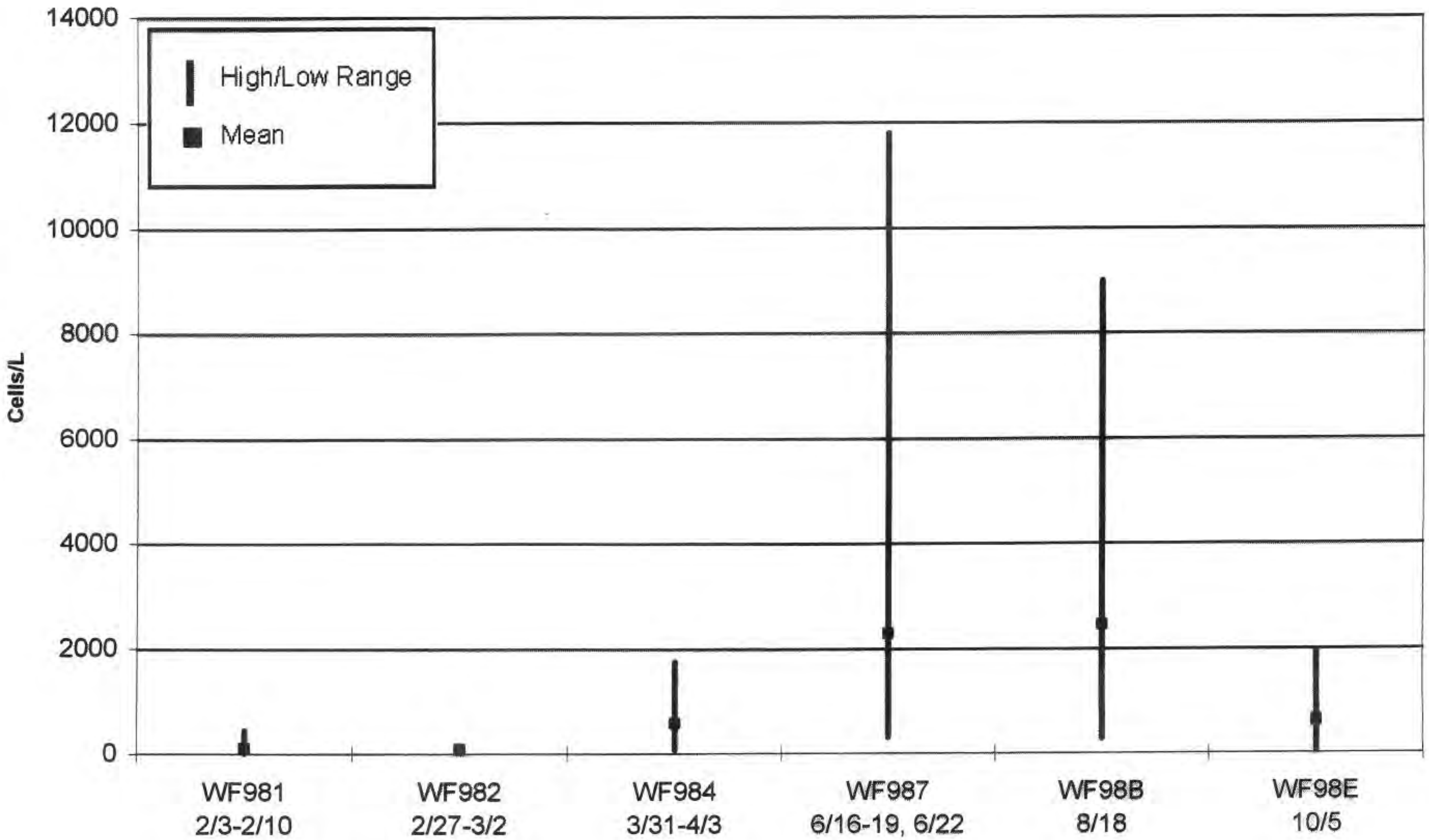
245

Water Column Monitoring and Nutrient Cycling
1998 Plankton Overview *(Dr. Jefferson Turner, UMass – Dartmouth)*

Farfield Whole Water Phytoplankton

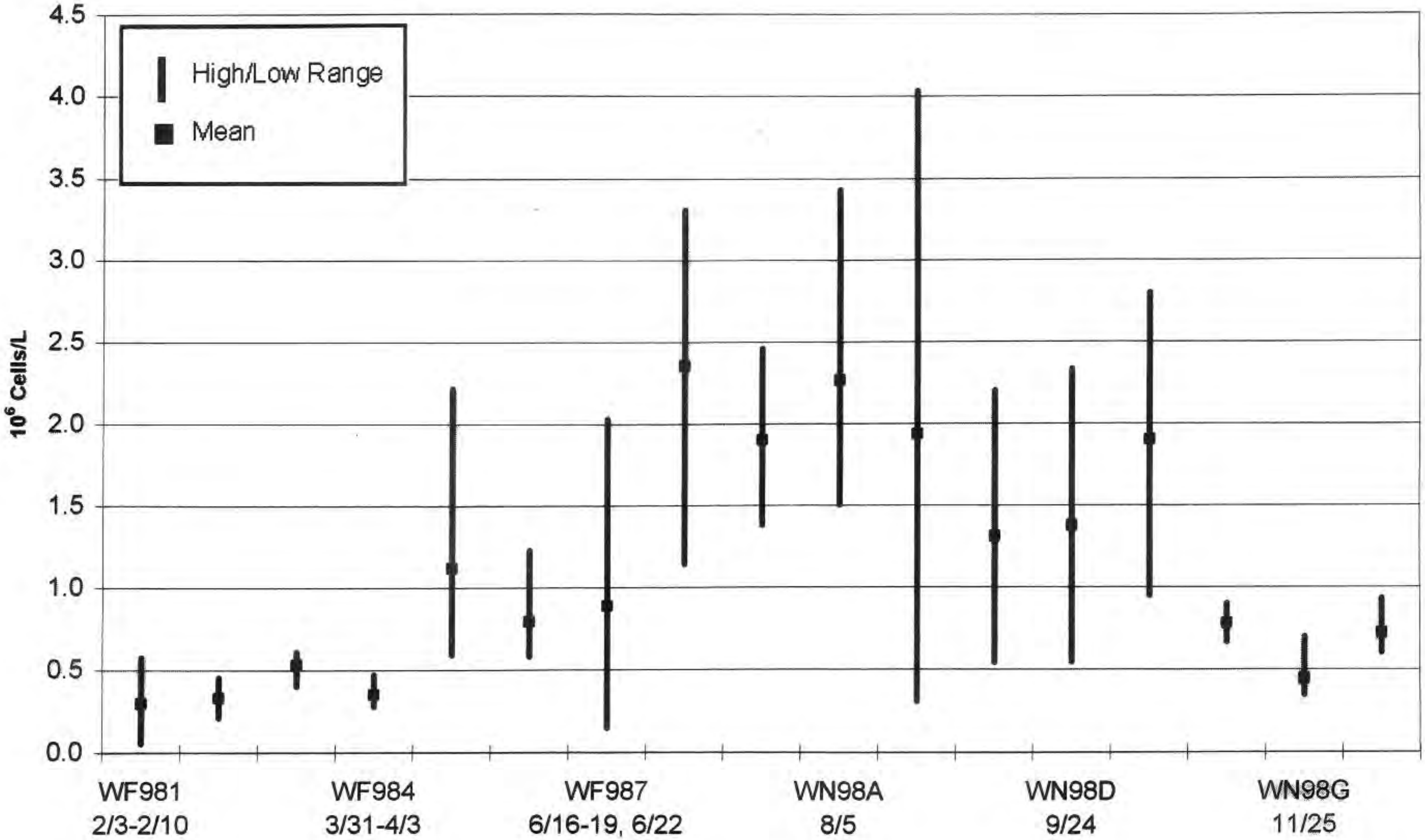


Farfield Screened Phytoplankton

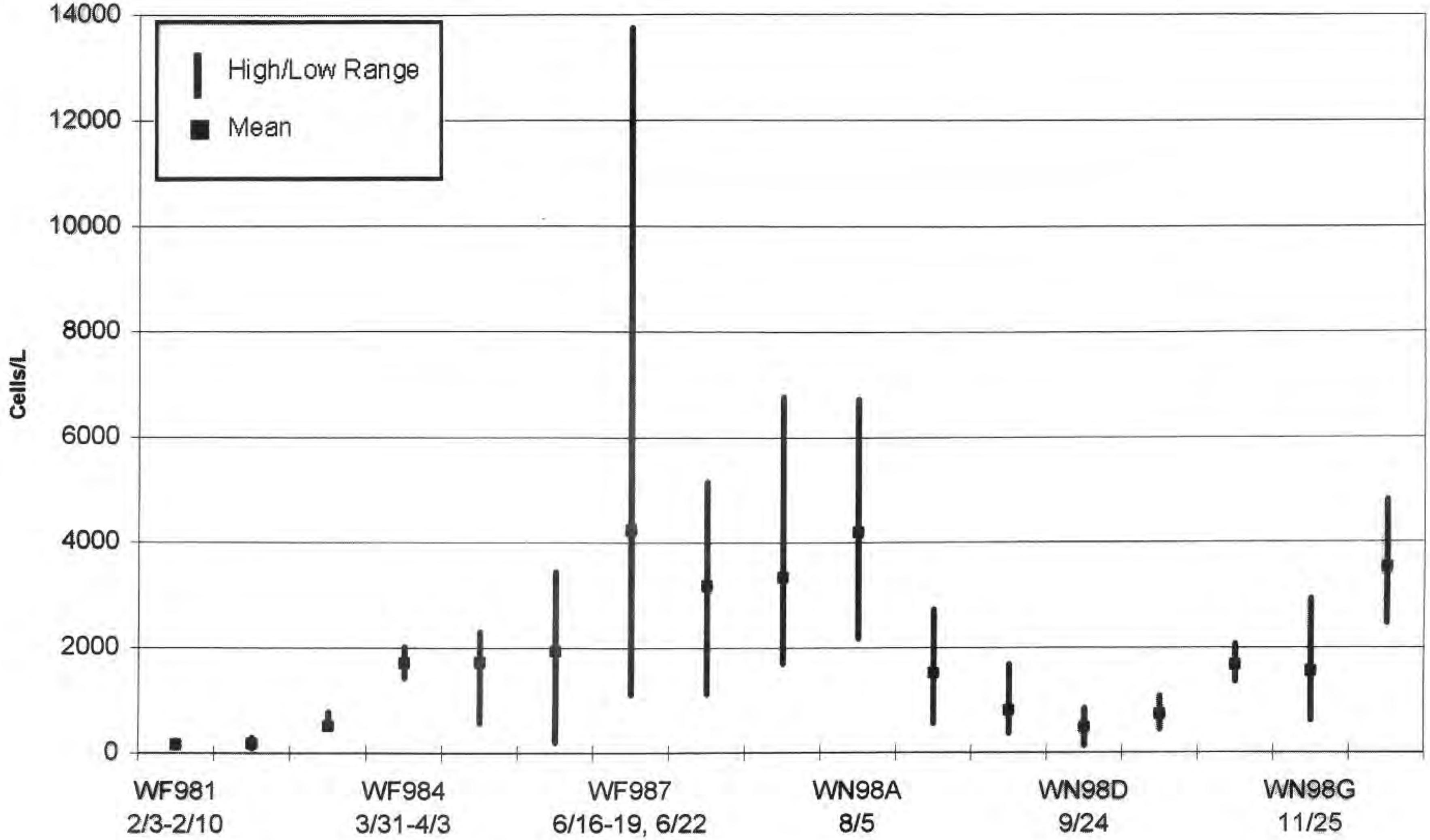


248

Nearfield Whole Water Phytoplankton



Nearfield Screened Phytoplankton



250

Seasonal Whole-water Phytoplankton Assemblages

Microflagellates are usual numerical-dominants throughout the year, and their abundance generally tracks water temperature, being most abundant in summer and least abundant in winter.

In addition to microflagellates, the following are dominant in different periods:

<u>Winter (primarily February)</u> – diatoms abundant

Chaetoceros debilis, C. socialis, Thalassiosira nordenskioldii, T. rotula

<u>Spring (March, April, May)</u> – usually diatoms, except during *Phaeocystis* years

assorted species of *Thalassiosira, Chaetoceros, Heterocapsa rotundatum*, and (especially nearshore) cryptomonads

<u>Summer (June, July, August)</u> – microflagellates at peak abundance, with cryptomonads, *Skeletonema costatum* (especially nearshore), *Leptocylindrus danicus, Rhizosolenia delicatula, Ceratulina pelagica*, and various small-sized species of *Chaetoceros*.

<u>Fall (September through December)</u> – diatoms abundant

***Asterionellopsis glacialis, Rhizosolenia delicatula, Skeletonema costatum, Leptocylindrus minimus, L. danicus*, cryptomonads, and assorted gymnodinoid dinoflagellates**

Plankton Summary - 1998

Whole-Water Phytoplankton:

There was a sustained increase in total phytoplankton abundance from low levels in February through April (means of 0.3-0.8 x 10^6 cells/liter) to high levels in May through October (means of 0.7-3.5 x 10^6 cells/liter), followed by declines in November and December (Nearfield means of 0.4-0.7 x 10^6 cells/liter).

Unlike other years, there was not a major winter/spring bloom or fall bloom.

Phytoplankton assemblages were numerically dominated by microflagellates and cryptomonads (< 10 µm), with subdominant contributions by various chain-forming diatoms such as *Chaetoceros socialis* and *Skeletonema costatum* (winter and spring), *Leptocylindrus minimus, L. danicus, Rhizosolenia fragilissima, Proboscia alata*, and *S. costatum* (summer), and *Chaetoceros* spp., *Leptocylindrus* spp., *S. costatum*, and *Pseudo-nitzschia* spp. in the fall.

Therre were no confirmed blooms of nuisance algae in 1998, although the fall *Pseudo-nitzschia* records for *P. "pungens"* could have included some of the domoic-acid-producing species *P. multiseries*. However, total abundances of *Pseudo-nitzschia "pungens"* did not exceed 82 x 10^3 cells/liter.

Screened Water Phytoplankton (> 20 µm):

The silicoflagellate *Distephanus speculum* was dominant in February, with subdominant contributions by the dinoflagellates *Ceratium longipes* and *C. tripos*.

From March onward, *C. longipes* and *C. tripos* were dominant, with subdominant contributions by other dinoflagellates such as *C. furca, C. fusus, C. lineatum, Dinophysis norvegica* and *Protoperidinium trochoidium*.

The sustained bloom of *Ceratium longipes* and *C. tripos* was the major event for screened-water taxa.

Plankton Summary – 1998

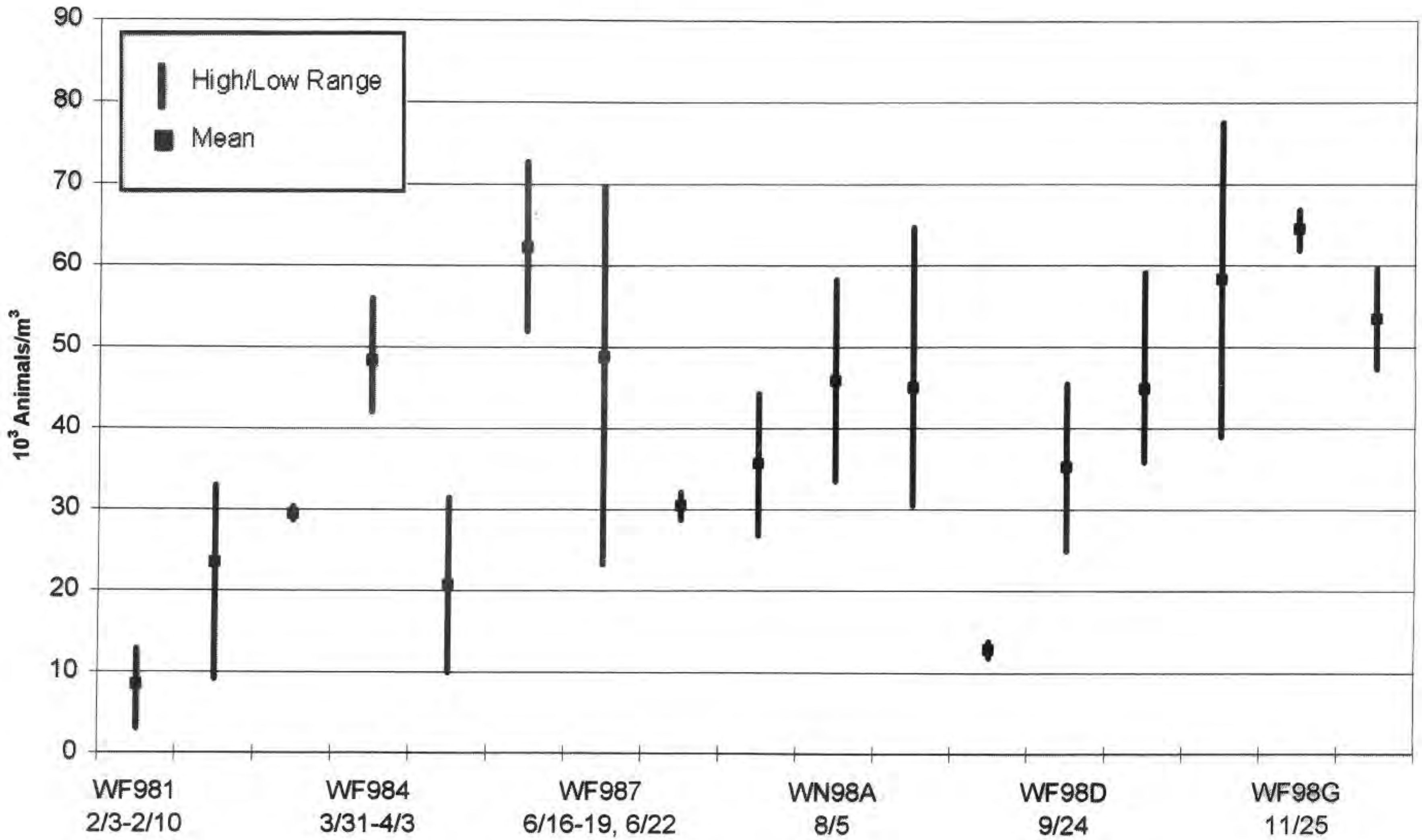
Zooplankton:

The zooplankton were dominated, as usual, by copepod nauplii, adults and copepodites of the small copepods *Oithona similis* and *Pseudocalanus* spp., with seasonal subdominant contributions from gastropod and bivalve veligers, and a mixture of other normally-occurring taxa.

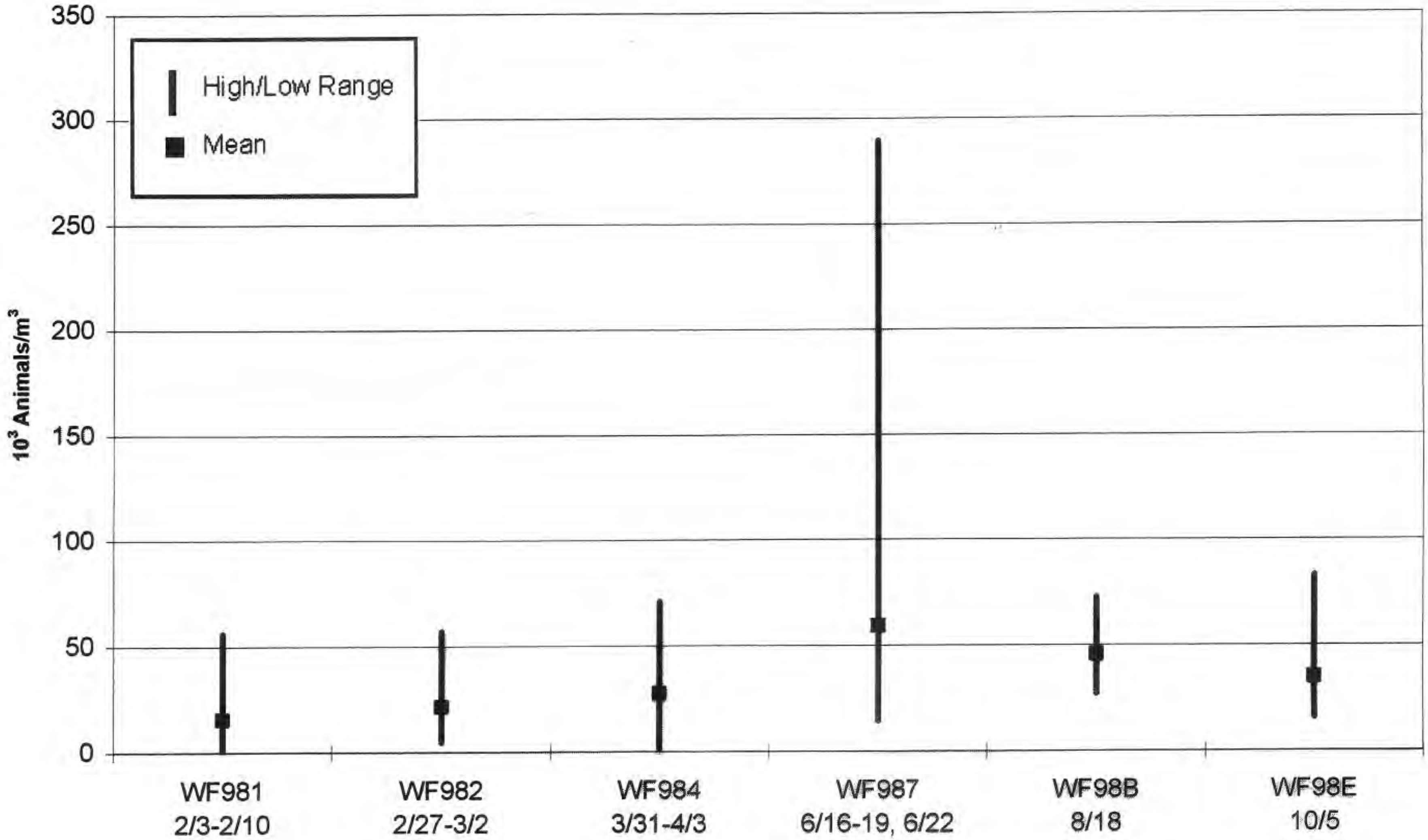
Addition of stations F32 and F33 in Cape Cod Bay during WF981, WF982, and WF984 extended the range of total abundance recorded for F01 and F02 from 12-24 to 28-56 x 10^3 animals m^{-3} during WF981, from 15-24 to 27-29 x 10^3 animals m^{-3} during WF982, and from 13 to 19-28 x 10^3 animals m^{-3} during WF984.

During WF984, abundance of *Calanus finmarchicus* copepodites comprised only 3-4% of the catch at F01 and F02, but 7-11% at F32 and F33. Thus, for this important forage item of right whales that feed in Cape Cod Bay at this time of the year, addition of the two new stations captured a three-fold increase in patchiness of this copepod that would have been missed by sampling only Stations F01 and F02.

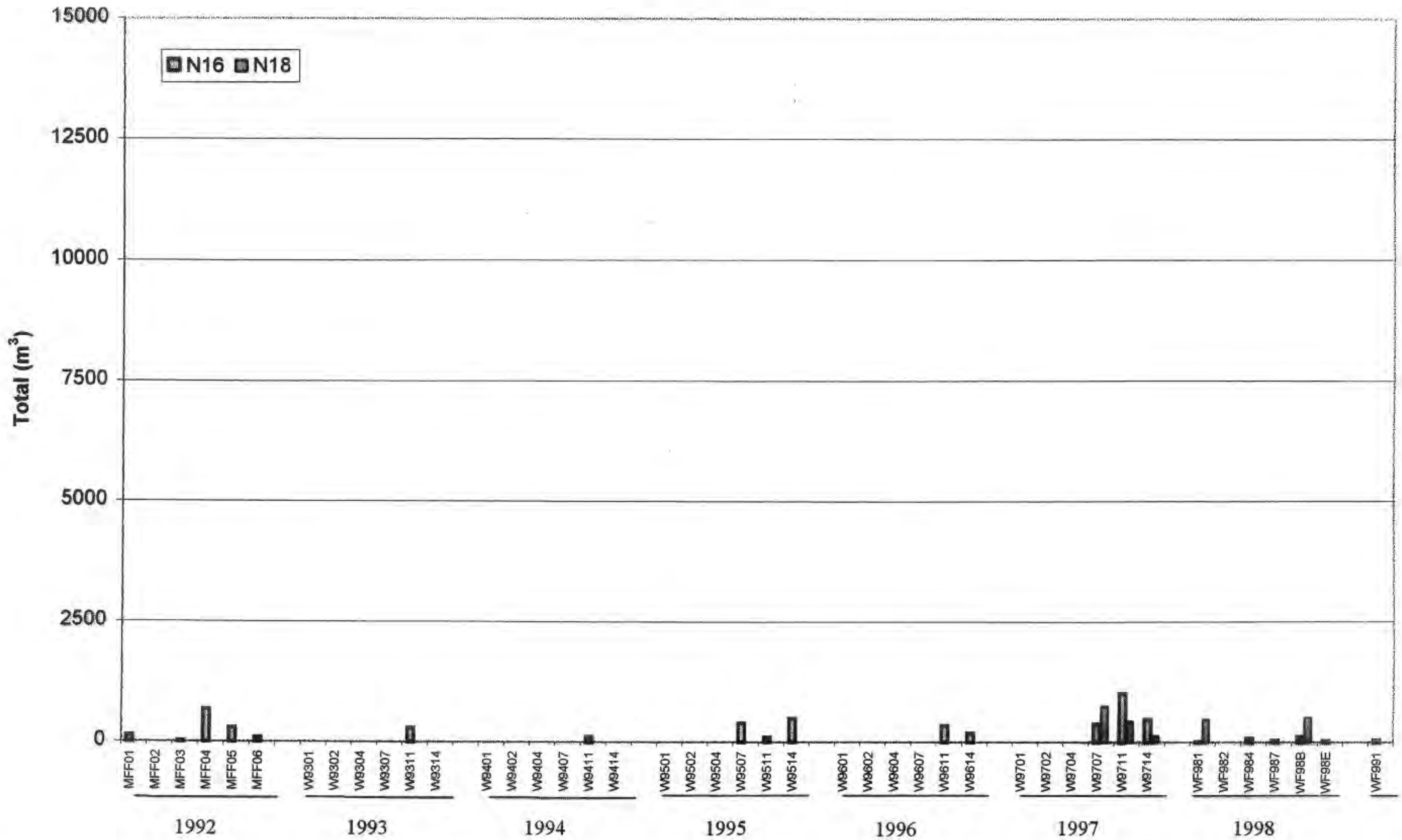
Nearfield Zooplankton



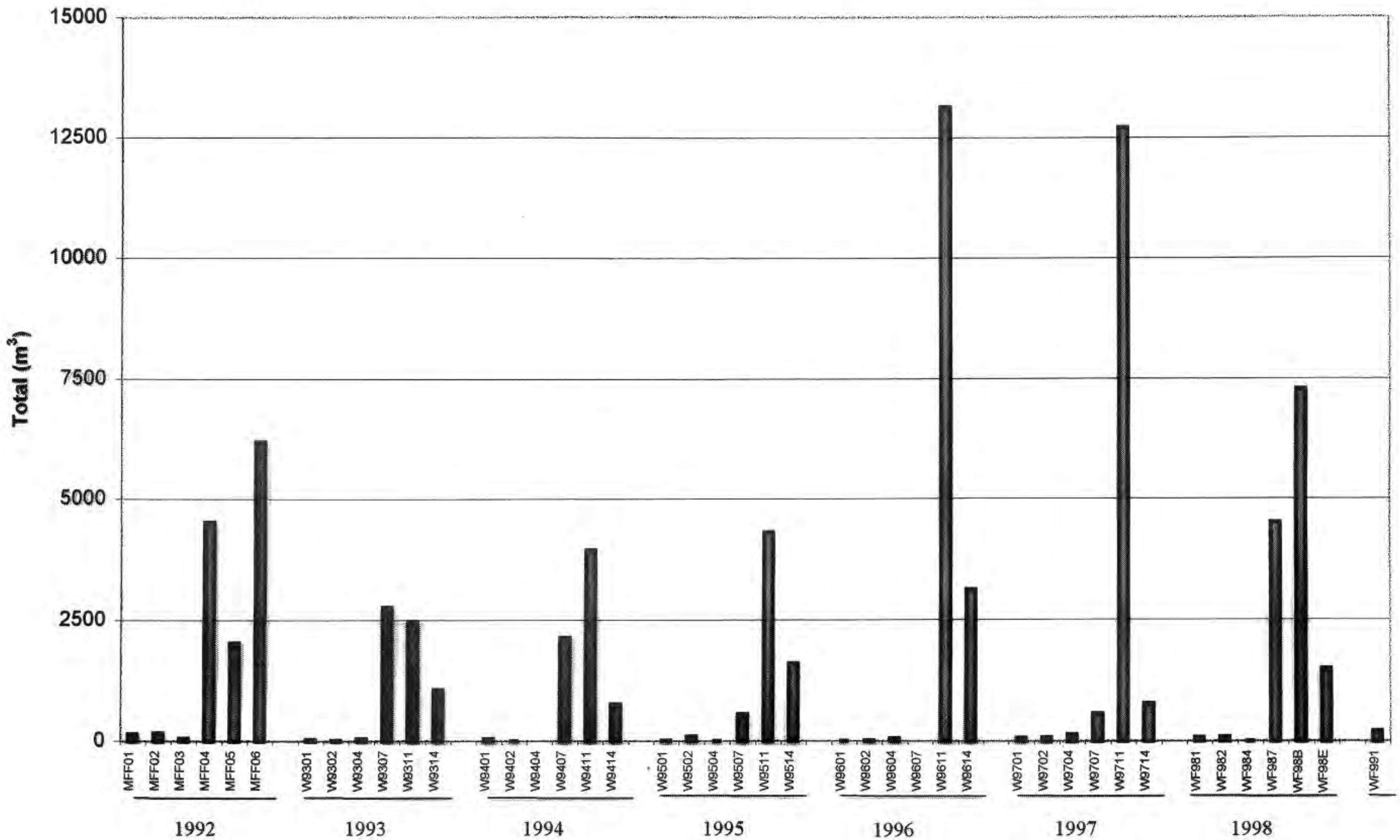
Farfield Zooplankton



Station N16 and N18

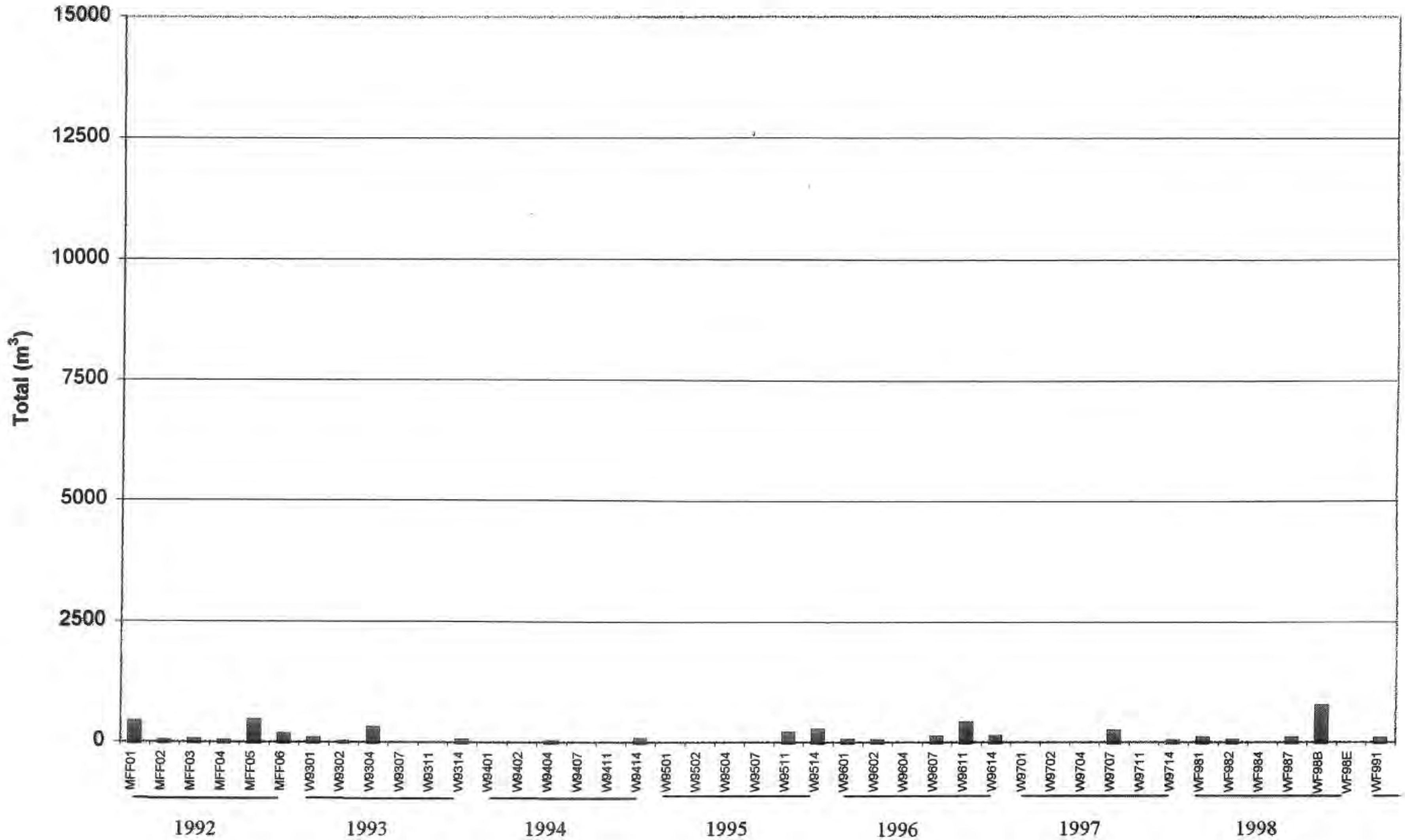


Station F23



257

Station F02



258

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Why is *Acartia tonsa* (Copepoda: Calanoida) restricted to nearshore environments?

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ABSTRACT: The copepod *Acartia tonsa* is adapted to high food concentrations which it encounters in estuaries and upwelled waters. It cannot obtain sufficient food for reproduction on the middle and outer shelf, where food concentrations are usually low, because it decreases clearance rates when concentrations of *Thalassiosira weissflogii* fall below 0.25 $mm^3\ l^{-1}$. In comparison, the offshore copepod *Paracalanus* sp. continues to increase its clearance rate when food levels are below the above-mentioned concentration. Several factors are thought to be responsible for this reduction of clearance rates of *A. tonsa* feeding on *T. weissflogii*: (1) The proportion of time during which water is transported towards the copepod decreases with decreasing food concentration. (2) The efficiency of capturing food particles decreases below 22 $\mu g\ C\ l^{-1}$ (= 0.28 $mm^3\ l^{-1}$ of *T. weissflogii*). (3) *A. tonsa* does not seem to reroute phytoplankton cells individually towards its median, and therefore cannot use a, hypothesized, increased sensitivity of its chemoreceptors at low chlorophyll concentrations to increase clearance rate.

INTRODUCTION

The genus *Acartia* (Copepoda: Calanoida) occurs mostly in estuaries and nearshore environments although several representatives of the genus are found offshore (i.e. *A. danae, A. negligens*; Bowman 1971). *A. tonsa* is found throughout the year in the estuaries of Georgia and South Carolina, USA, when water temperatures range from 9 to 30 °C (Lonsdale & Coull 1977, Paffenhöfer unpubl.). In terms of biomass it is the most abundant zooplankton species in the estuaries of North and South Carolina (Lonsdale & Coull 1977, Fulton 1984). It is the most frequently occurring zooplankton species in Georgia estuaries (Jacobs 1968, Stickney & Knowles 1975). However, *A. tonsa* is rarely abundant (> 100 ind m^{-3}) on the middle and outer shelf (Paffenhöfer unpubl.). There, throughout most of the year, representatives of the genus *Paracalanus* are among the most abundant copepods. In estuaries, their close relative *Parvocalanus crassirostris* is often as abundant as *A. tonsa* (Lonsdale & Coull 1977).

Why is *Acartia tonsa* abundant in estuaries but not on the shelf? In order to answer this question, we considered 4 variables: temperature, salinity, predation and food. Temperature is not considered a limiting factor since it is higher during winter and slightly lower during summer on the shelf than in the estuaries. Thus, *A. tonsa* would experience less temperature stress offshore than in the estuary. Also, *A. tonsa* is able to adapt to temperatures ranging from −1 to 32 °C (Gonzalez 1974). Neither is salinity limiting: at 17 °C, *A. tonsa* females survived about equally well at salinities ranging from 11 to 36 ‰ (Lance 1964). Predation does not appear to be the decisive variable in restricting *A. tonsa* offshore distribution, since the species maintains its high abundance near- and inshore, partly because of its superior ability (as compared to *Paracalanus* and others) to avoid predation by planktivorous fish (Kimmerer 1986, for *A. tranteri*). This leaves only food with all the components of animal-algae interactions as a possible controlling variable.

259

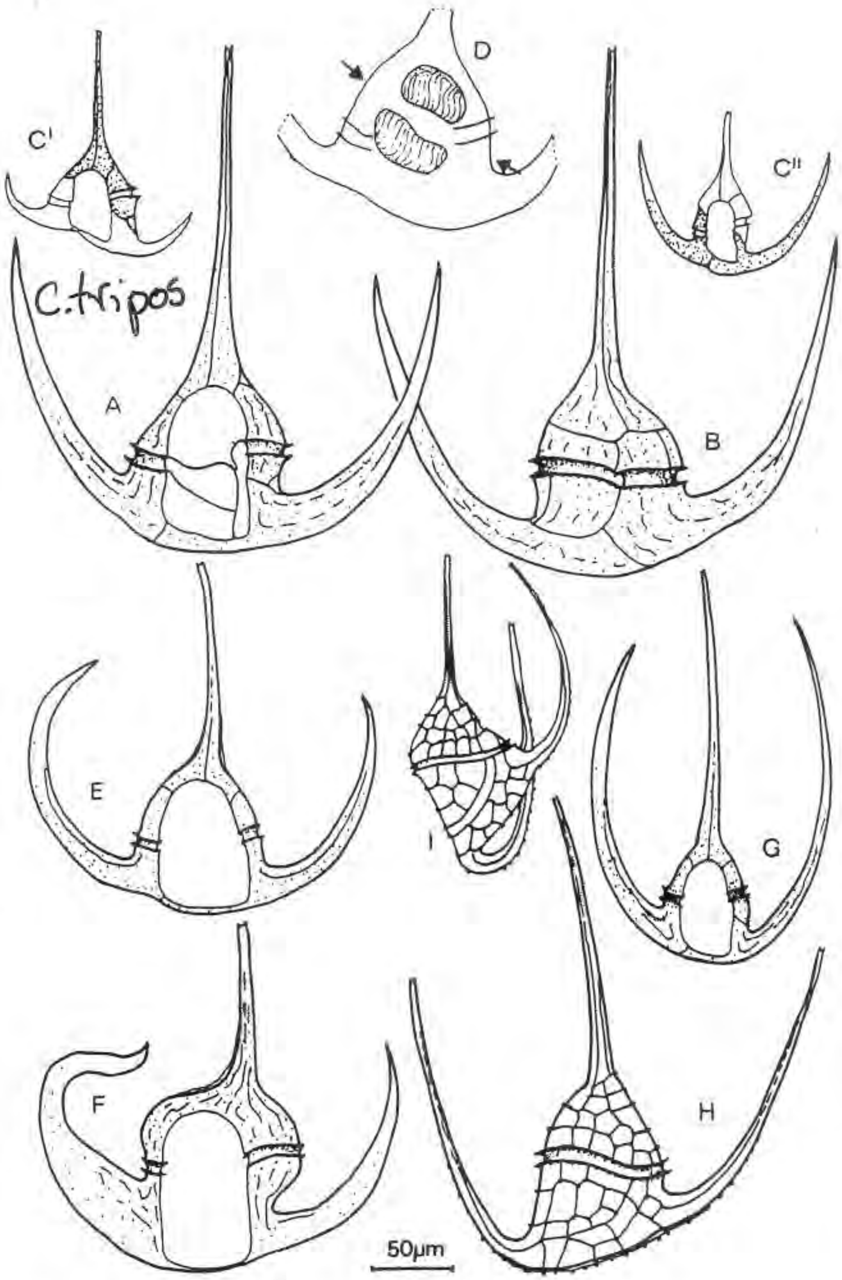


Fig. 30 CERATIUM
A. *C. tripos* ventral view to show the plates (after Wall & Evitt 1975)
B. *C. tripos* dorsal view to show the plates (after Wall & Evitt 1975)
C. I and II recently divided *C. tripos* to show development of new parts
D. *C. tripos* telophase to show plane of cell division E. *C. arietinum*
F. *C. gibb* [illegible] G. *C. symmetricum* H. *C. hexacanthum* dorsal view
I. *C. hexa*[illegible] *um* side view to show twisting

260

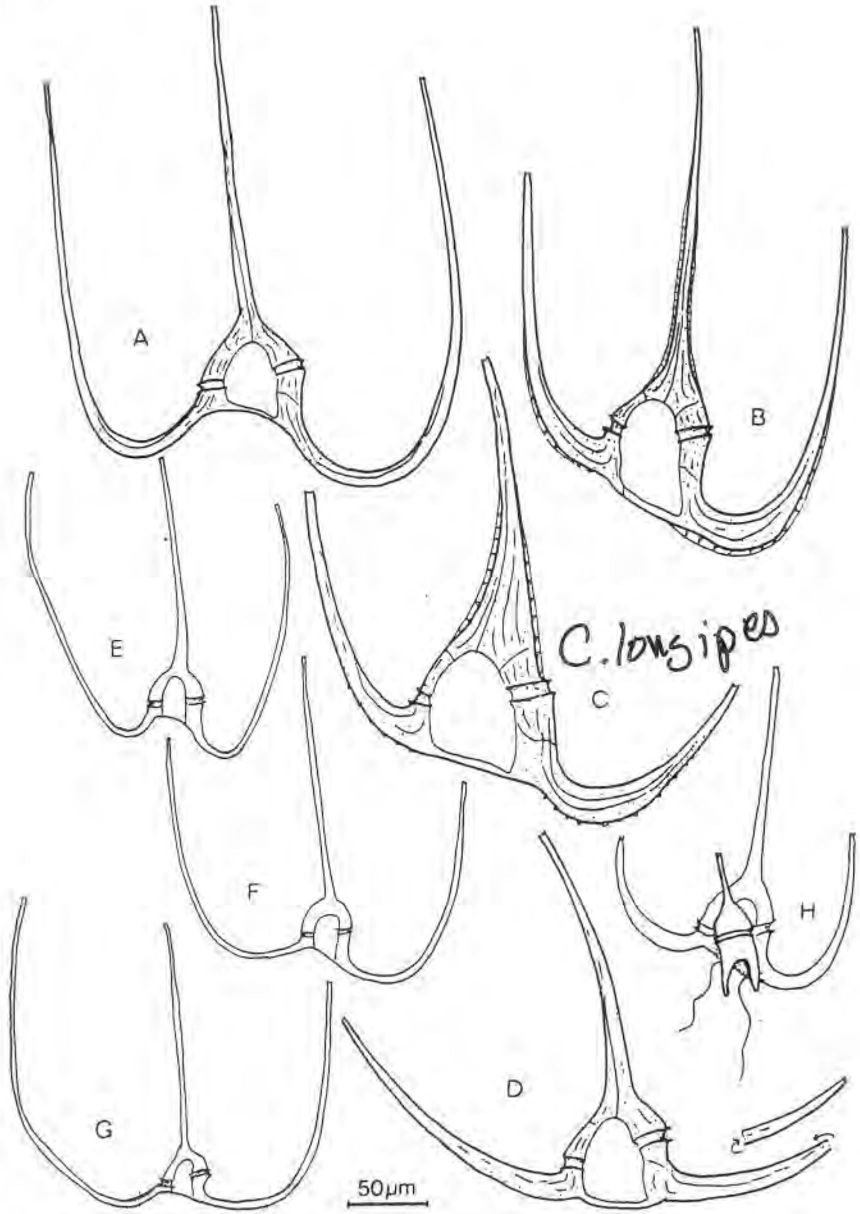
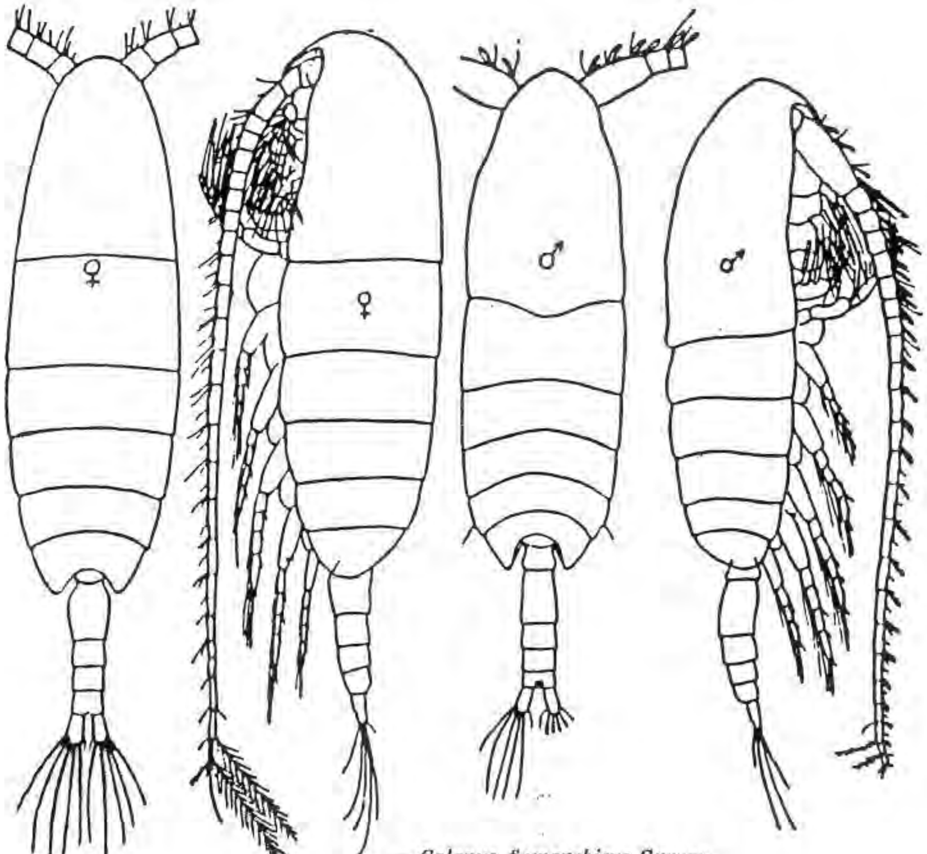


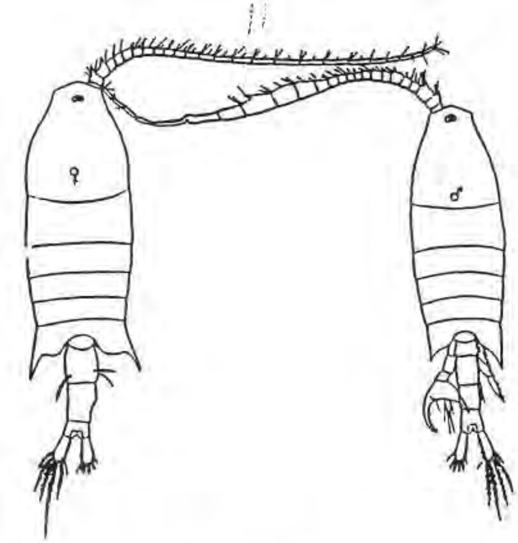
Fig. 31 CERATIUM
A. *C. macroceros* B *C. horridum* C. *C. longipes* D. *C. longipes* f *arcticum*
To half scale
E. *C. massiliense* F. *C. trichoceros* G. *C. carriense* H. *C. horridum* copulation between a macroswarmer and microswarmer (after Von Stosch, 1964)



— *Calanus finmarchicus* Gunner,

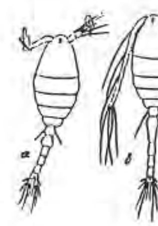
— L. ♀ 2,7-5,4 mm.;

♂ 2,35-3,6 mm.

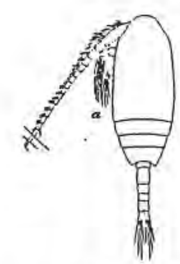


— *Centropages typicus* Kröyer,

— L. ♀ 1,6-2 mm.; ♂ 1,4-1,9 mm.



—*Oithona similis: a*, Male, dorsal; *b*, female, dorsal;
Total length, 0.7–0.95 mm.



—*Paracalanus parvus: a*, Male, dorsal;
Total length, 0.75–1 mm.

Why Is *Acartia tonsa* Restricted to Estuarine Habitats?[1)]

Patricia A. Tester[2)] and Jefferson T. Turner[3)]

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Southeast Fisheries Research Center, Beaufort Laboratory
Beaufort, North Carolina 28516, USA
[3)] *Southeastern Massachusetts Univesity*
North Dartmouth, Massachusetts 02747, USA

Abstract

The salinity tolerance of naupliar stages is a major factor in restricting the abundant calanoid copepod *Acartia tonsa* to estuarine and nearshore waters. There is significantly greater naupliar survival at salinities less than full strength seawater, and salinity-temperature interaction experiments indicate optimal conditions for *A. tonsa* nauplii are <25 ppt and >15℃. The early naupliar stages do exhibit some osmoregulatory ability, however. Demonstrations using fluorescein dye show that even the non-feeding, N1 stage can drink. While adult *A. tonsa* are good osmoregulators and, consequently tolerate a wide range of salinities, the restriction of this species to estuarine and coastal habitats may be a function of the physiology of the nauplii rather than the adult.

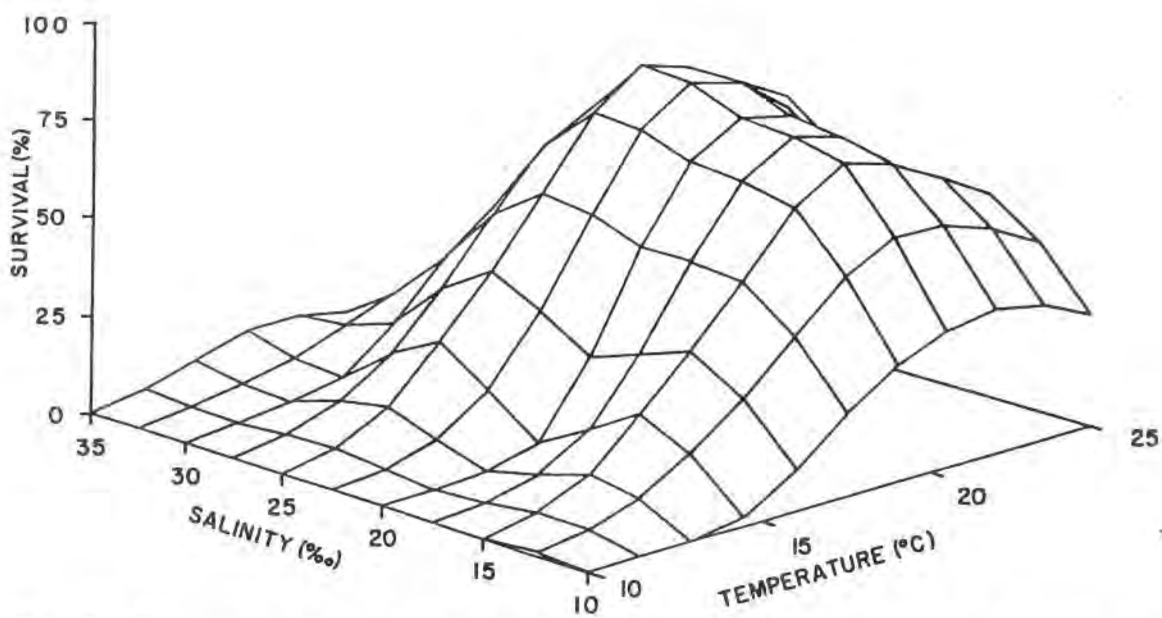


Fig. 1. Percent survival of *Acartia tonsa* nauplii as a function of salinity and temperature. Observed % naupliar survival included in Table 1.

262

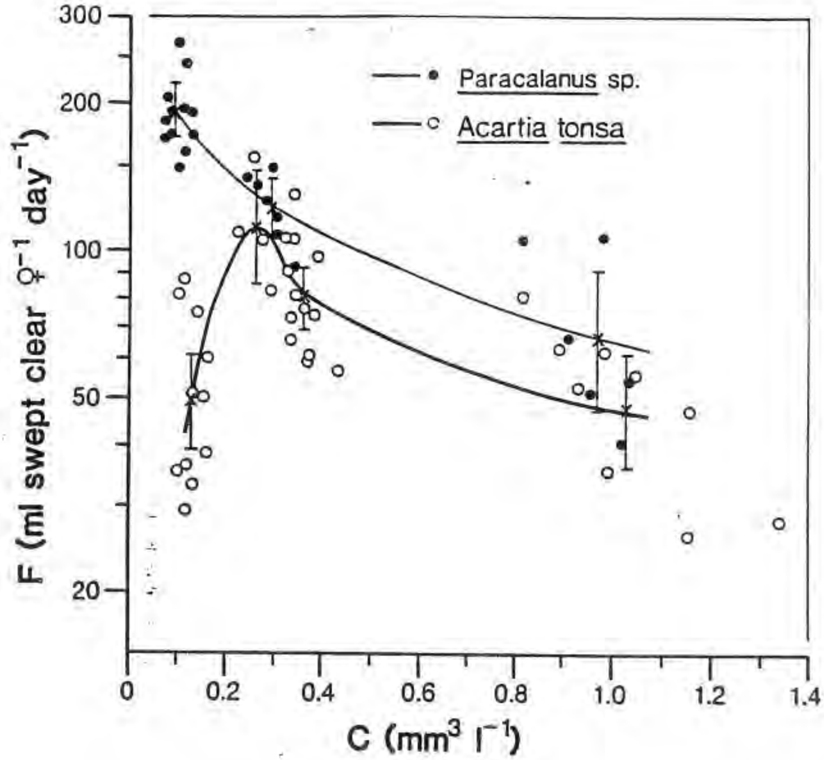


Fig. 1. *Paracalanus* sp. and *Acartia tonsa*. Clearance rate (F) of adult females feeding on the diatom *Thalassiosira weissflogii*. Clearance rates of *Paracalanus* sp. are the geometric means of the following ranges of food concentration: 0.05 to 0.20, 0.20 to 0.35, 0.80 to 1.10 $mm^3\,l^{-1}$. For *A. tonsa* geometric means were calculated for the following ranges: 0.05 to 0.20, 0.20 to 0.30, 0.30 to 0.45, 0.80 to 1.40 $mm^3\,l^{-1}$. Bars: 95 % confidence limits. Lines drawn by hand

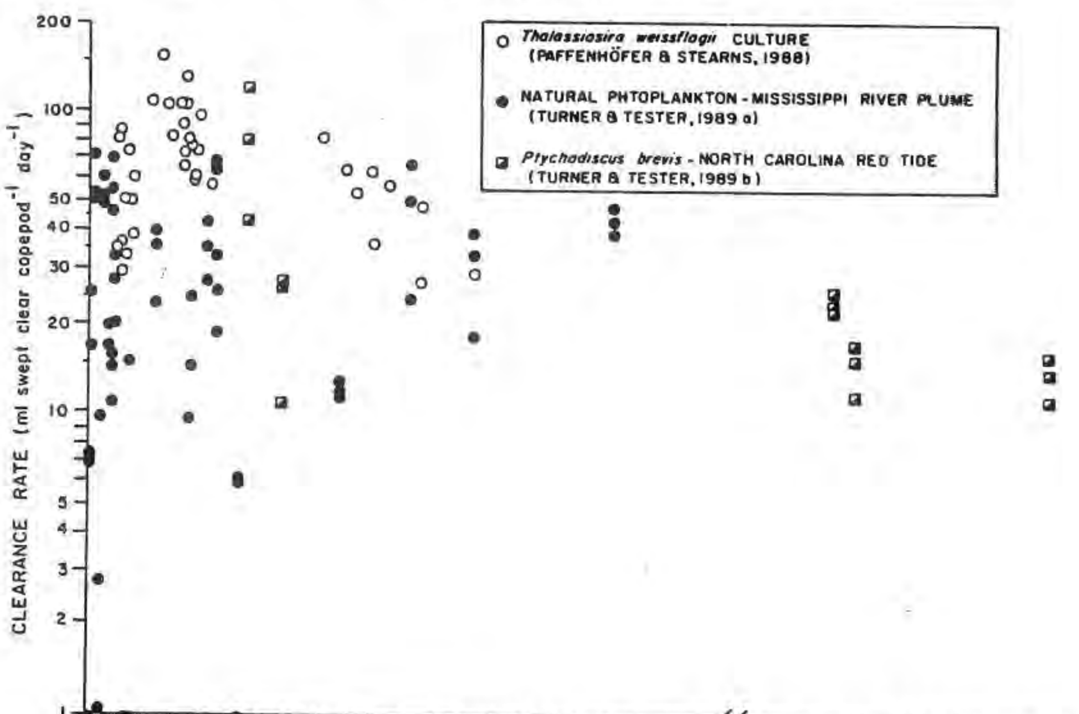
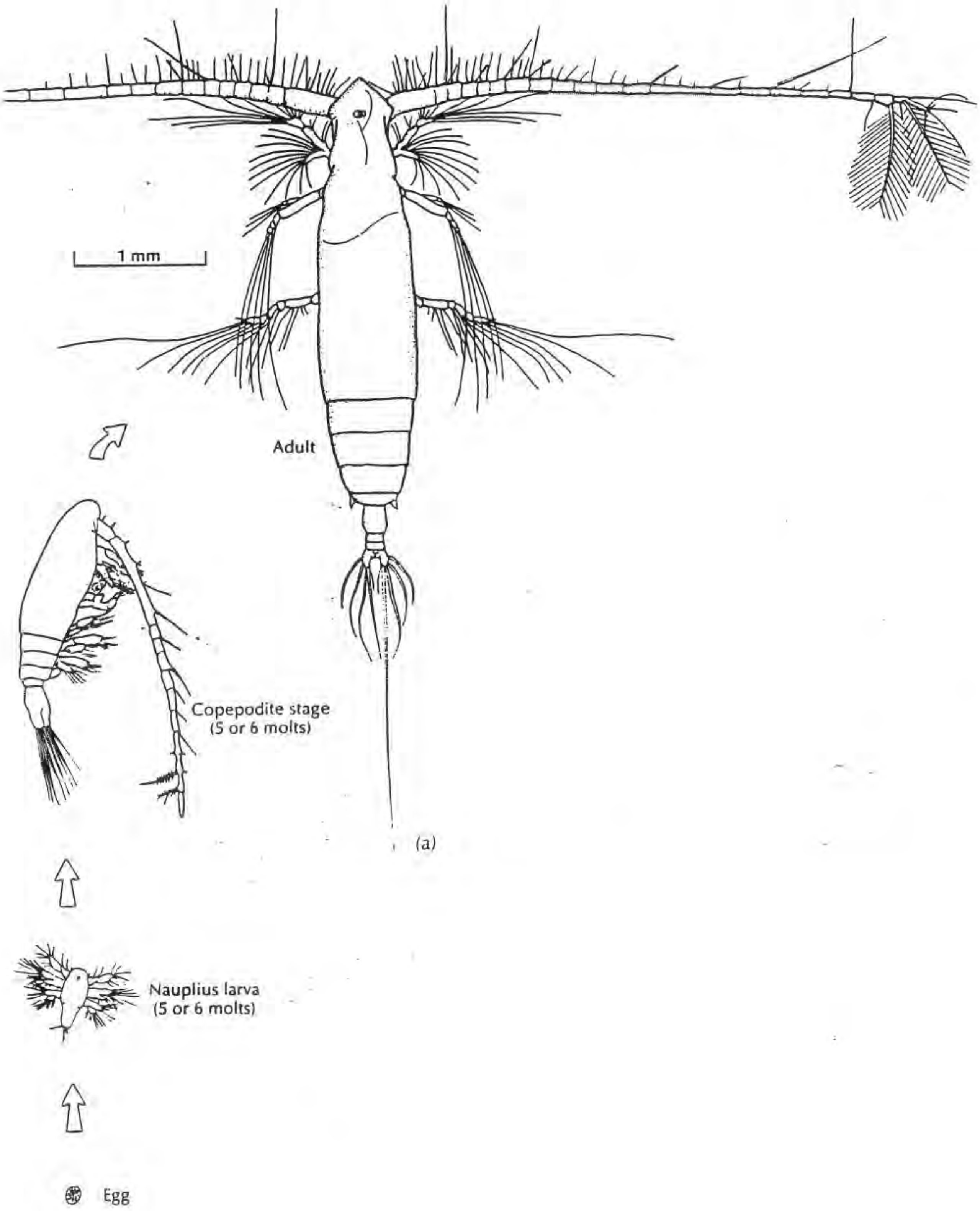


Fig. 3. Comparison of the clearance rates for *Acartia tonsa* fed on *Thalassiosira weissflogii* cultures (Paffenhöfer & Stearns 1988) and natural phytoplankton in the Mississippi River plume (Turner & Tester 1989a), and on *Gymnodinium breve* during a red tide (Turner & Tester 1989b)

203


1 mm
Adult
Copepodite stage
(5 or 6 molts)
Nauplius larva
(5 or 6 molts)
Egg

(a)

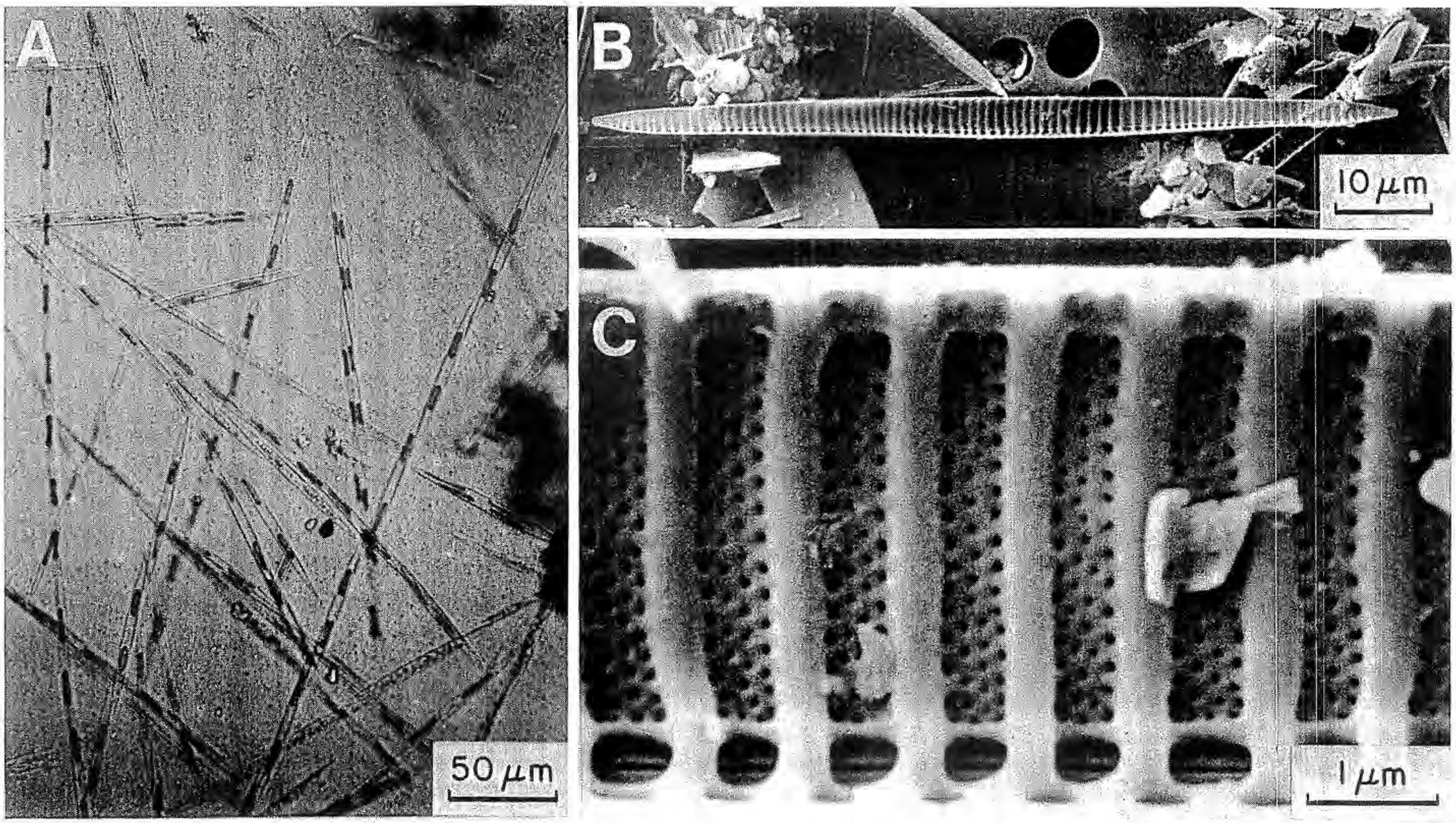


FIG. 4. *Nitzschia pungens* f. *multiseries* from Cardigan Bay: (A) light photomicrograph showing chains of *N. pungens*; (B) scanning electron micrograph of a single valve showing the costae; and (C) same valve at higher magnification, showing the rows of poroids between the costae.

Suggested Zooplankton Threshold:

If the *Acartia tonsa/A. hudsonica* abundance at the nearfield stations in any given sample ever exceeded 50% of total non-naupliar copepods (ie. adults plus copepodites), then we would know there had been a big change. Whether such a change was due to eutrophication or salinity would not be known based on that, but if *Acartia*'s ever exceed 50% of the copepod abundance, then we would know that something had happened.

The reason that I suggest >50% *Acartia* abundance in the nearfield, is that I suspect that it will never happen, and that anything else would be within the very broad quantitative envelope of variability for abundances of a few repeatedly and perennially dominant taxa.

Presently, and I fully expect after the outfall goes on line, the copepod abundance in the nearfield, and farfield outside Boston Harbor will be dominated by *Oithona similis, Pseudocalanus* spp., and to a much lesser extent *Paracalanus parvus, Centropages typicus* and *C. hamatus, Calanus finmarchicus* and other typically "offshore" copepods. Since these "non-*Acartia*'s" often co-occur at varying, and for all but *Oithona* and *Pseudocalanus* copepodites, low numbers throughout the nearfield and farfield, any thresholds based upon their numbers would not be clear-cut. However, if we see *Acartia* spp. ever comprising over half the copepods anywhere but inside the harbor, then we know that, for whatever reason, there had been a big change (for example a runoff pulse due to a hurricane).

In terms of meroplankton (planktonic larvae of benthic invertebrates), while they often dominate the numbers in many zooplankton samples, their periods of abundance are "spikey," and likely more related to reproductive cycles of the macrobenthic parents, than to processes in the plankton.

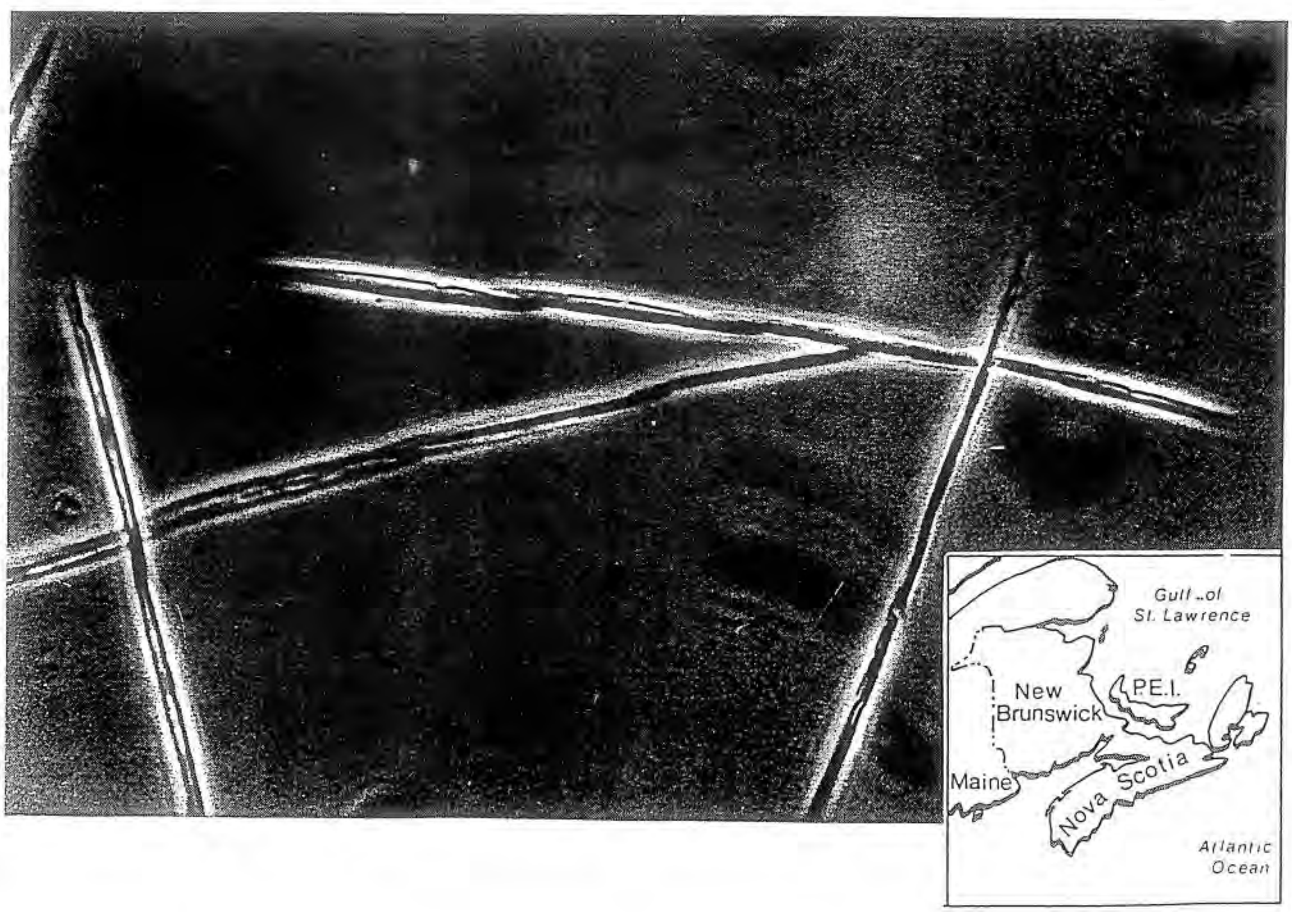
Pennate Diatom *Nitzschia pungens* as the Primary Source of Domoic Acid, a Toxin in Shellfish from Eastern Prince Edward Island, Canada[1]

S. S. Bates[2], C. J. Bird, A. S. W. de Freitas[3], R. Foxall, M. Gilgan[4], L. A. Hanic[5], G. R. Johnson[6], A. W. McCulloch, P. Odense, R. Pocklington[7], M. A. Quilliam, P. G. Sim, J. C. Smith[8], D. V. Subba Rao[7], E. C. D. Todd[9], J. A. Walter, and J. L. C. Wright.

Atlantic Research Laboratory, National Research Council of Canada, 1411 Oxford St., Halifax, N.S. B3H 3Z1

Bates, S. S., C. J. Bird, A. S. W. de Freitas, R. Foxall, M. Gilgan, L. A. Hanic, G. R. Johnson, A. W. McCulloch, P. Odense, R. Pocklington, M. A. Quilliam, P. G. Sim, J. C. Smith, D. V. Subba Rao, E. C. D. Todd, J. A. Walter, and J. L. C. Wright. 1989. Pennate diatom *Nitzschia pungens* as the primary source of domoic acid, a toxin in shellfish from eastern Prince Edward Island, Canada. Can. J. Fish. Aquat. Sci. 46: 1203–1215.

An outbreak of food poisoning in Canada during autumn 1987 was traced to cultured blue mussels (*Mytilus edulis*) from the Cardigan Bay region of eastern Prince Edward Island (P.E.I.). The toxin, identified as domoic acid, had not previously been found in any shellfish and this outbreak represents the first known occurrence of human poisoning by this neurotoxin. A plankton bloom at the time of the outbreak consisted almost entirely of the pennate diatom, *Nitzschia pungens* f. *multiseries*, and a positive correlation was found between the number of *N. pungens* cells and the concentration of domoic acid in the plankton. *Nitzschia pungens* f. *multiseries* isolated from Cardigan Bay produced domoic acid in culture at levels (1 to 20 pg·cell^{-1}) comparable with values estimated for *N. pungens* in the plankton samples. Isolates of several Cardigan Bay phytoplankton, including the closely related species *Nitzschia seriata*, failed to produce domoic acid. Other *Nitzschia* spp. and two *Amphora coffeaeformis* isolates also failed to produce domoic acid. We conclude that *N. pungens* was the major source of the domoic acid in toxic mussels in eastern P.E.I. The recurrence, in November 1988, of a monospecific bloom of *N. pungens* and the presence of domoic acid in plankton and mussels reinforced this conclusion.



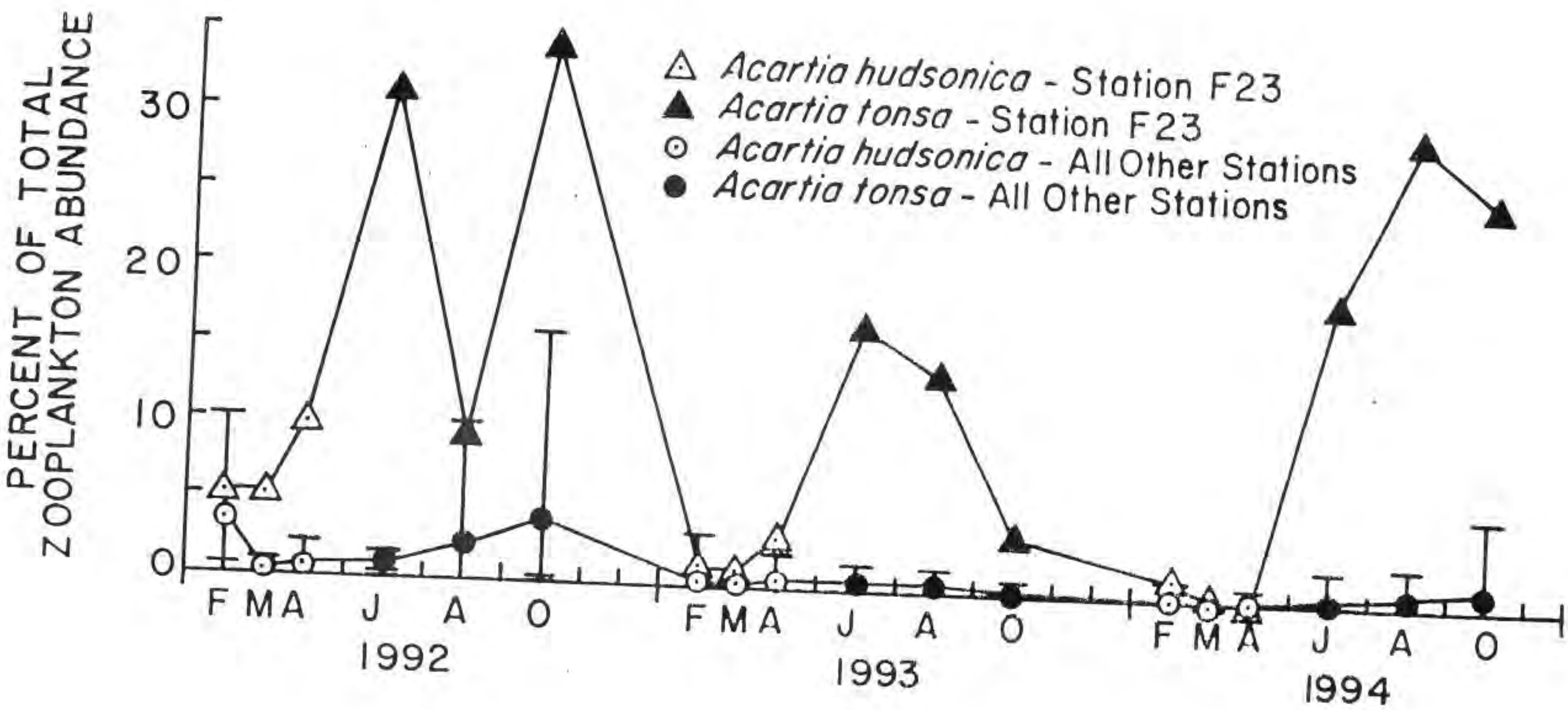

PERCENT OF TOTAL
ZOOPLANKTON ABUNDANCE
30
20
10
0
Acartia hudsonica - Station F23
Acartia tonsa - Station F23
Acartia hudsonica - All Other Stations
Acartia tonsa - All Other Stations
F M A J A O
1992
F M A J A O
1993
F M A J A O
1994

Fig. 5

208

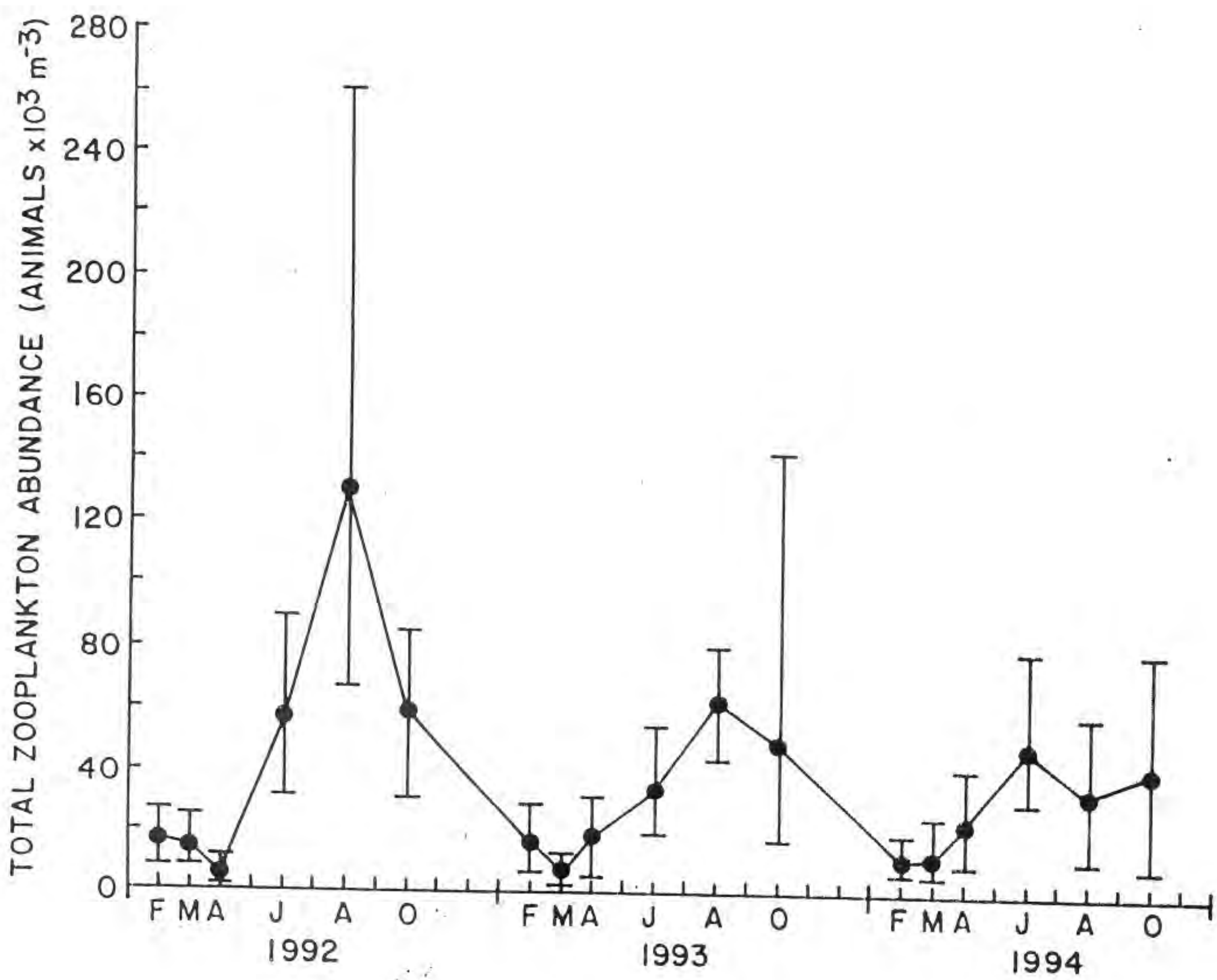

TOTAL ZOOPLANKTON ABUNDANCE (ANIMALS x10^{3} m^{-3})
280
240
200
160
120
80
40
0
F M A J A O
1992
F M A J A O
1993
F M A J A O
1994

Fig. 2

2209

Water Column Monitoring and Nutrient Cycling

1998 Productivity Overview *(Dr. Aimee Keller, URI)*

ACKNOWLEDGEMENTS:

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Laura Reed
Gwynne Holcombe
Tarquin Dorrington
Scott Sauchuk
Andy Parrella
Liz Bruce

Funding: MWRA

Introduction
C-14 Production

Changes in Methodology

Results
- Model Parameters
- Daily Production
- Annual Production

Bloom Failure

Modeling

CHANGES IN C-14 METHODOLOGY
1998 vs 1995-97

Volume incubated reduced to 5 ml

Samples not filtered

Incubated at 16 light levels (2 dark)

Range of light: 0 to 2000 uE m^{-2} s^{-1}

Incubation period: 1-2 h

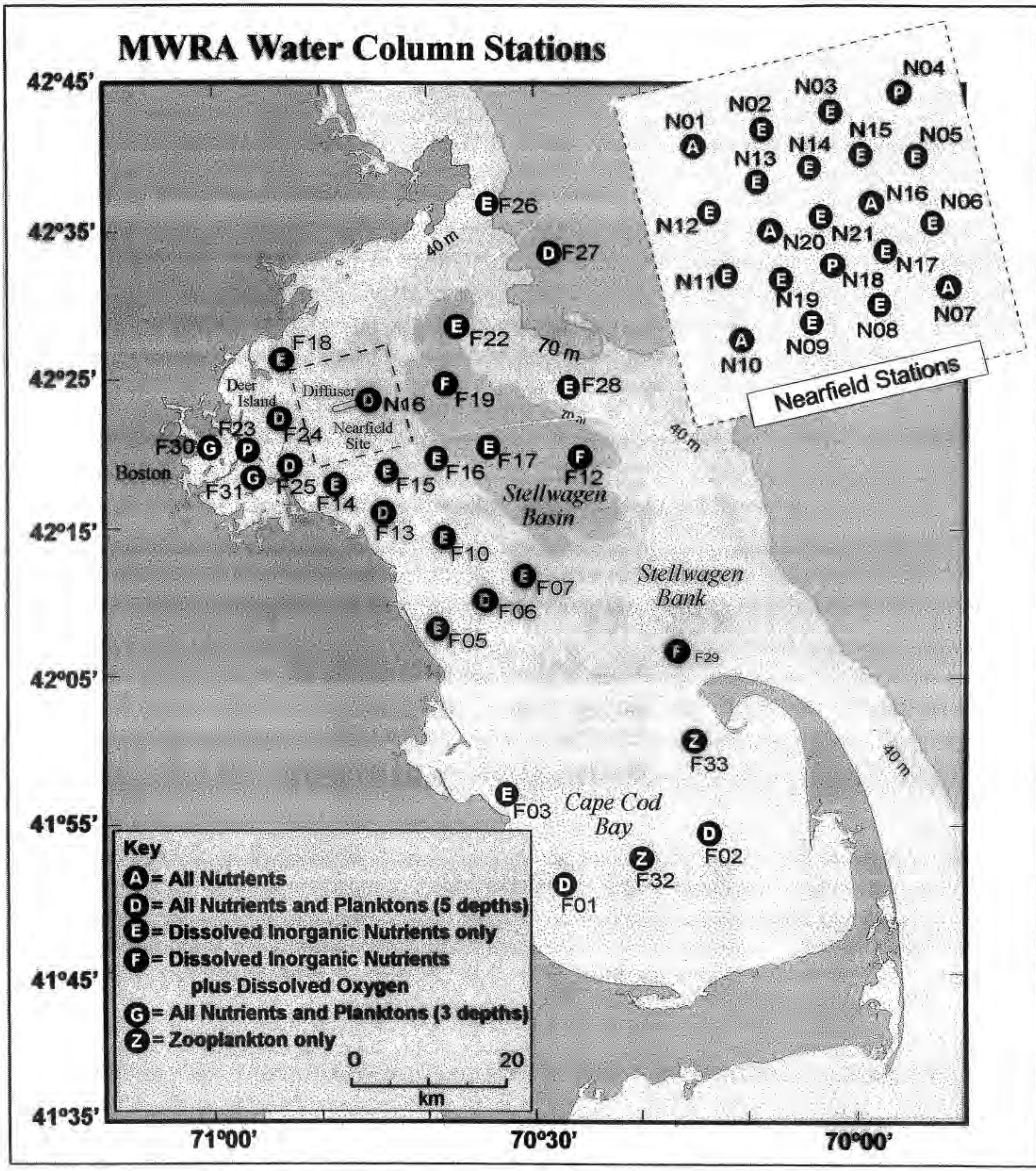
Sampling Primary Productivity

Stations: N04, N18 - Nearfield
F23 - Harbor

Depths: S, MS, M, MB, B

Surveys:
N04-N18 (17 total, Feb.-Dec. 1998)
F23 (6 total, Feb.-Oct. 1998)

MWRA Water Column Stations



Introduction
C-14 Production

Changes in Methodology

Results

- Model Parameters
- Daily Production
- Annual Production

Bloom Failure

Modeling

P-I Curves

1. Webb et al. 1974 - No Photoinhibition

$$P(I) = P_{max} \left(1 - e^{-\alpha I / P_{max}}\right)$$

with: $P(I)$ = primary production at irradiance I
P_{max} = light saturated maximum production
α = initial slope of P-I curve

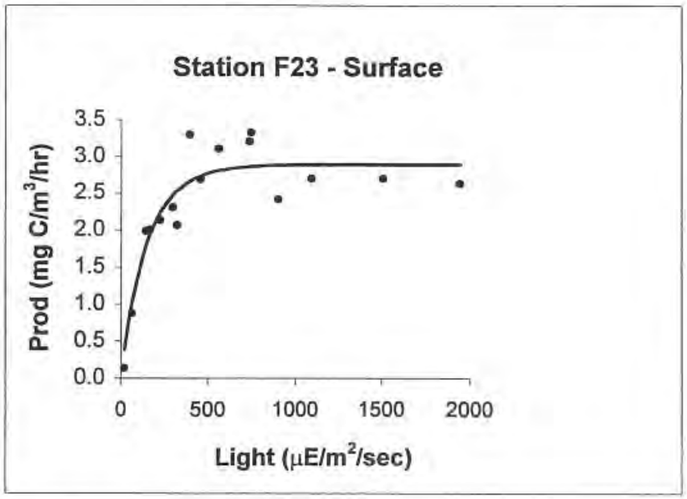
2. Platt et al. 1980 - Photoinhibition

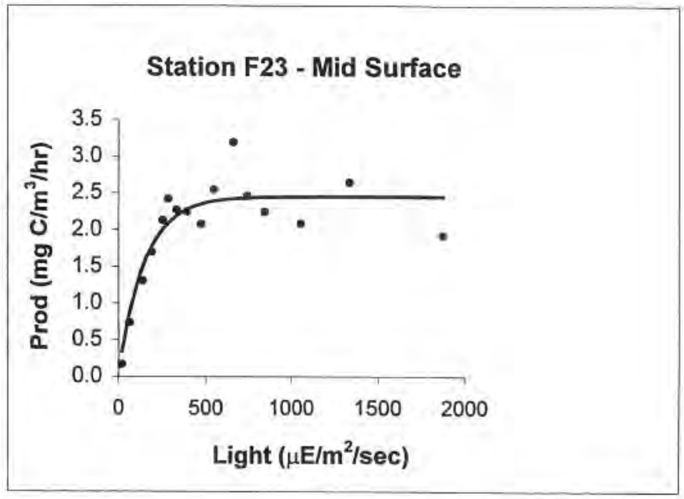
$$P(I) = P_{sb} \left(1 - e^{-\alpha I / P_{sb}}\right) e^{-\beta I / P_{sb}}$$

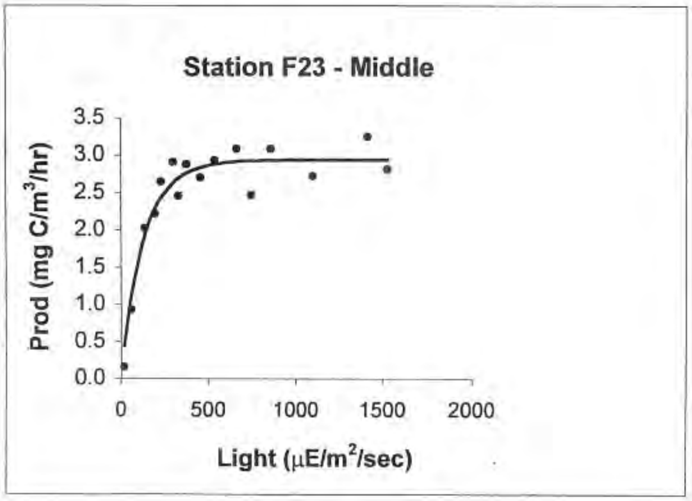
with: $P(I)$ = primary production at irradiance I
P_{sb} = theoretical maximum production without photoinhibition
α = initial slope of P-I curve
β = term indicating degree of inhibition

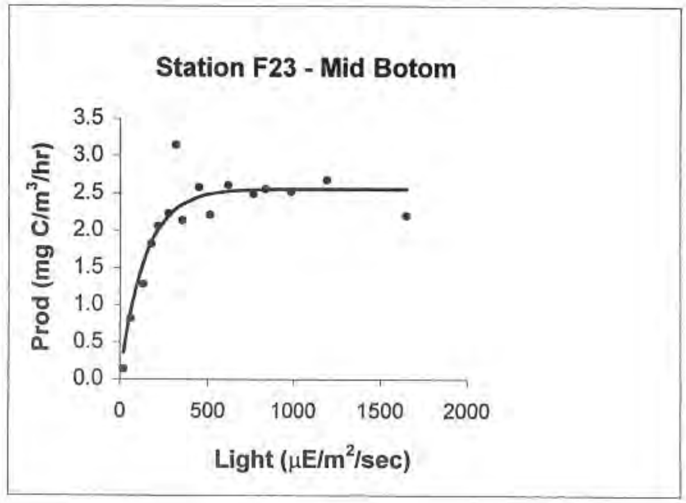
note: $P_{max} = P_{sb} \left[\alpha / (\alpha + \beta)\right] \left[\beta / (\alpha + \beta)\right]^{\beta / \alpha}$

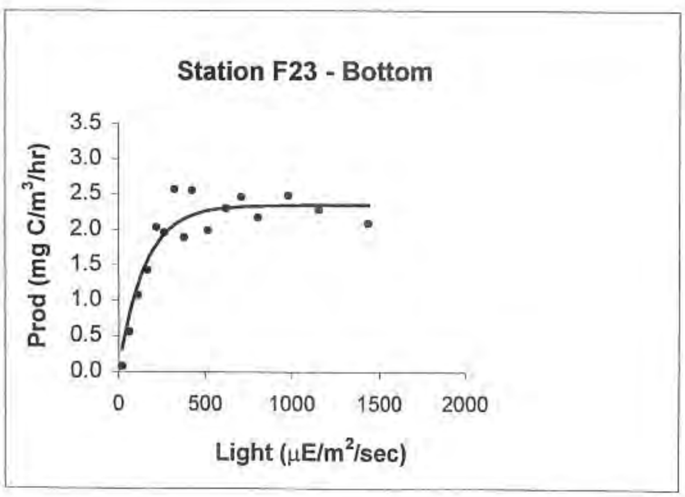
WF984


Station F23 - Surface
Prod (mg C/m³/hr)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
500
1000
1500
2000
Light (μE/m²/sec)


Station F23 - Mid Surface
Prod (mg C/m³/hr)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
500
1000
1500
2000
Light (μE/m²/sec)


Station F23 - Middle
Prod (mg C/m³/hr)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
500
1000
1500
2000
Light (μE/m²/sec)


Station F23 - Mid Botom
Prod (mg C/m³/hr)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
500
1000
1500
2000
Light (μE/m²/sec)


Station F23 - Bottom
Prod (mg C/m³/hr)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
500
1000
1500
2000
Light (μE/m²/sec)

WN98A **Station N04**

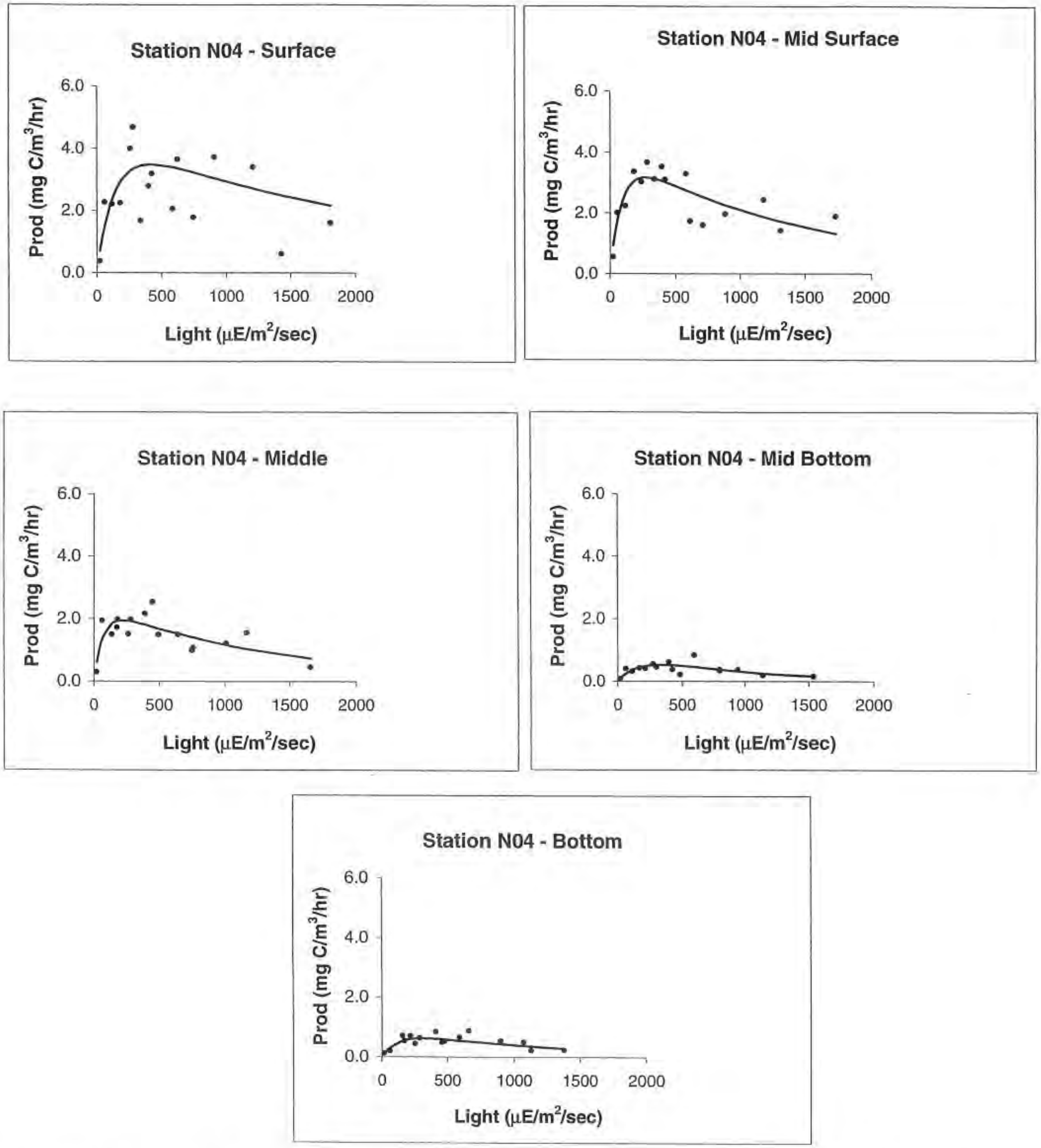
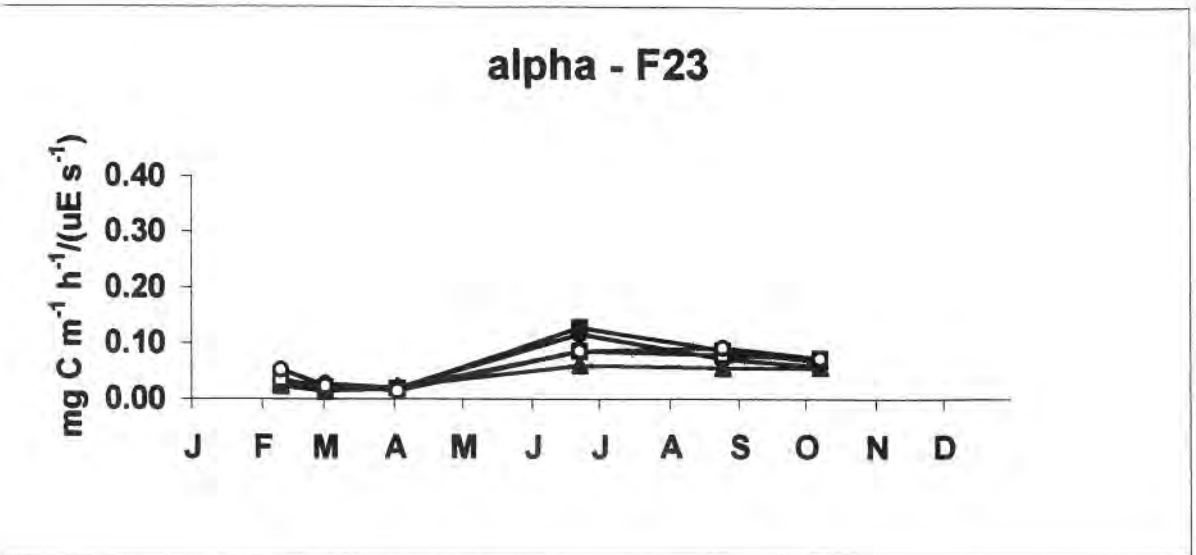
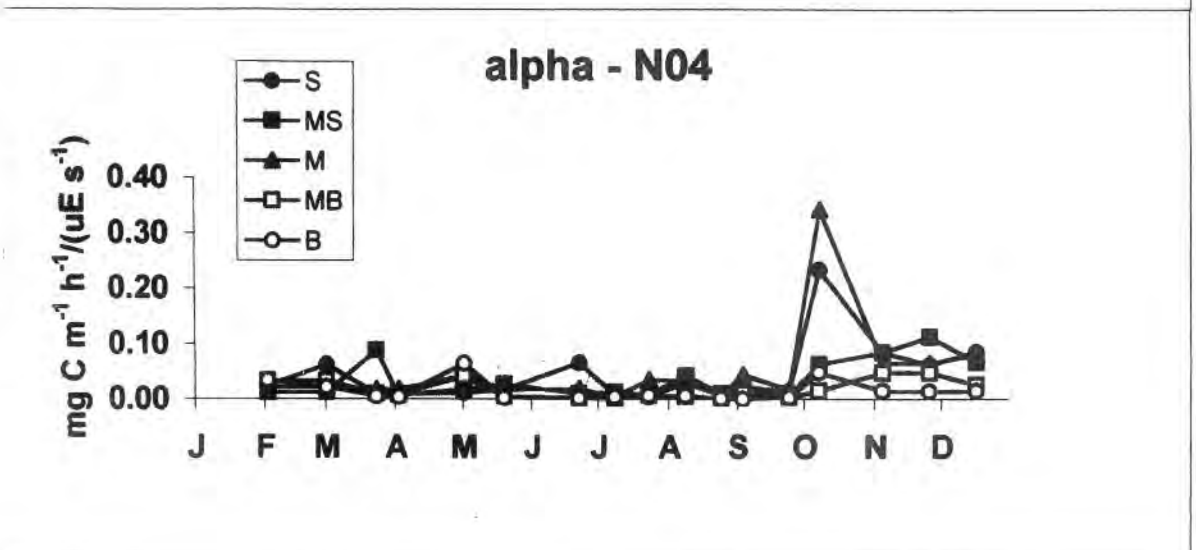
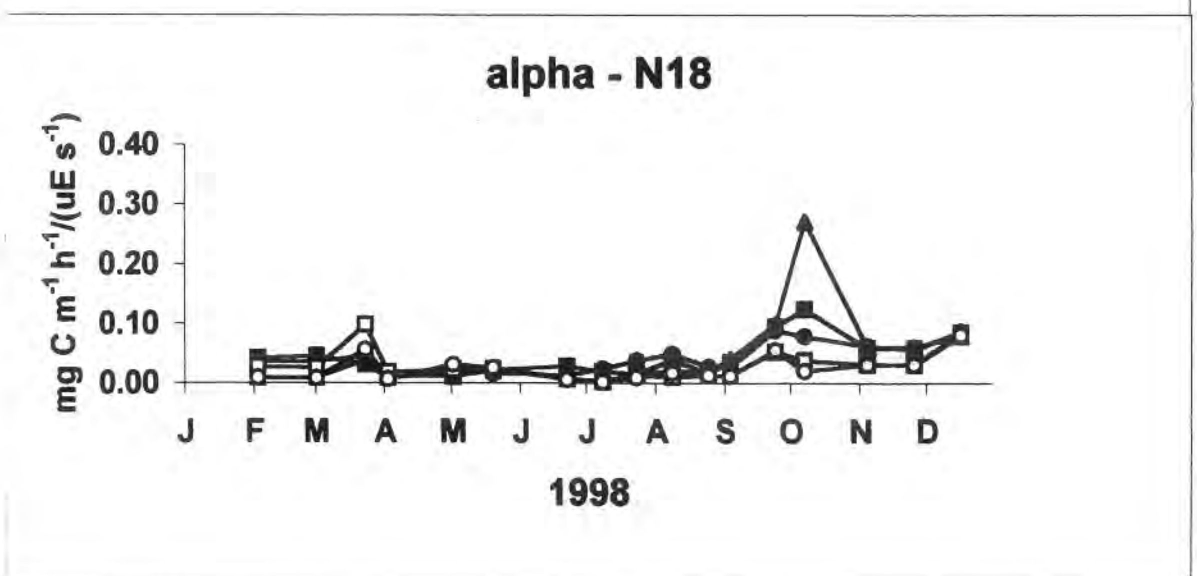
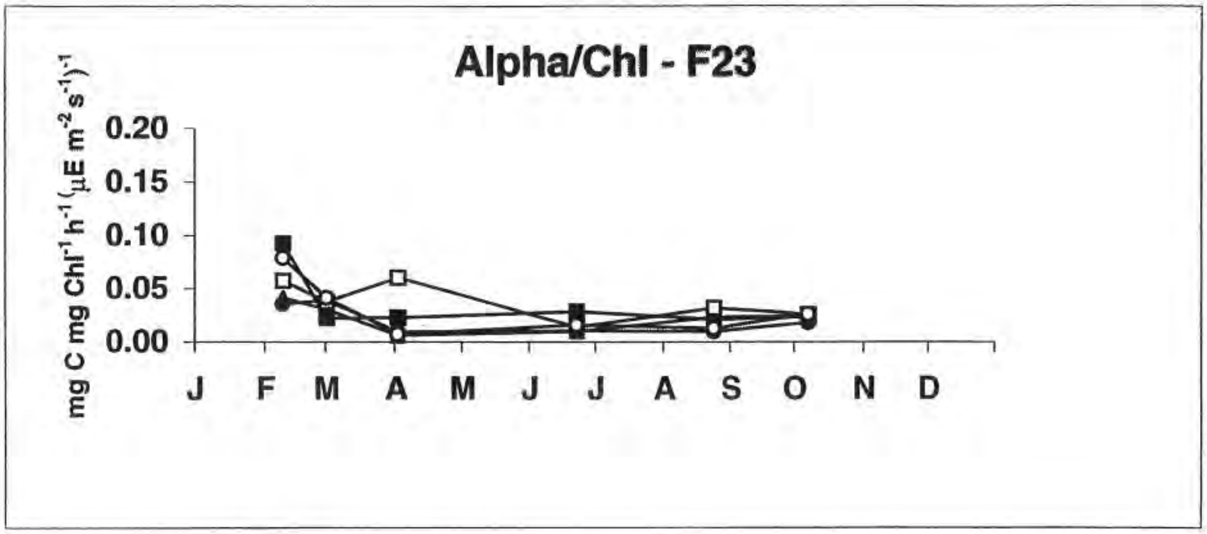


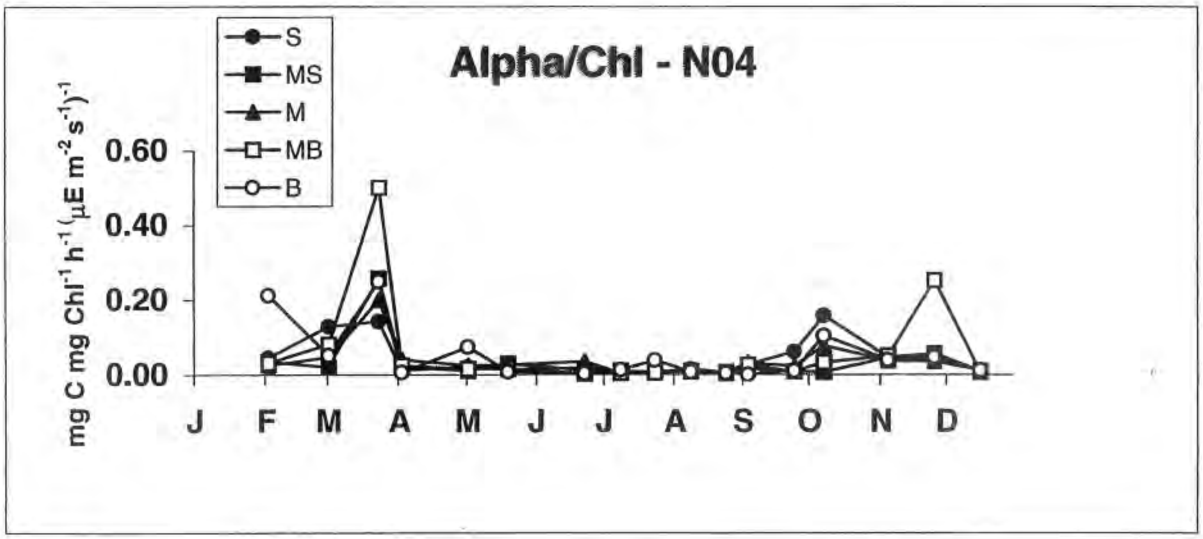
Figure 5.1 An Example Photosynthesis-Irradiance Curve From Station N04 Collected in August

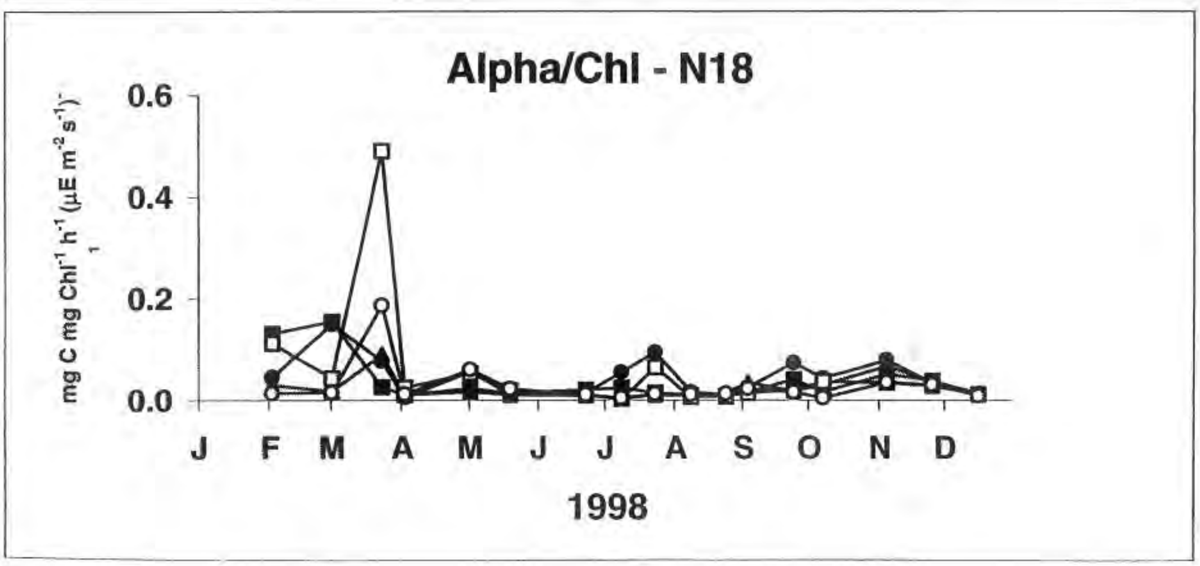

alpha - F23
mg C m-1 h-1/(uE s-1)
0.40
0.30
0.20
0.10
0.00
J F M A M J J A S O N D

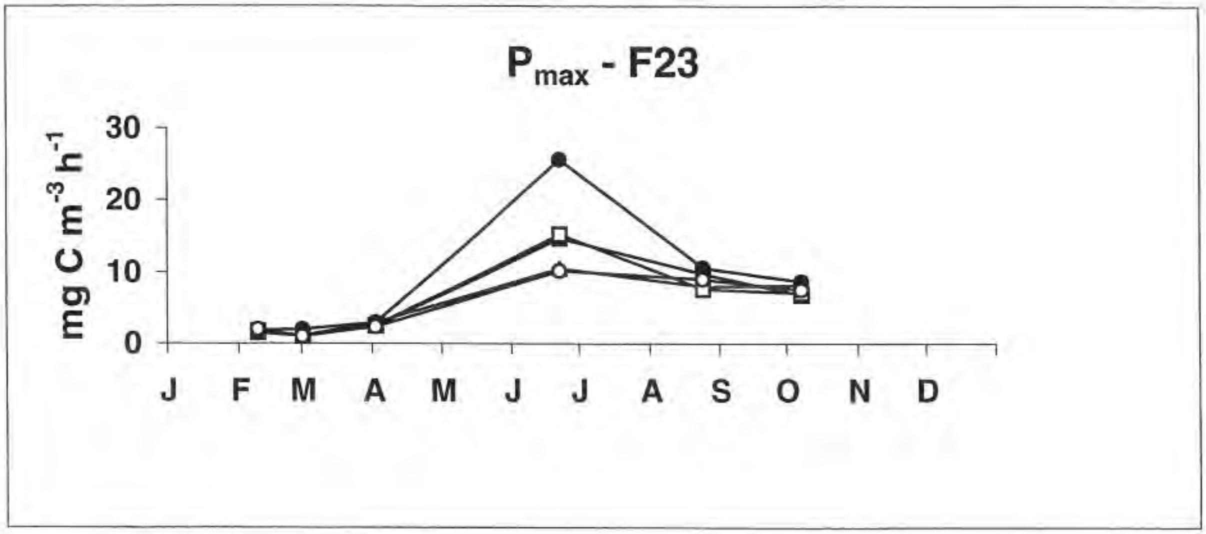

alpha - N04
S
MS
M
MB
B
mg C m-1 h-1/(uE s-1)
0.40
0.30
0.20
0.10
0.00
J F M A M J J A S O N D

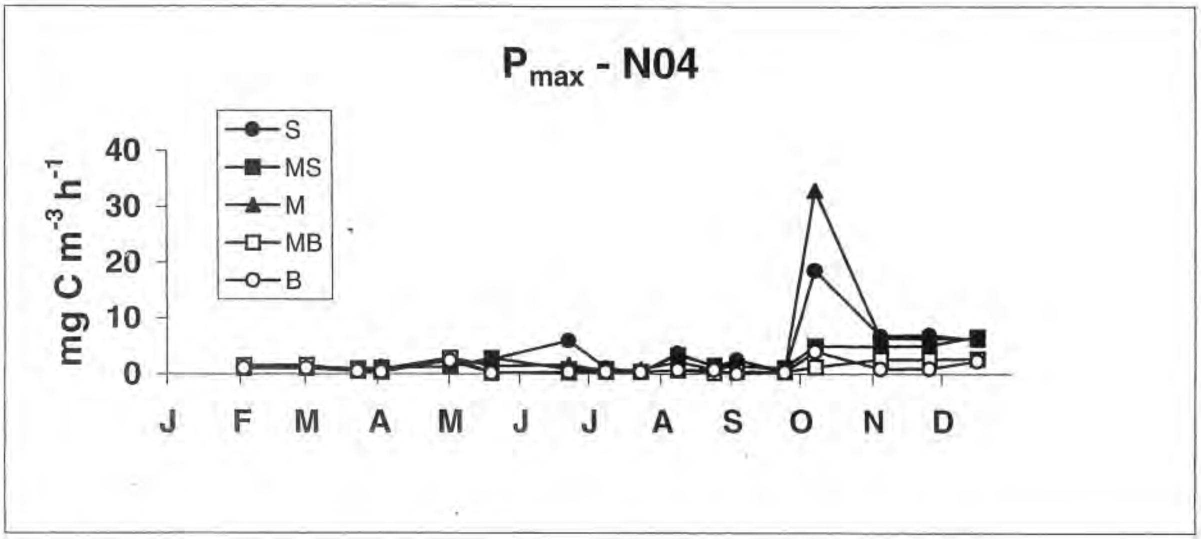

alpha - N18
mg C m-1 h-1/(uE s-1)
0.40
0.30
0.20
0.10
0.00
J F M A M J J A S O N D
1998

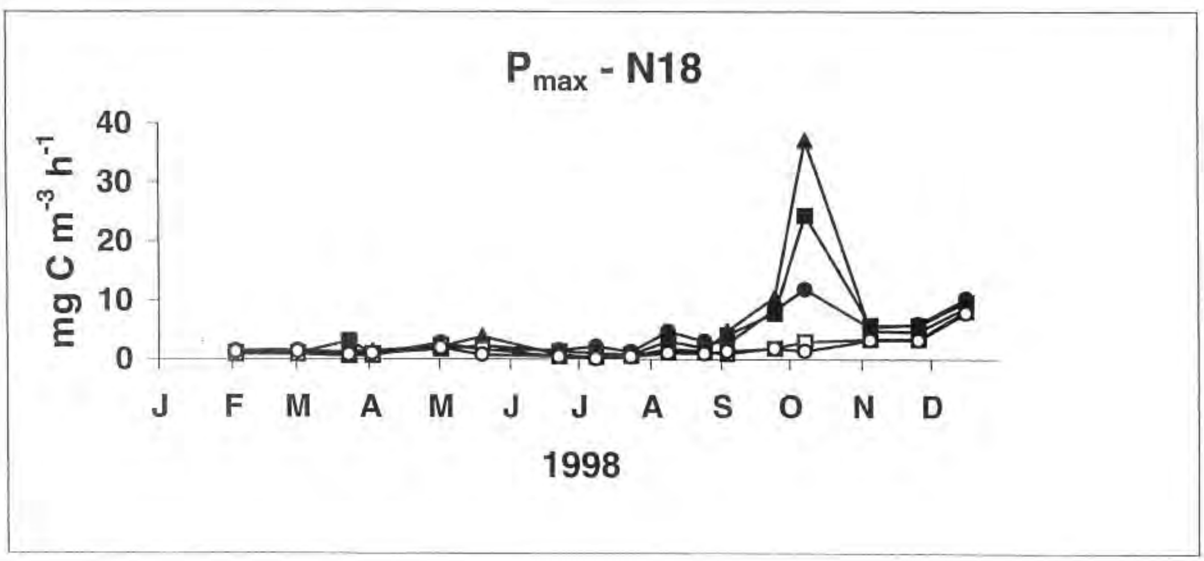

Alpha/Chl - F23
mg C mg Chl-1 h-1 (µE m-2 s-1)-1
0.20
0.15
0.10
0.05
0.00
J F M A M J J A S O N D

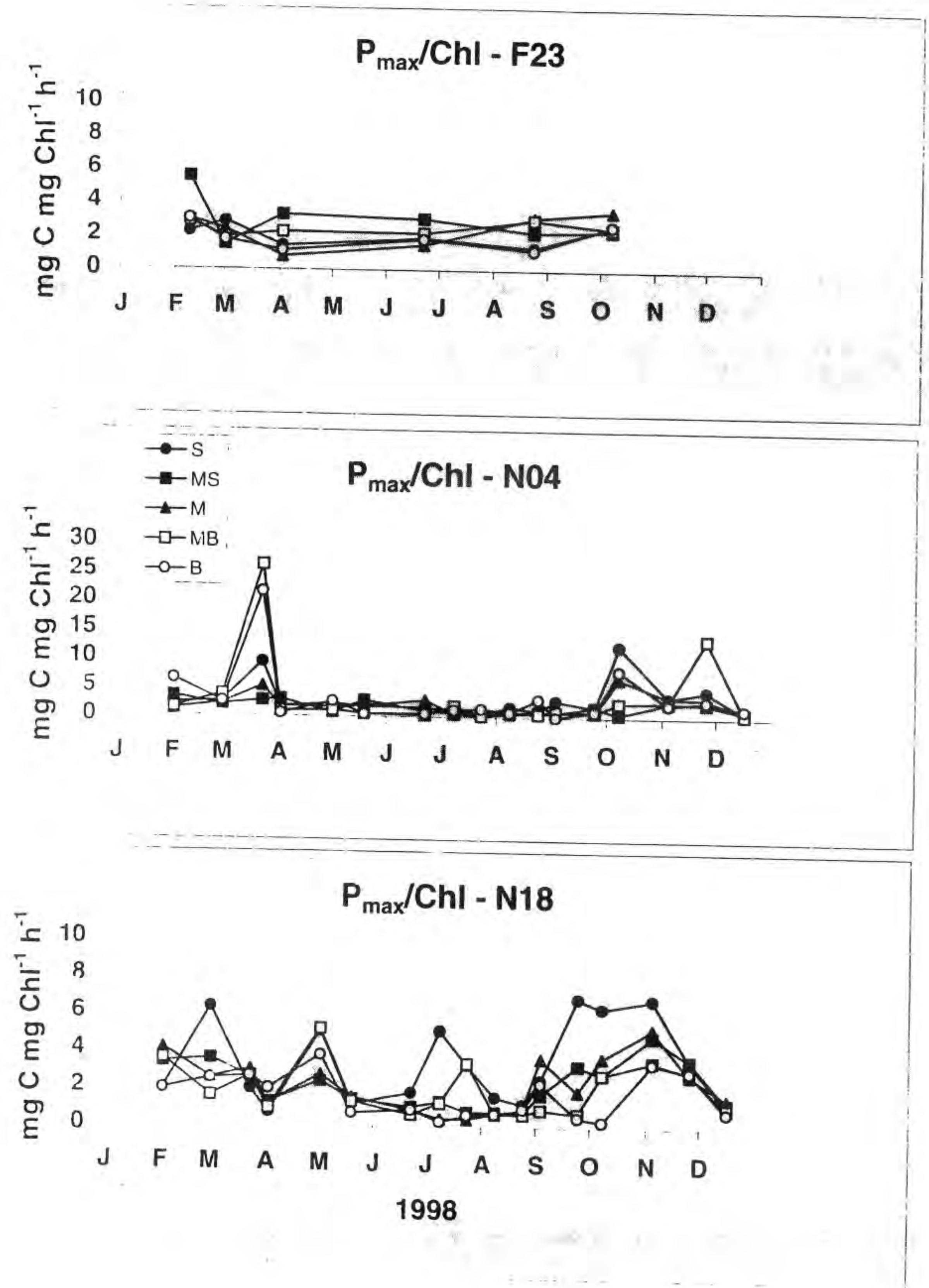

S
MS
M
MB
B
Alpha/Chl - N04
mg C mg Chl-1 h-1 (µE m-2 s-1)-1
0.60
0.40
0.20
0.00
J F M A M J J A S O N D

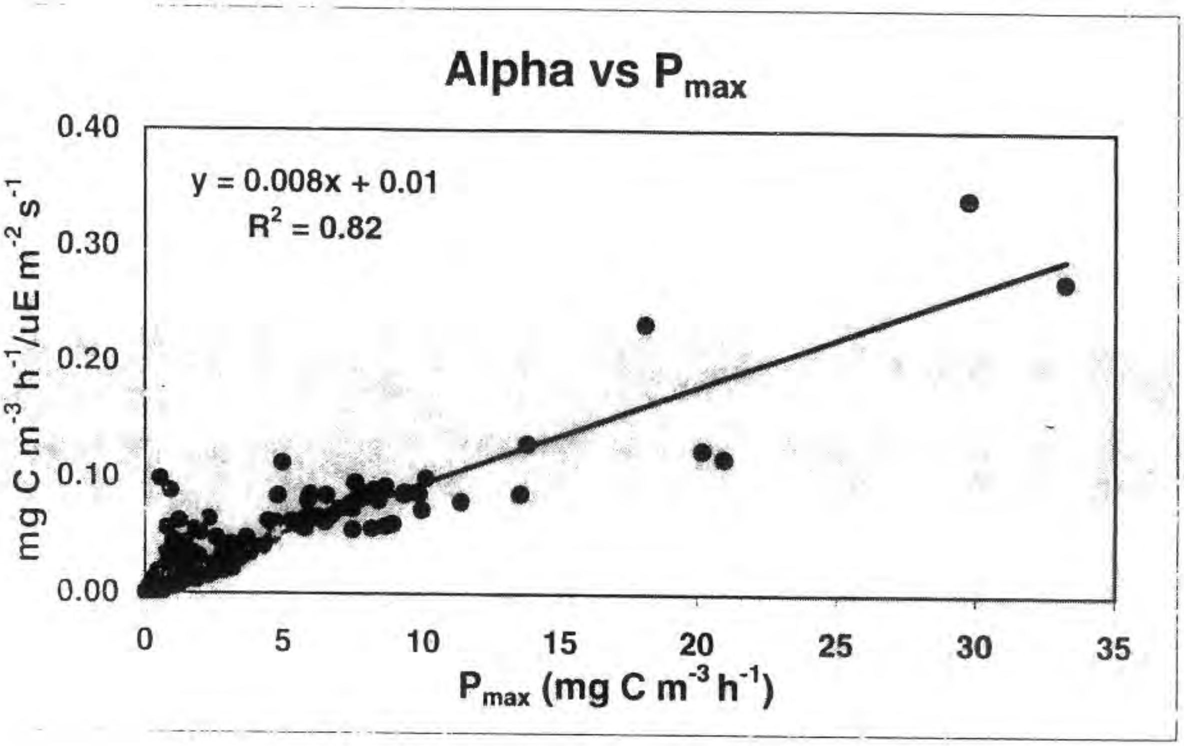

Alpha/Chl - N18
mg C mg Chl-1 h-1 (µE m-2 s-1)-1
0.6
0.4
0.2
0.0
J F M A M J J A S O N D
1998

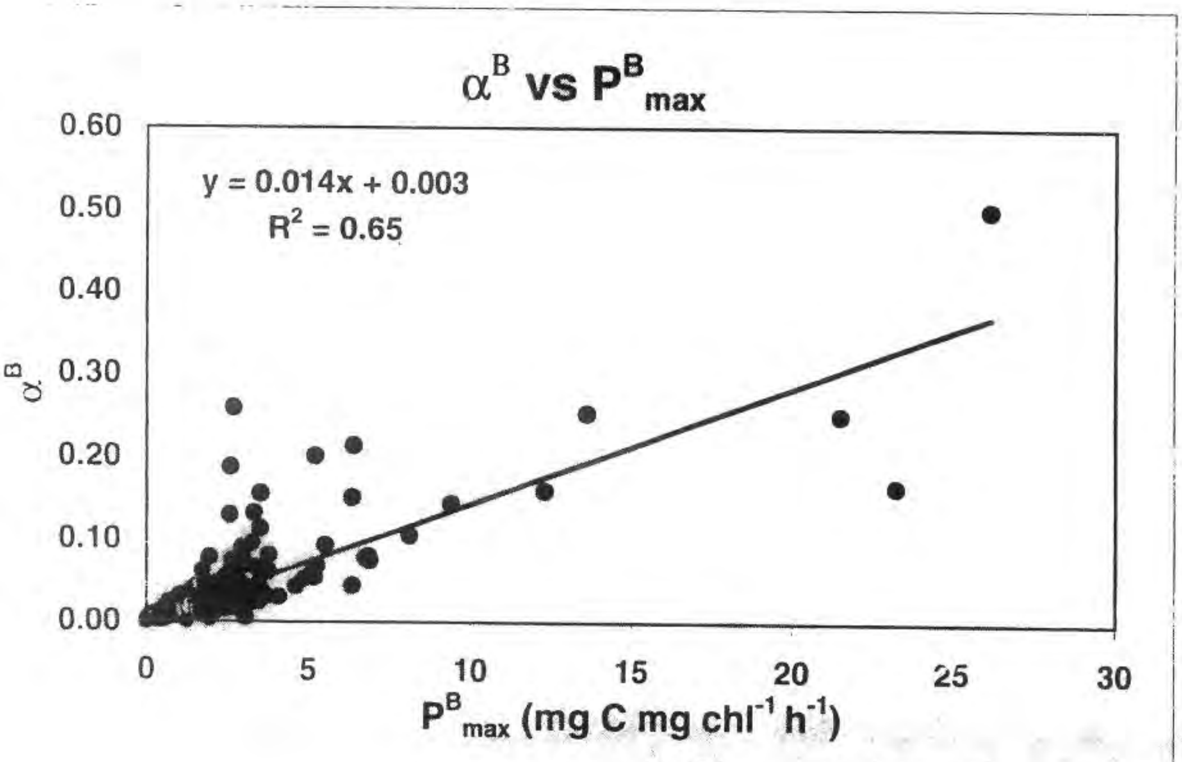

Pmax - F23
mg C m-3 h-1
30
20
10
0
J F M A M J J A S O N D

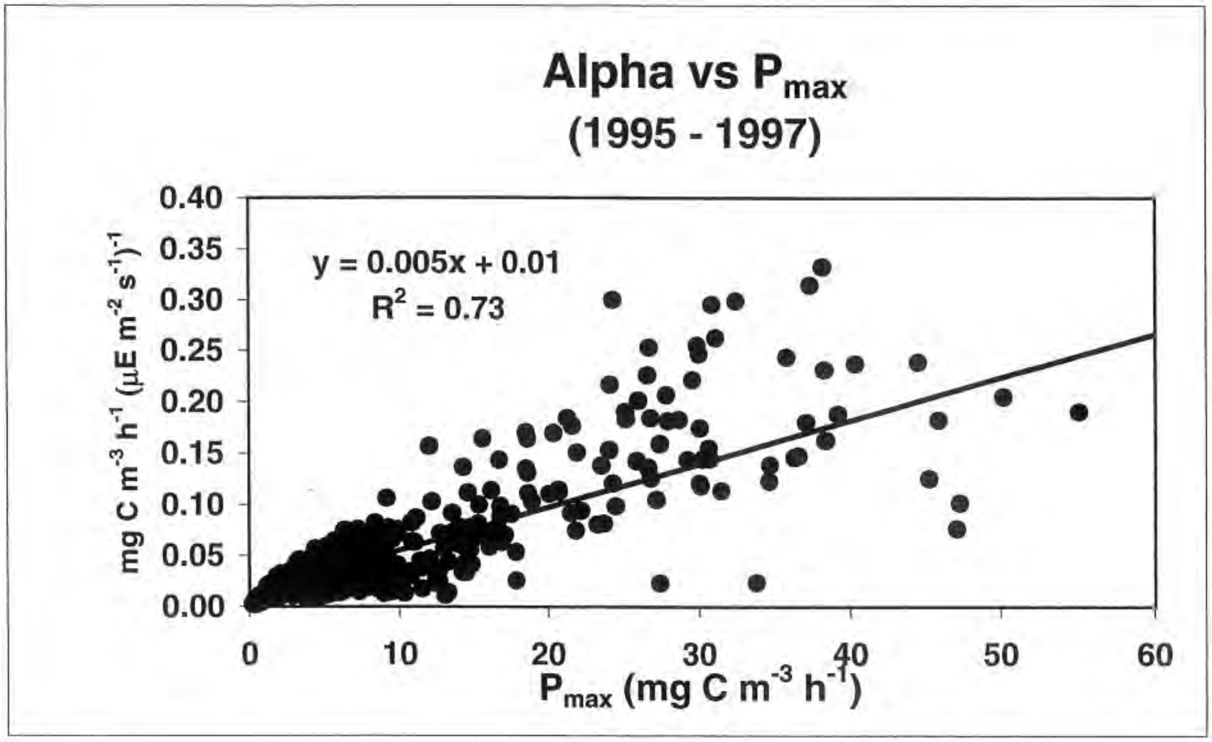

Pmax - N04
S
MS
M
MB
B
mg C m-3 h-1
40
30
20
10
0
J F M A M J J A S O N D


Pmax - N18
mg C m-3 h-1
40
30
20
10
0
J F M A M J J A S O N D
1998

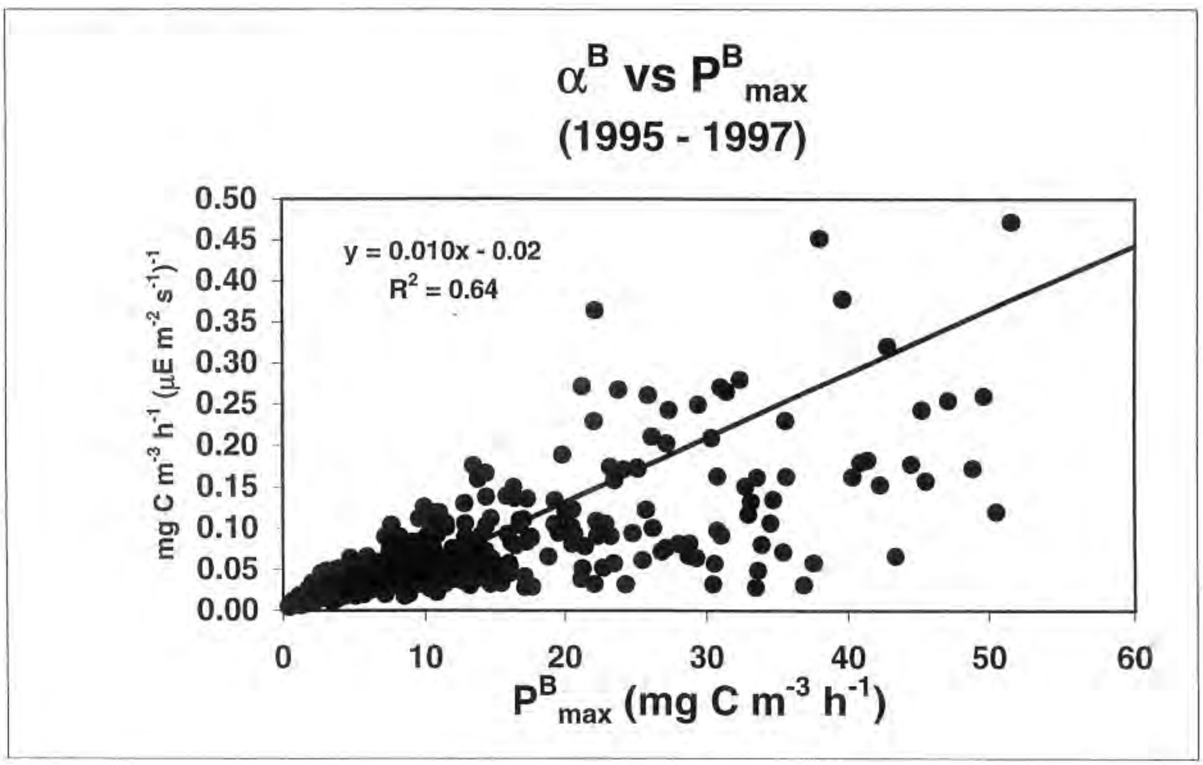

P_{max}/Chl - F23
mg C mg Chl^{-1} h^{-1}
10
8
6
4
2
0
J F M A M J J A S O N D
S
MS
M
MB
B
P_{max}/Chl - N04
mg C mg Chl^{-1} h^{-1}
30
25
20
15
10
5
0
J F M A M J J A S O N D
P_{max}/Chl - N18
mg C mg Chl^{-1} h^{-1}
10
8
6
4
2
0
J F M A M J J A S O N D
1998


Alpha vs Pmax
0.40
0.30
0.20
0.10
0.00
mg C m-3 h-1/uE m-2 s-1
y = 0.008x + 0.01
R2 = 0.82
0
5
10
15
20
25
30
35
Pmax (mg C m-3 h-1)

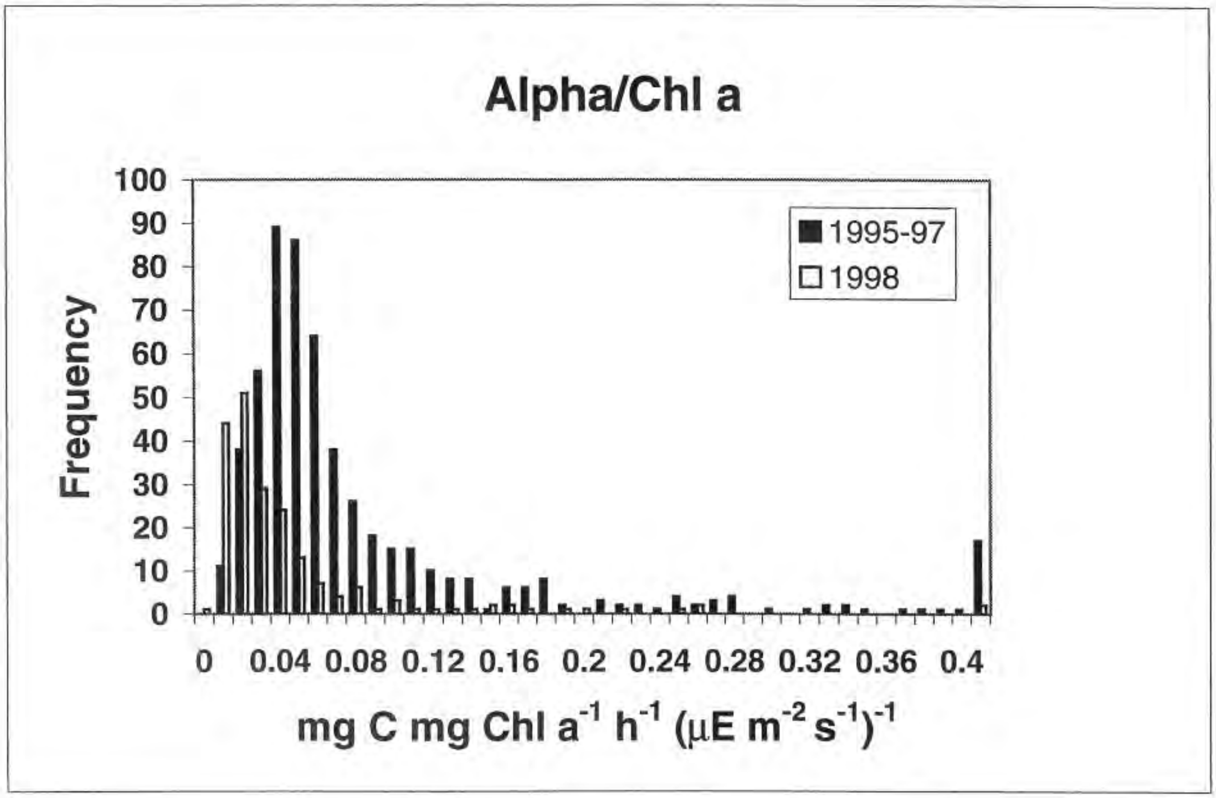

αB vs PBmax
0.60
0.50
0.40
0.30
0.20
0.10
0.00
αB
y = 0.014x + 0.003
R2 = 0.65
0
5
10
15
20
25
30
PBmax (mg C mg chl-1 h-1)

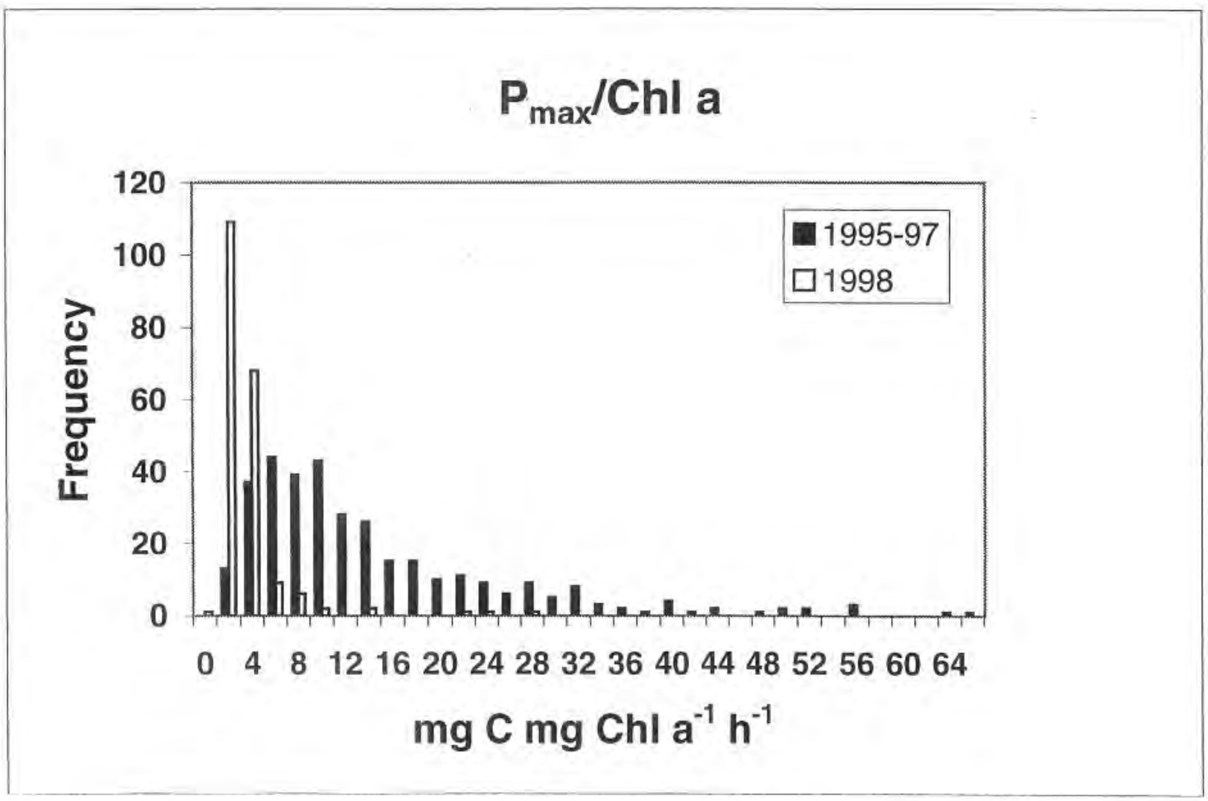


Alpha vs P max
(1995 - 1997)
y = 0.005x + 0.01
R2 = 0.73
mg C m-3 h-1 (µE m-2 s-1)-1
P max (mg C m-3 h-1)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
50
60



αB vs PB max
(1995 - 1997)
y = 0.010x - 0.02
R2 = 0.64
mg C m-3 h-1 (µE m-2 s-1)-1
PB max (mg C m-3 h-1)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
50
60


Alpha/Chl a
Frequency
1995-97
1998
0 0.04 0.08 0.12 0.16 0.2 0.24 0.28 0.32 0.36 0.4
mg C mg Chl a-1 h-1 (μE m-2 s-1)-1


Pmax/Chl a
Frequency
1995-97
1998
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64
mg C mg Chl a-1 h-1

MODEL PARAMETERS - SUMMARY

- Seasonal pattern for N04 and N18 different from F23

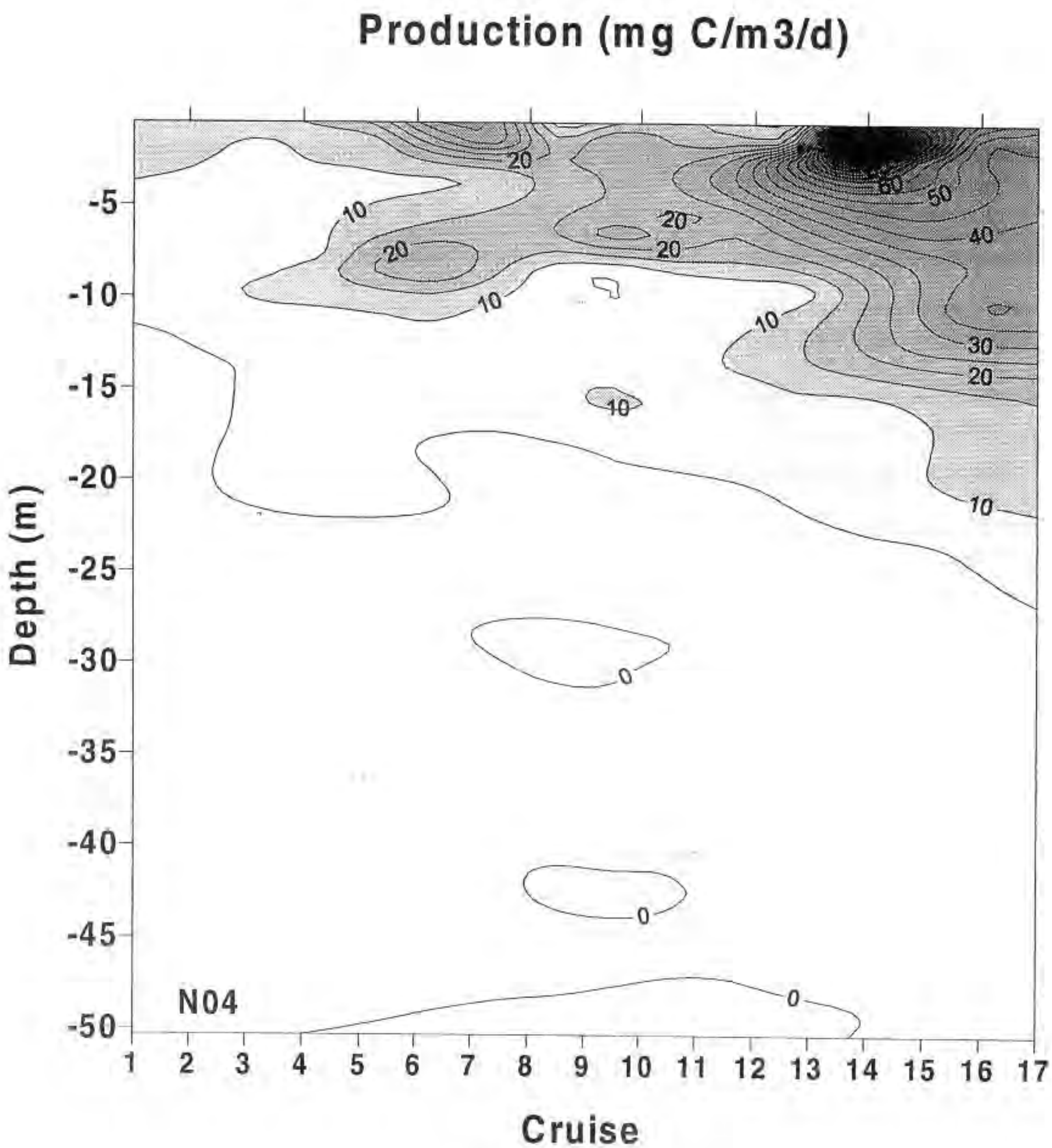
- Parameters generally decreased with increased depth

- Chl-specific parameters increased during the spring and fall bloom periods (but no spring bloom materialized)

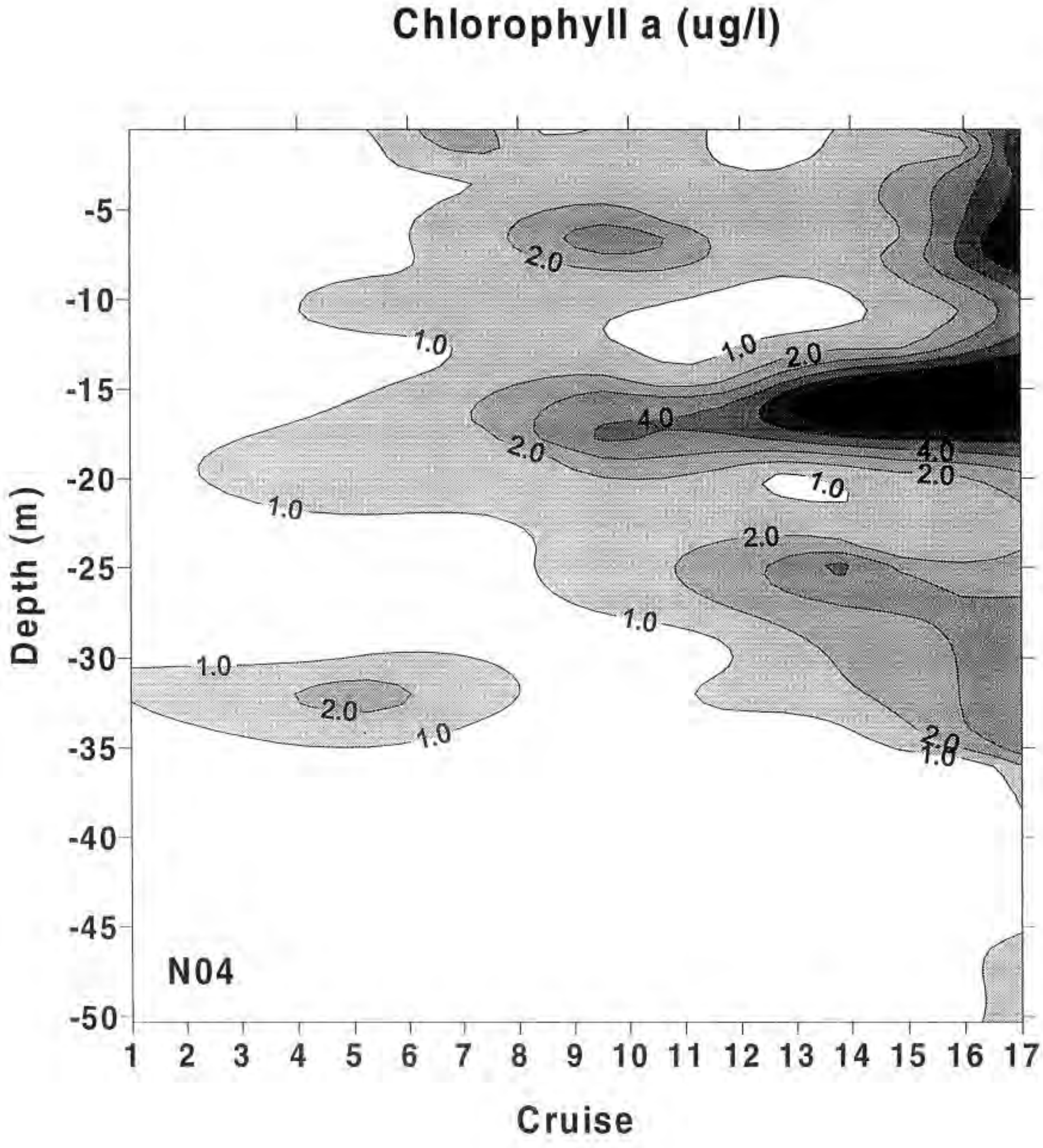
- Increased photosynthetic efficiency related to:
  1-elevated light in spring
  2-improved nutrient availability in fall

- Parameters significantly correlated (as in prior years)

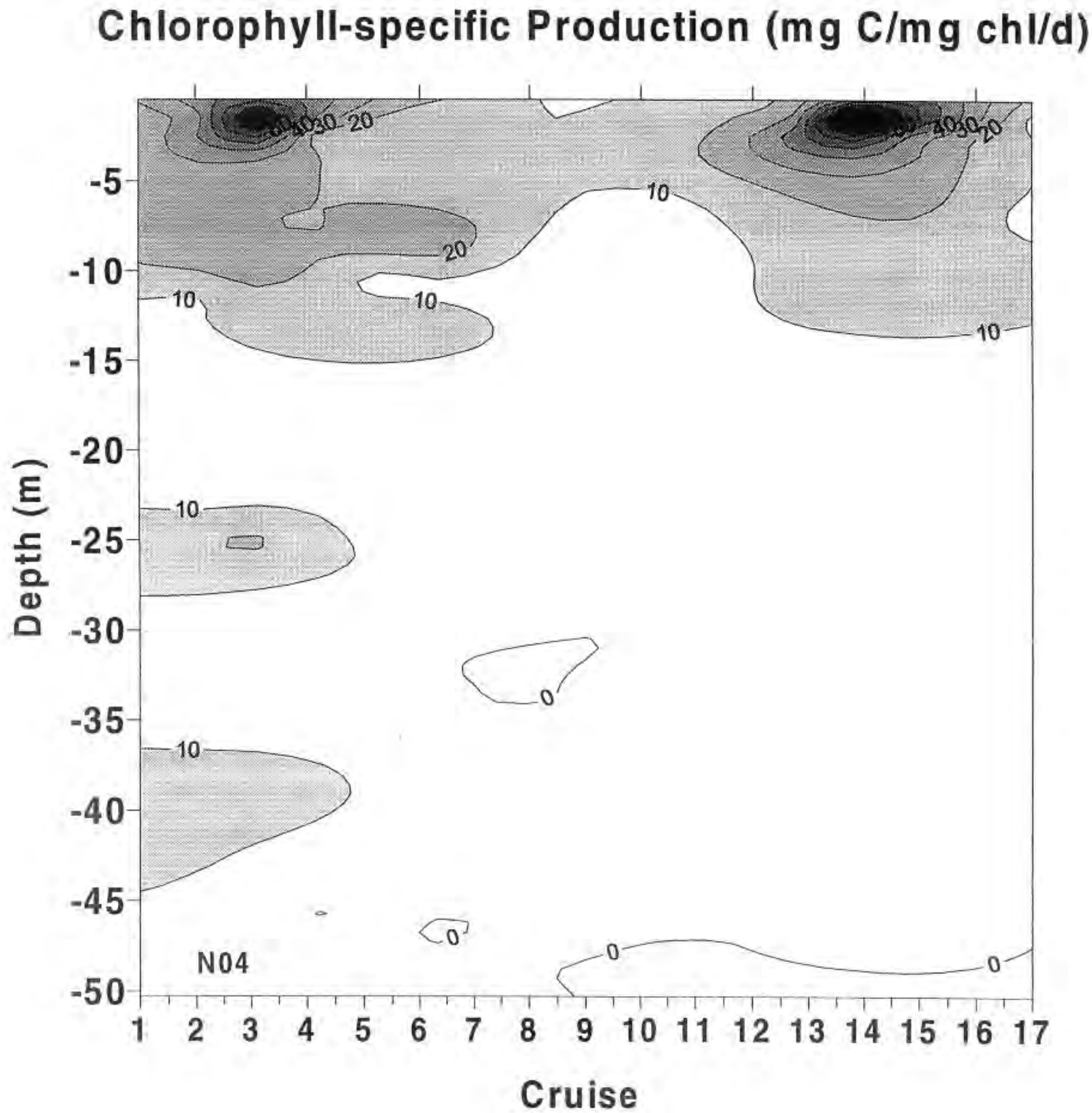
- Frequency distributions skewed to the left relative to 1995-97



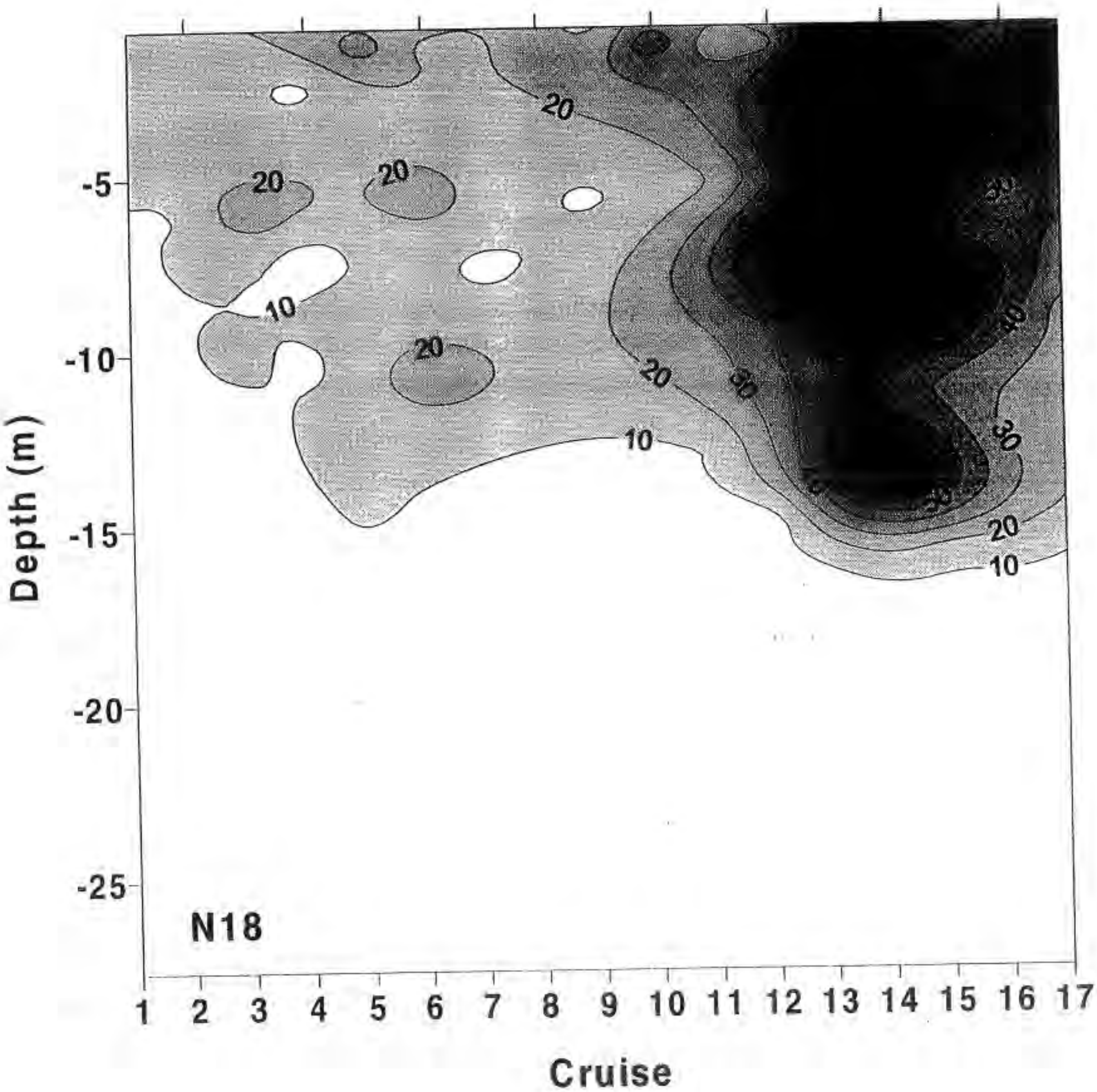
Production (mg C/m3/d)
Depth (m)
Cruise
N04
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
10
20
30
40
50
60
0

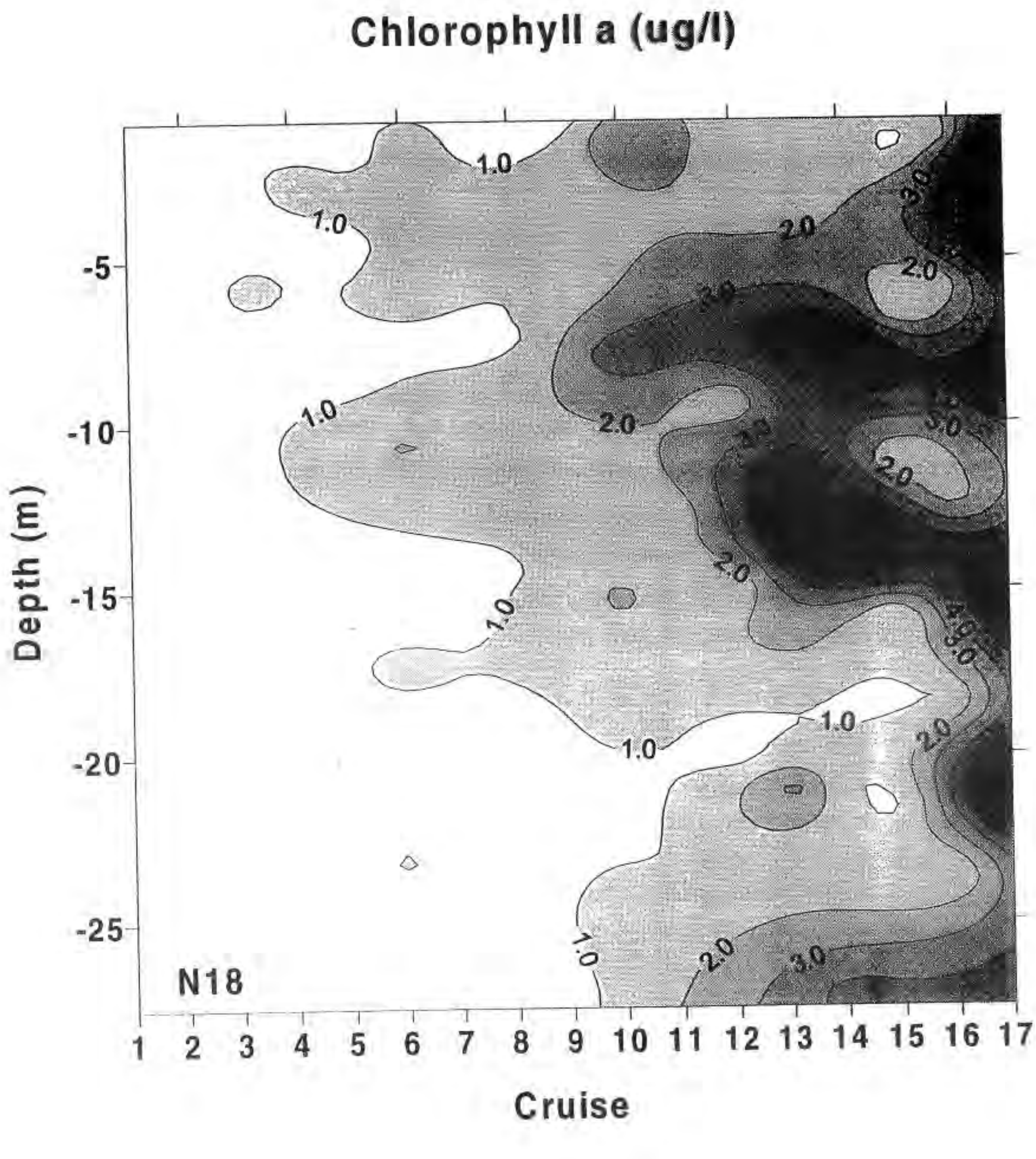


Chlorophyll a (ug/l)
Depth (m)
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
Cruise
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
1.0
2.0
4.0
N04

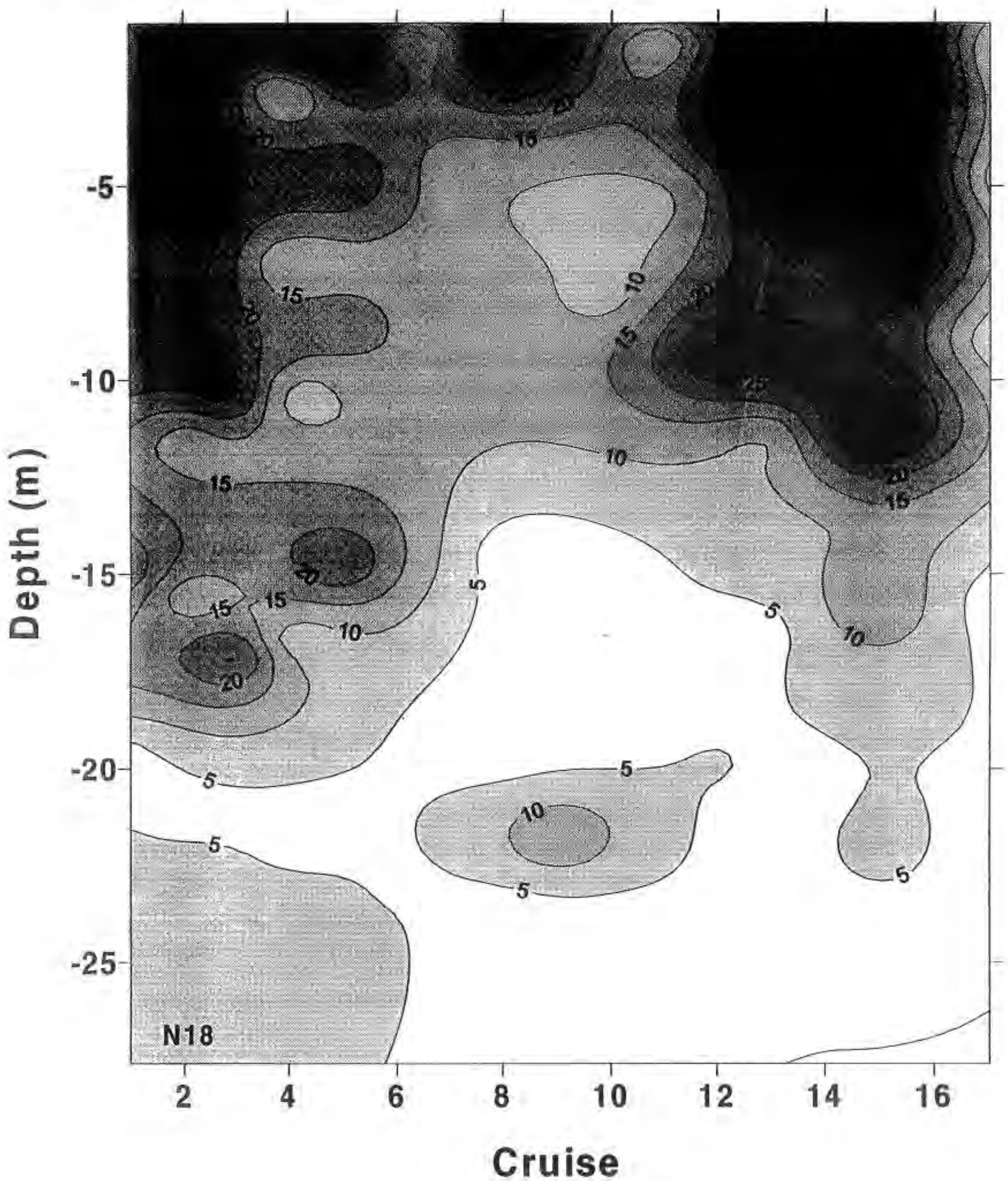

Chlorophyll-specific Production (mg C/mg chl/d)
Depth (m)
Cruise
N04
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
10
20
30
40
0

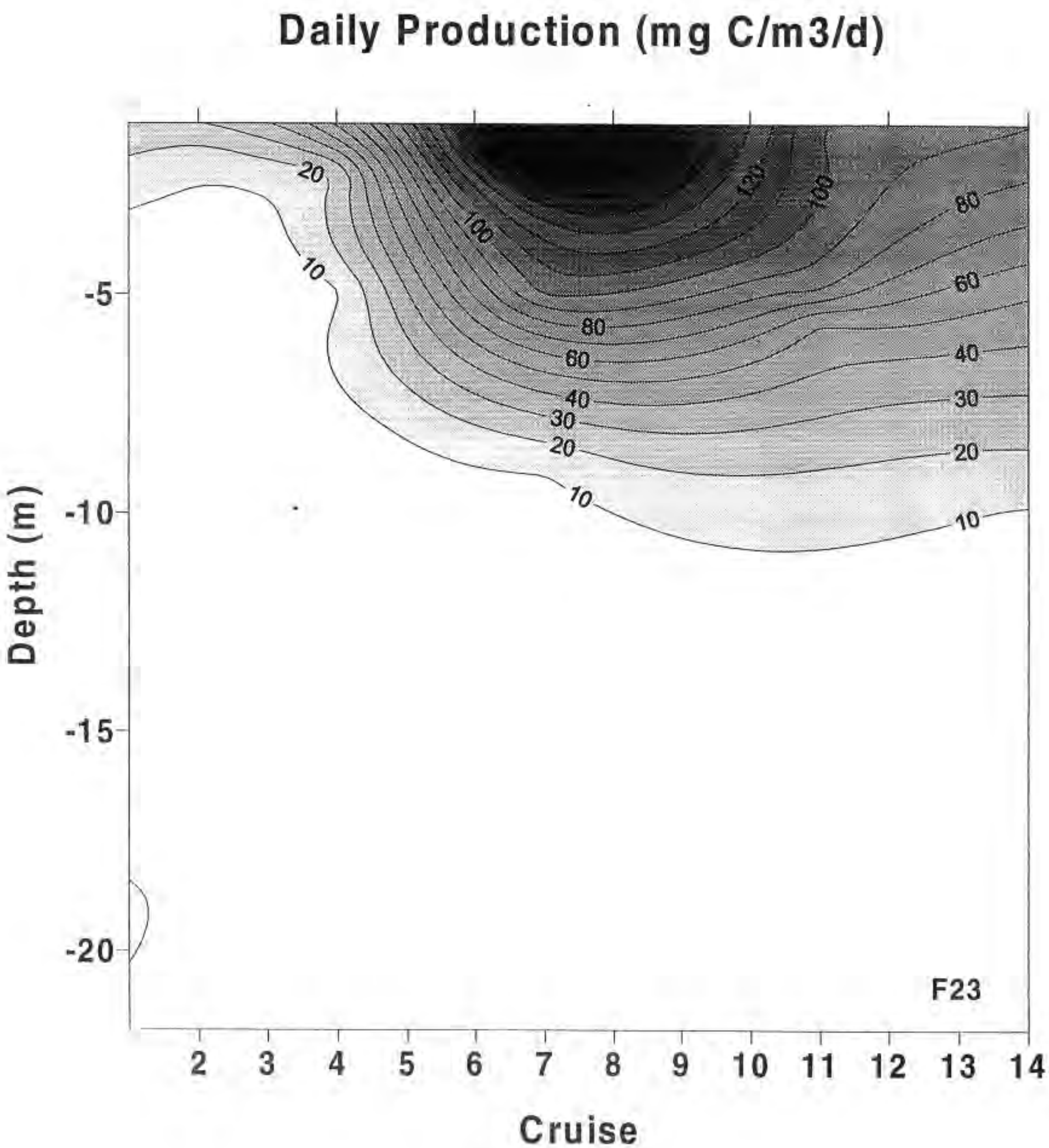
Daily Production (mg C m-3 d-1)

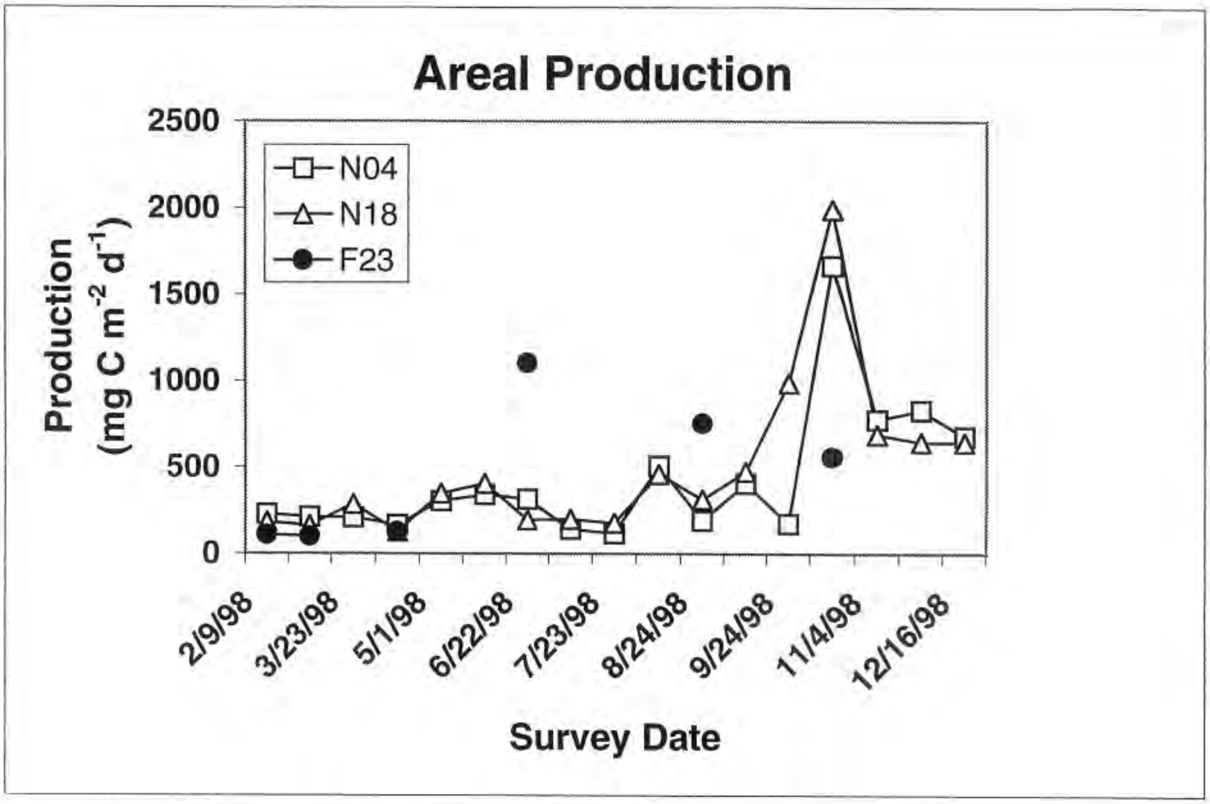


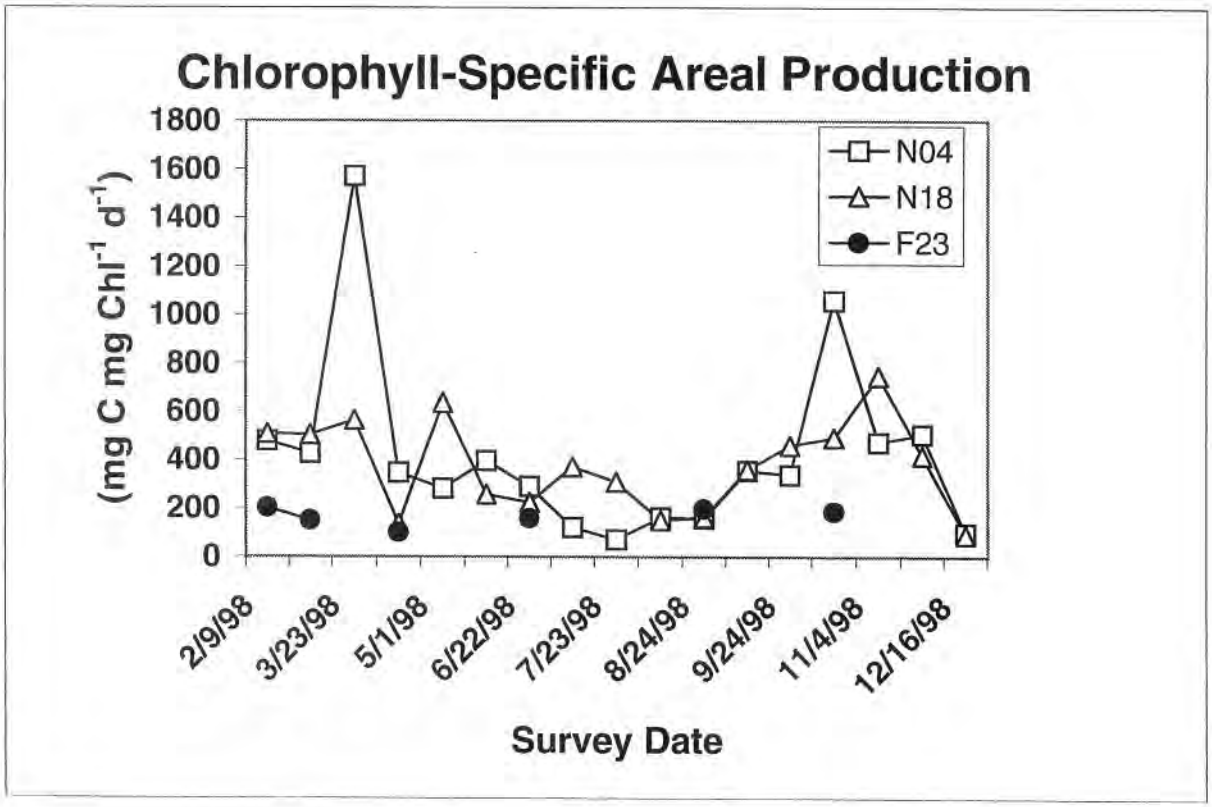

Chlorophyll a (ug/l)
Depth (m)
-5
-10
-15
-20
-25
1.0
2.0
3.0
4.0
5.0
N18
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Cruise

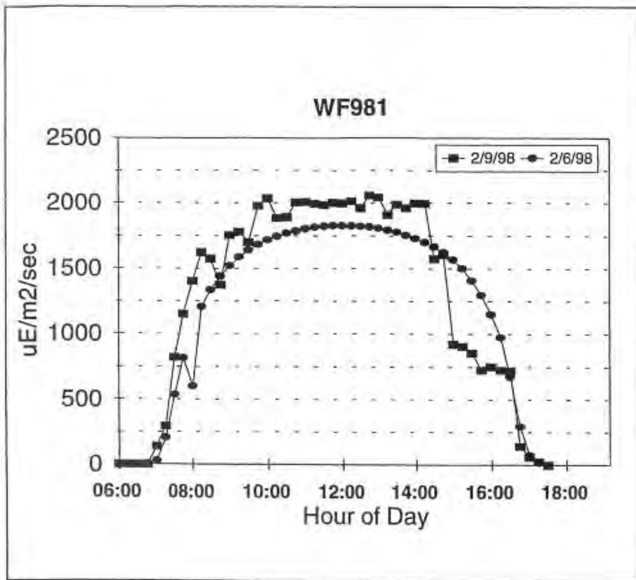
Chlorophyll-specific Production (mg C/mg chl/d)

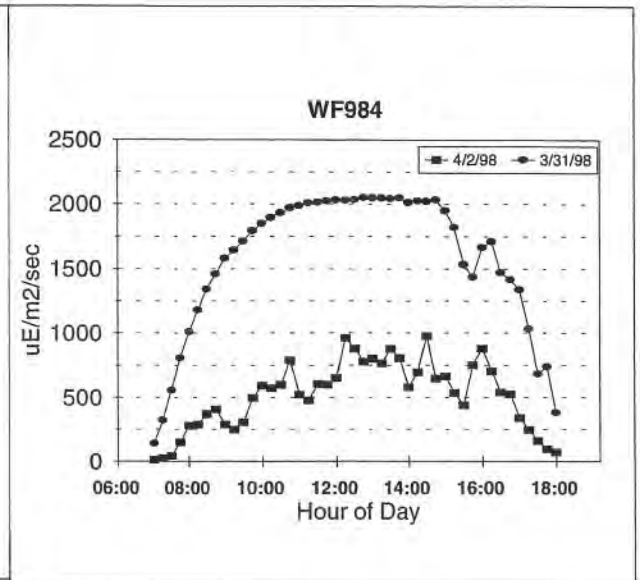


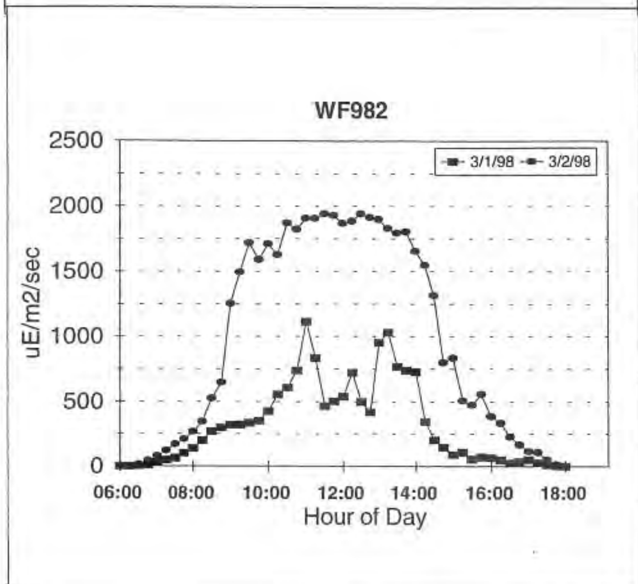

Daily Production (mg C/m3/d)
Depth (m)
-5
-10
-15
-20
2
3
4
5
6
7
8
9
10
11
12
13
14
Cruise
20
10
100
120
100
80
60
40
30
20
10
80
60
40
30
20
10
F23

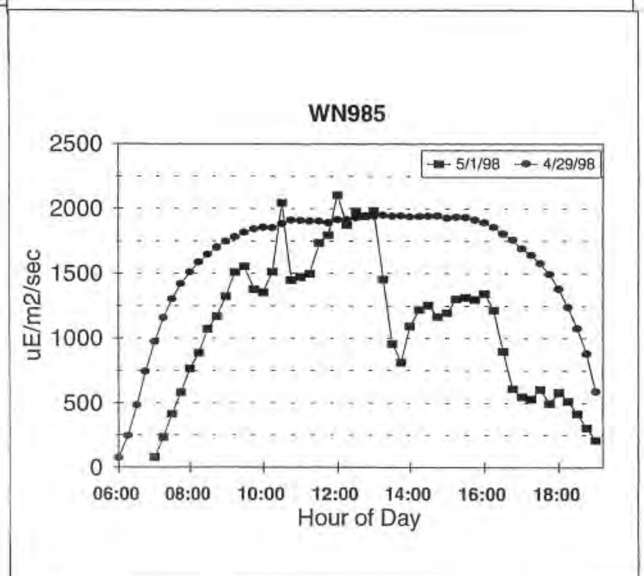

Areal Production
Production (mg C m-2 d-1)
2500
2000
1500
1000
500
0
N04
N18
F23
2/9/98
3/23/98
5/1/98
6/22/98
7/23/98
8/24/98
9/24/98
11/4/98
12/16/98
Survey Date

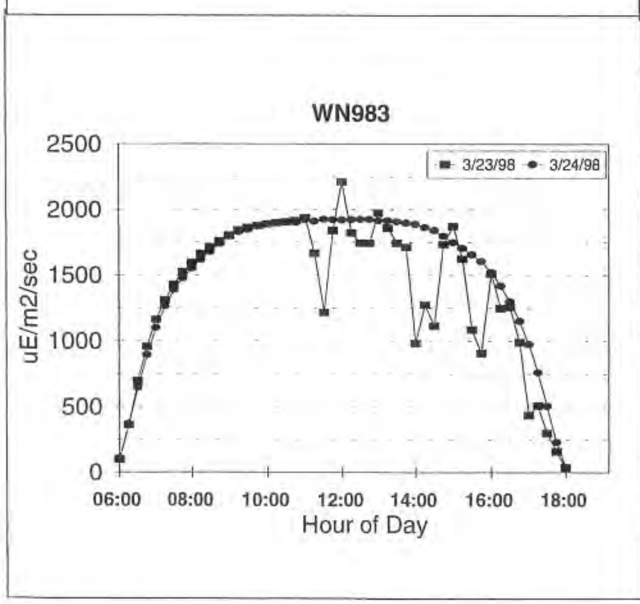

Chlorophyll-Specific Areal Production
(mg C mg Chl-1 d-1)
1800
1600
1400
1200
1000
800
600
400
200
0
N04
N18
F23
2/9/98
3/23/98
5/1/98
6/22/98
7/23/98
8/24/98
9/24/98
11/4/98
12/16/98
Survey Date

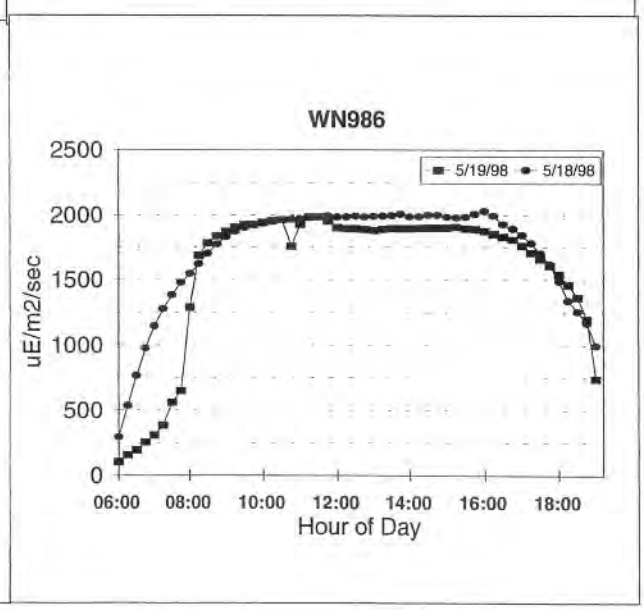

WF981
2/9/98
2/6/98
uE/m2/sec
Hour of Day

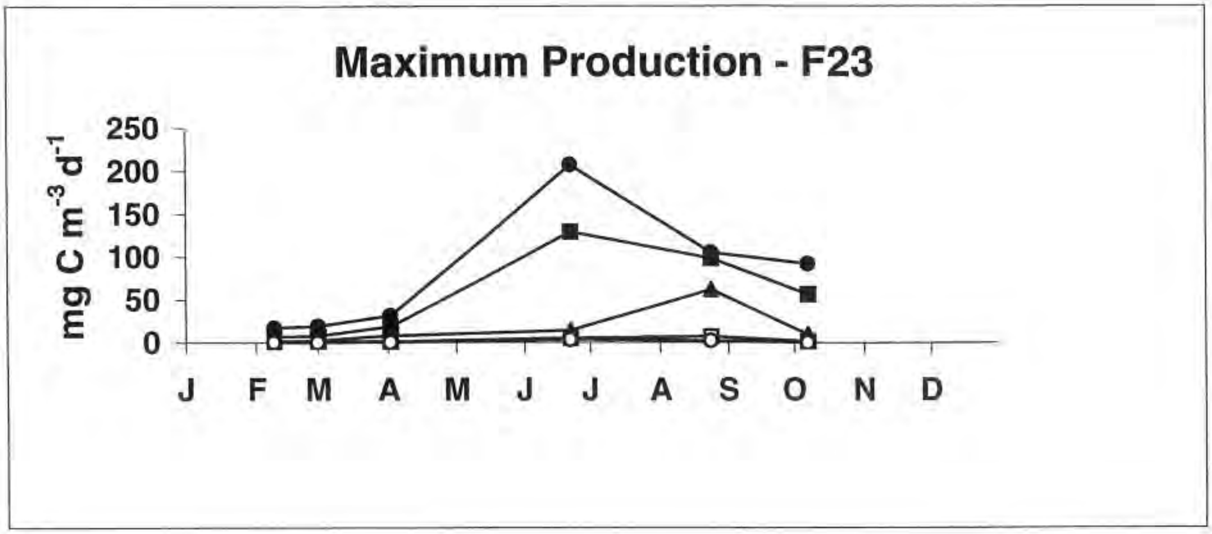

WF984
4/2/98
3/31/98
uE/m2/sec
Hour of Day

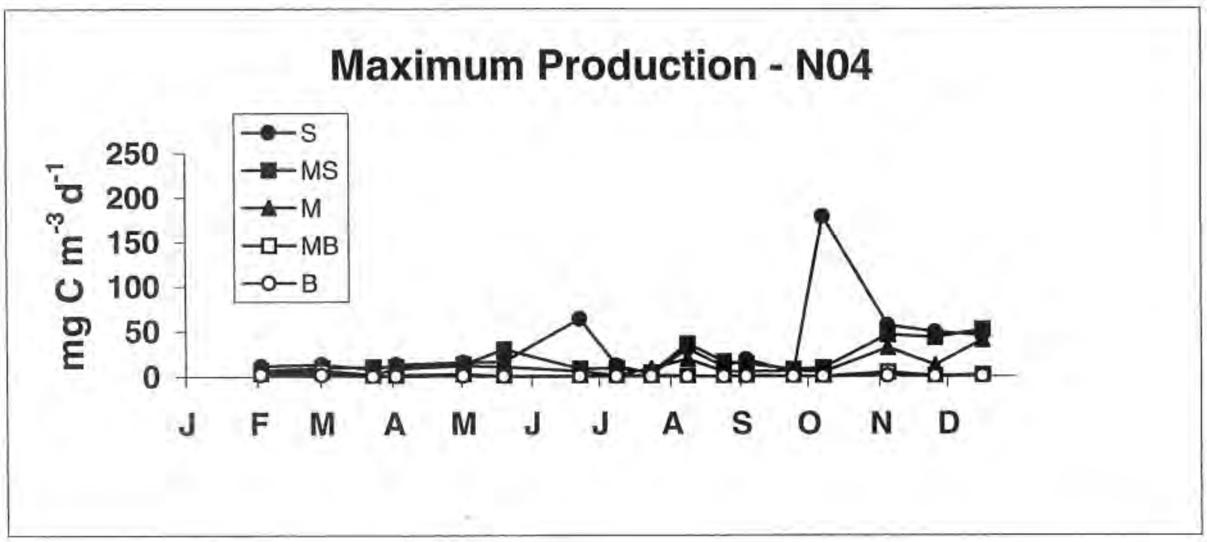

WF982
3/1/98
3/2/98
uE/m2/sec
Hour of Day

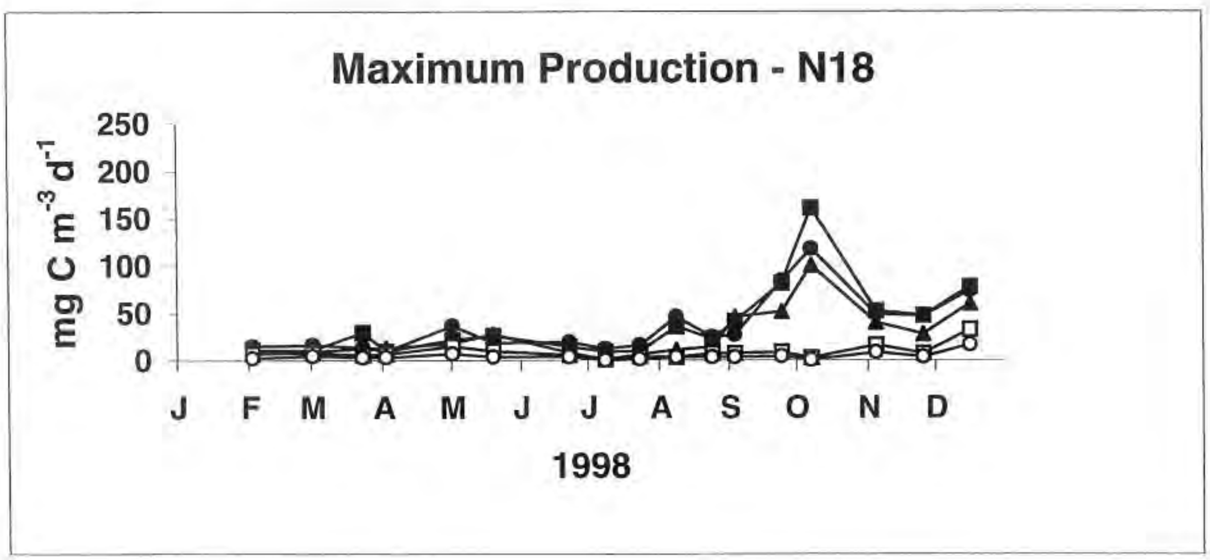

WN985
5/1/98
4/29/98
uE/m2/sec
Hour of Day

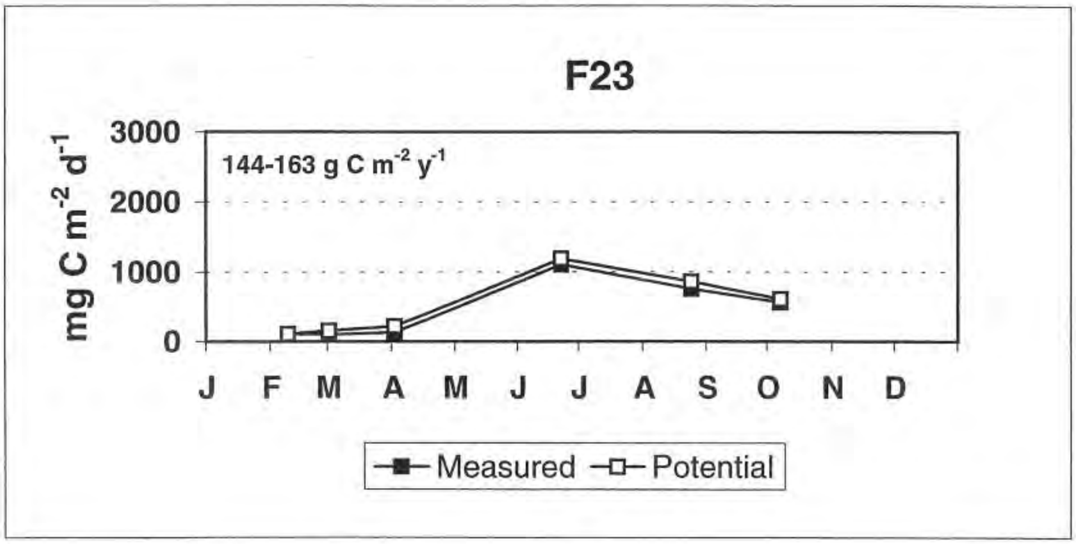

WN983
3/23/98
3/24/98
uE/m2/sec
Hour of Day

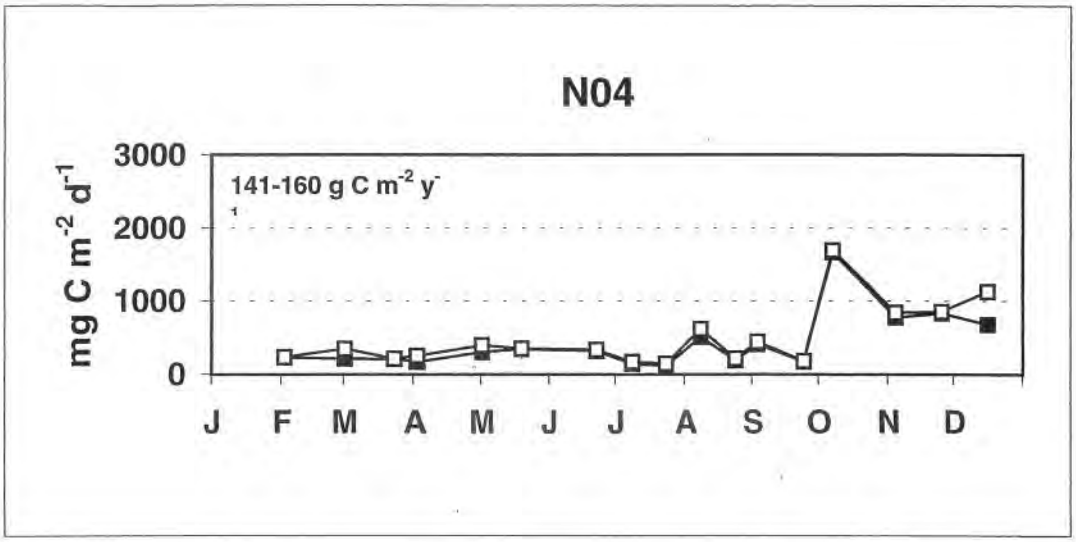

WN986
5/19/98
5/18/98
uE/m2/sec
Hour of Day

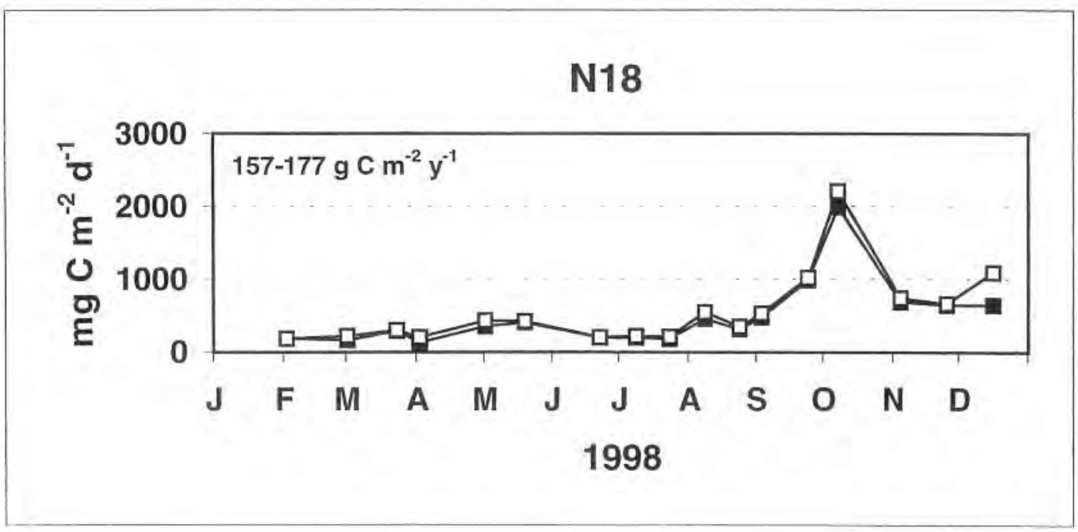

Maximum Production - F23
mg C m-3 d-1
250
200
150
100
50
0
J F M A M J J A S O N D


Maximum Production - N04
S
MS
M
MB
B
mg C m-3 d-1
250
200
150
100
50
0
J F M A M J J A S O N D

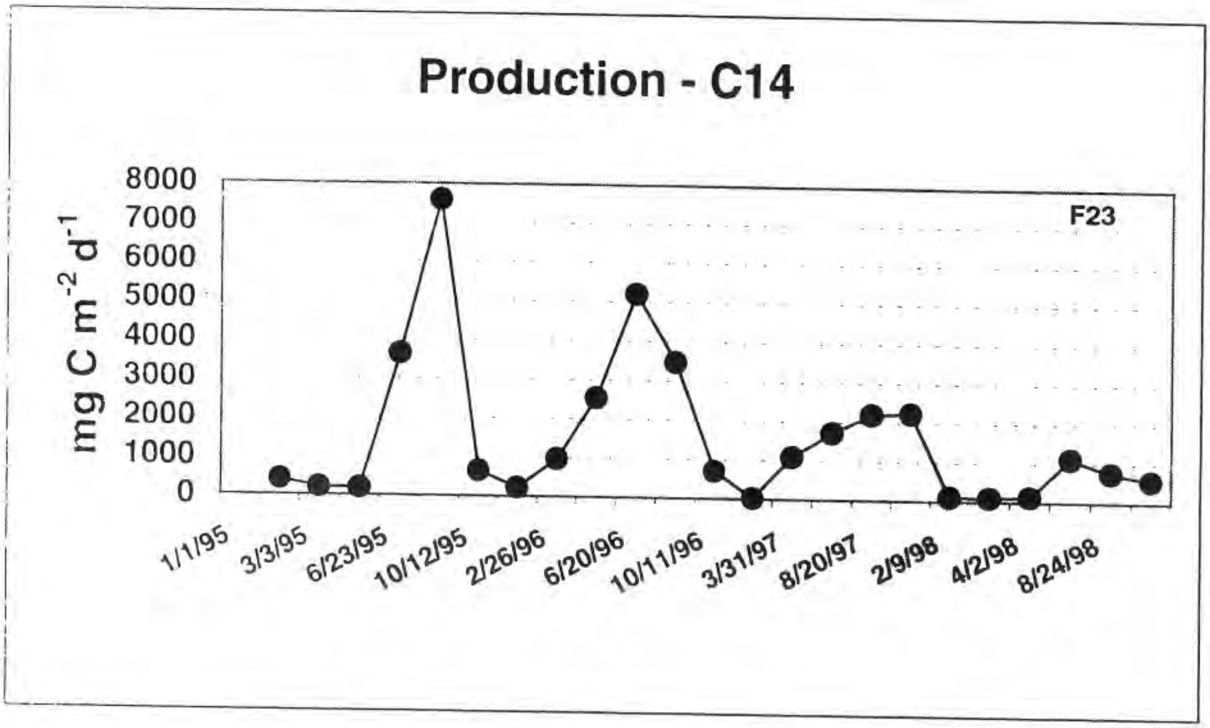

Maximum Production - N18
mg C m-3 d-1
250
200
150
100
50
0
J F M A M J J A S O N D
1998

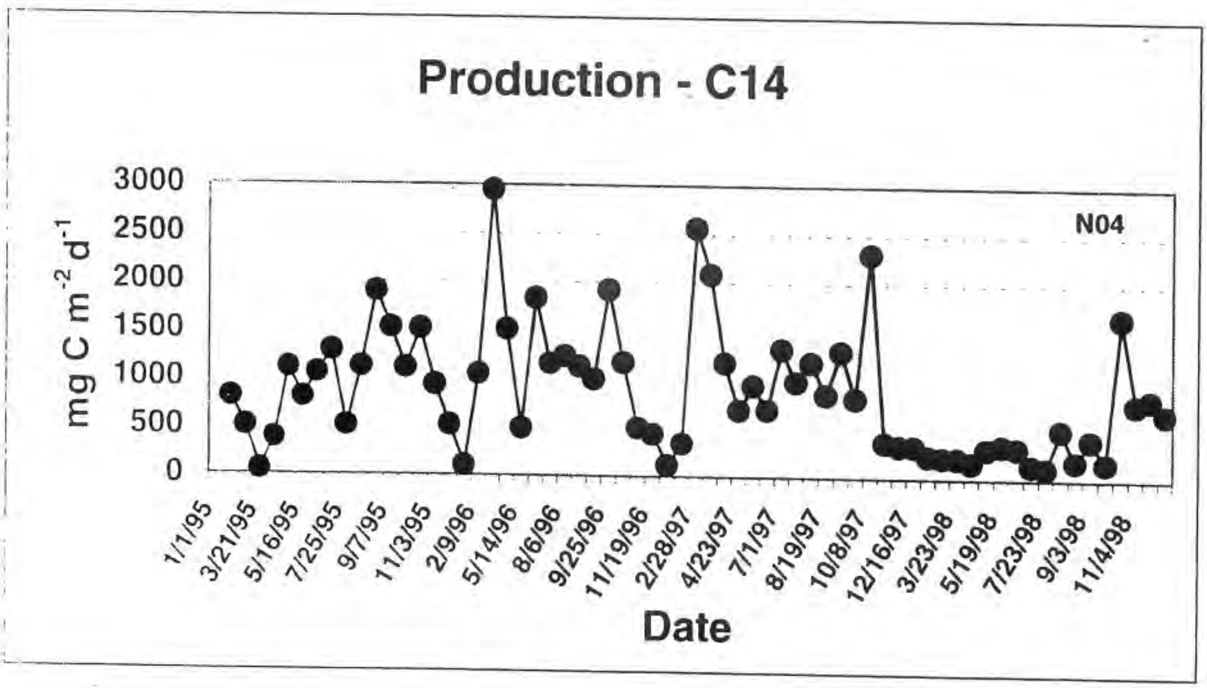

F23
144-163 g C m-2 y-1
mg C m-2 d-1
3000
2000
1000
0
J F M A M J J A S O N D
Measured
Potential

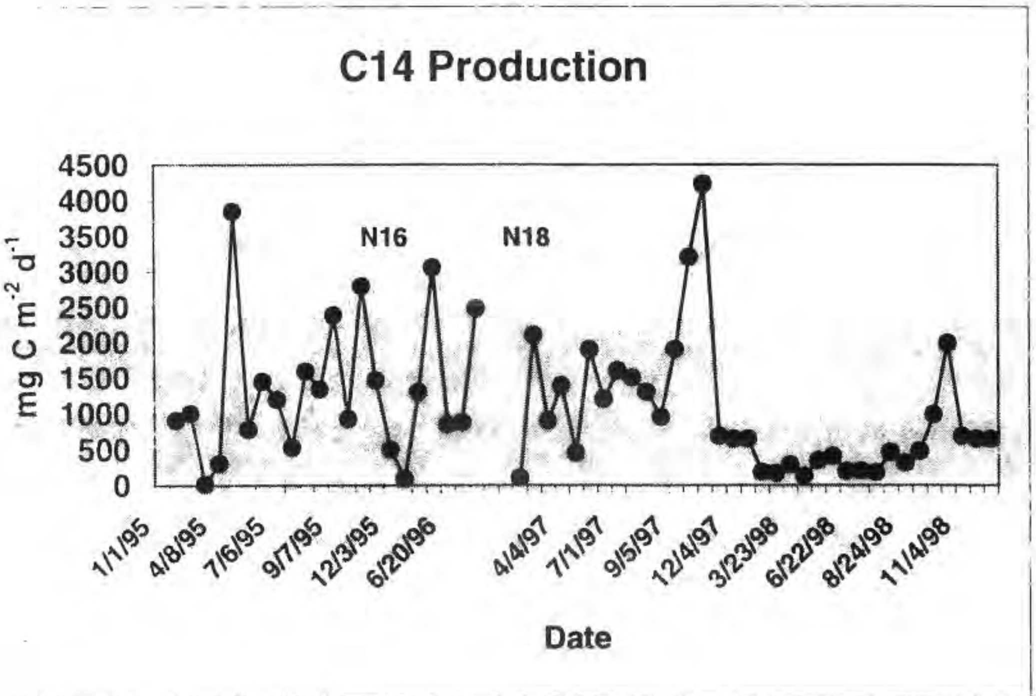

N04
141-160 g C m-2 y-1
mg C m-2 d-1
3000
2000
1000
0
J F M A M J J A S O N D

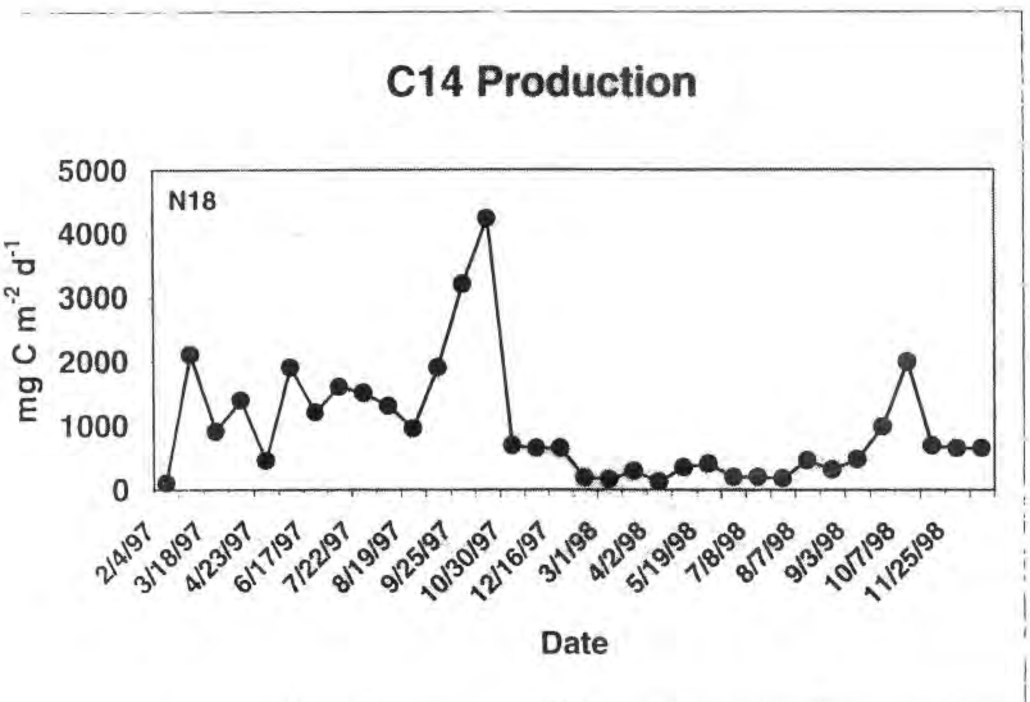

N18
157-177 g C m-2 y-1
mg C m-2 d-1
3000
2000
1000
0
J F M A M J J A S O N D
1998

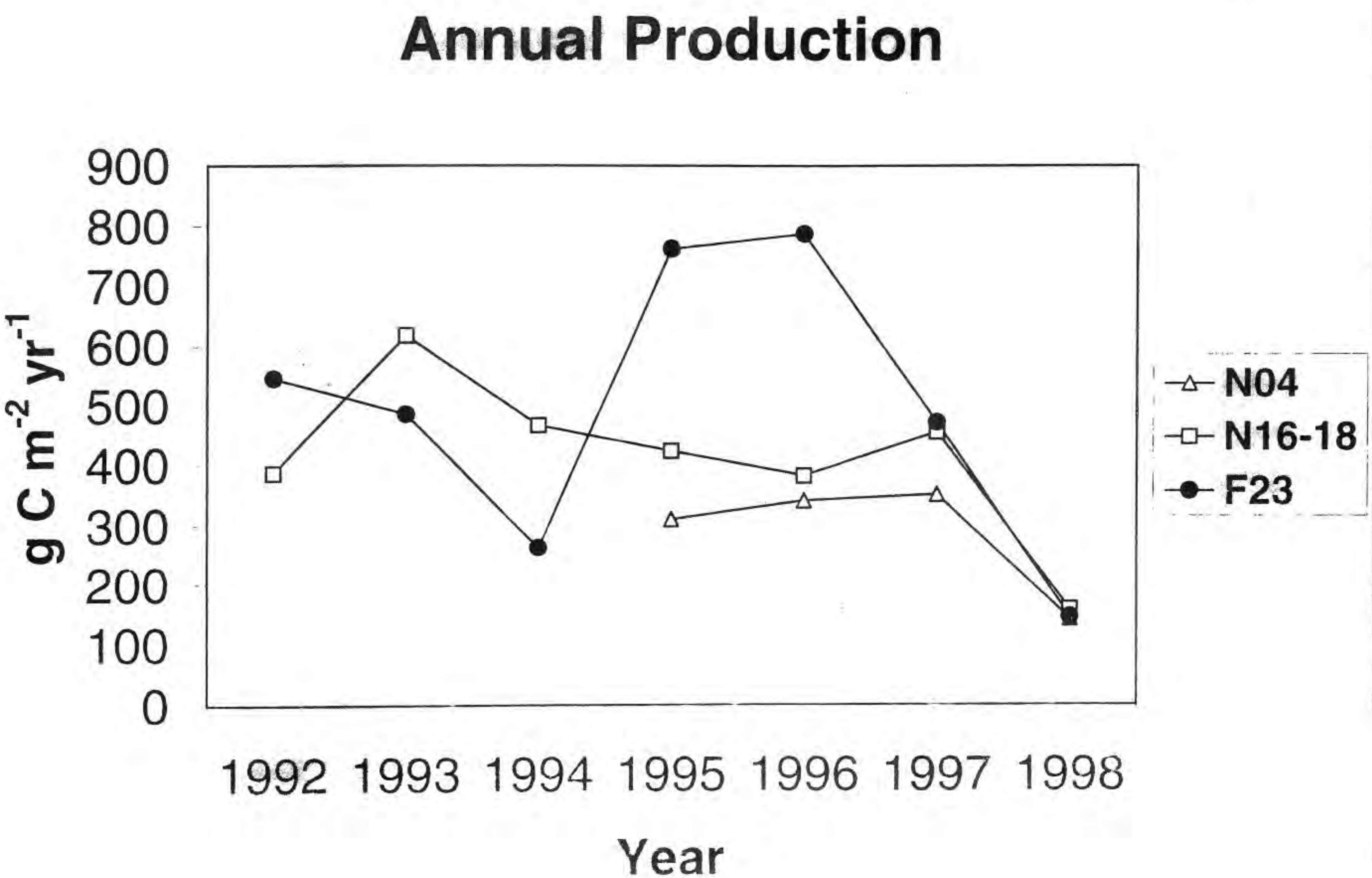
298


Production - C14
mg C m-2 d-1
8000
7000
6000
5000
4000
3000
2000
1000
0
F23
1/1/95
3/3/95
6/23/95
10/12/95
2/26/96
6/20/96
10/11/96
3/31/97
8/20/97
2/9/98
4/2/98
8/24/98


Production - C14
mg C m-2 d-1
3000
2500
2000
1500
1000
500
0
N04
1/1/95
3/21/95
5/16/95
7/25/95
9/7/95
11/3/95
2/9/96
5/14/96
8/6/96
9/25/96
11/19/96
2/28/97
4/23/97
7/1/97
8/19/97
10/8/97
12/16/97
3/23/98
5/19/98
7/23/98
9/3/98
11/4/98
Date


C14 Production
4500
4000
3500
3000
2500
2000
1500
1000
500
0
mg C m-2 d-1
N16
N18
1/1/95
4/8/95
7/6/95
9/7/95
12/3/95
6/20/96
4/4/97
7/1/97
9/5/97
12/4/97
3/23/98
6/22/98
8/24/98
11/4/98
Date


C14 Production
5000
4000
3000
2000
1000
0
mg C m-2 d-1
N18
2/4/97
3/18/97
4/23/97
6/17/97
7/22/97
8/19/97
9/25/97
10/30/97
12/16/97
3/1/98
4/2/98
5/19/98
7/8/98
8/7/98
9/3/98
10/7/98
11/25/98
Date


Annual Production
g C m-2 yr-1
900
800
700
600
500
400
300
200
100
0
1992
1993
1994
1995
1996
1997
1998
Year
N04
N16-18
F23

PRODUCTION - SUMMARY

- N04 and N18 exhibited peak productivity during the fall bloom (surface samples)
- Production at F23 increased through June then declined during the fall
- Subsurface chlorophyll maxima above 15 m characterized by elevated productivity (but not below 15 m)
- Chl-specific production increased during the spring bloom period (N04-18) but no bloom materialized
- Annual productivity low relative to prior years (since no spring bloom)
- Productivity decreasing at F23 over time, bloom peaks declining at N04

Potential Factors Infuencing Size of Spring Bloom

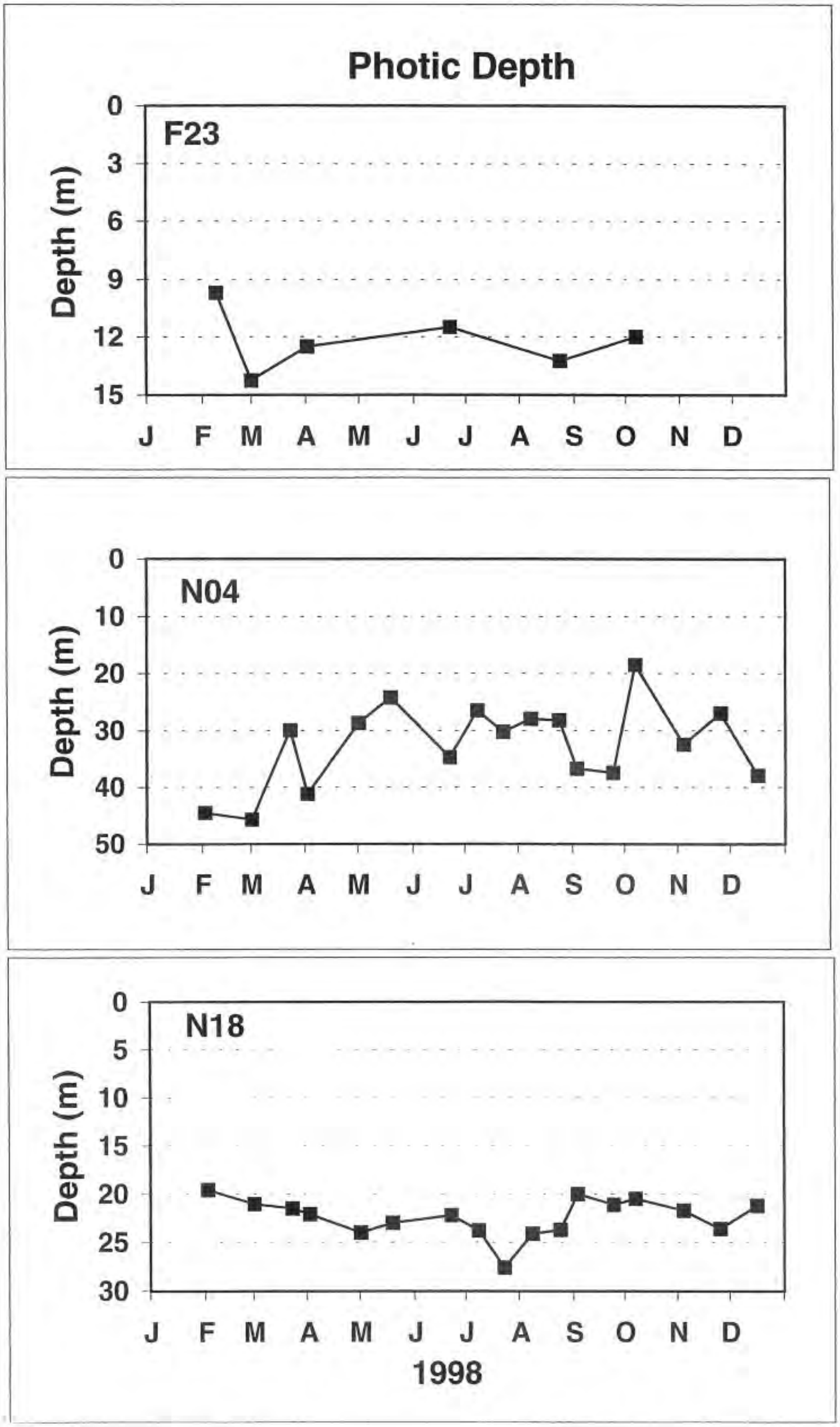
I_0 - Daily Incident Radiation

Limiting Nutrients

Photic Depth

Temperature - Direct and Indirect

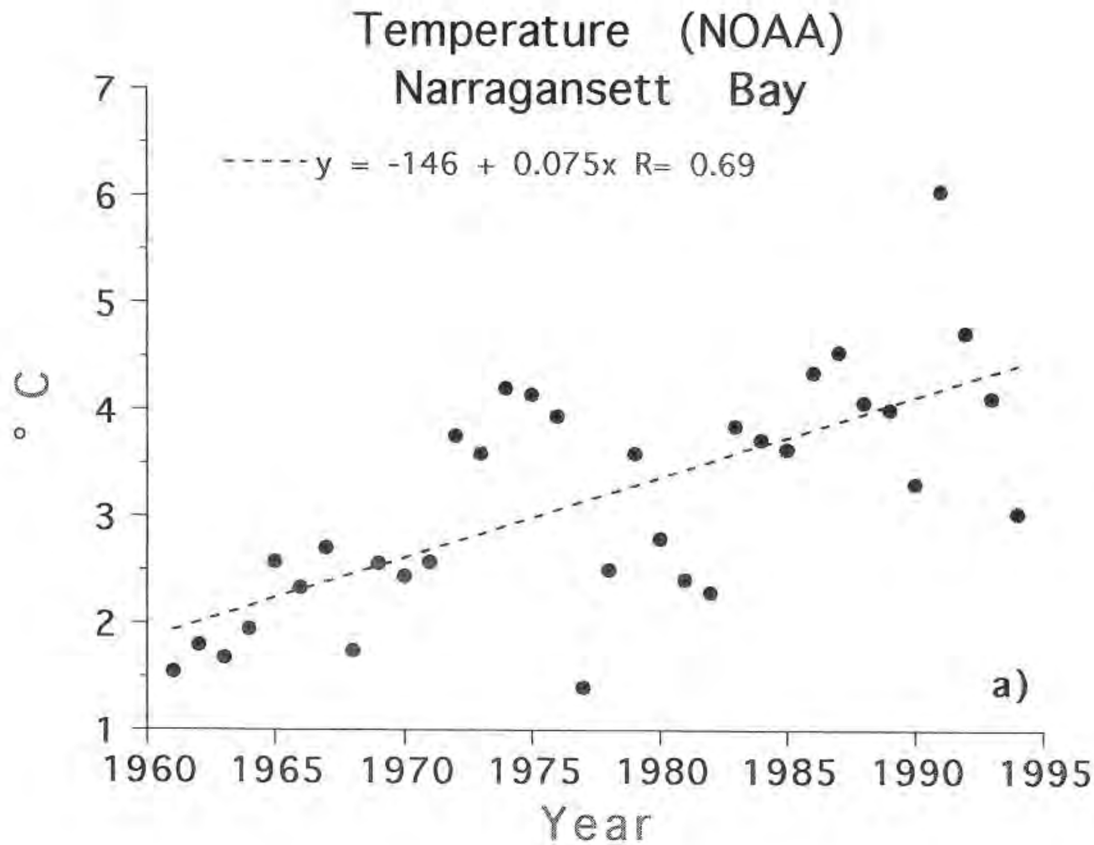
Predation - Zooplankton, Benthos

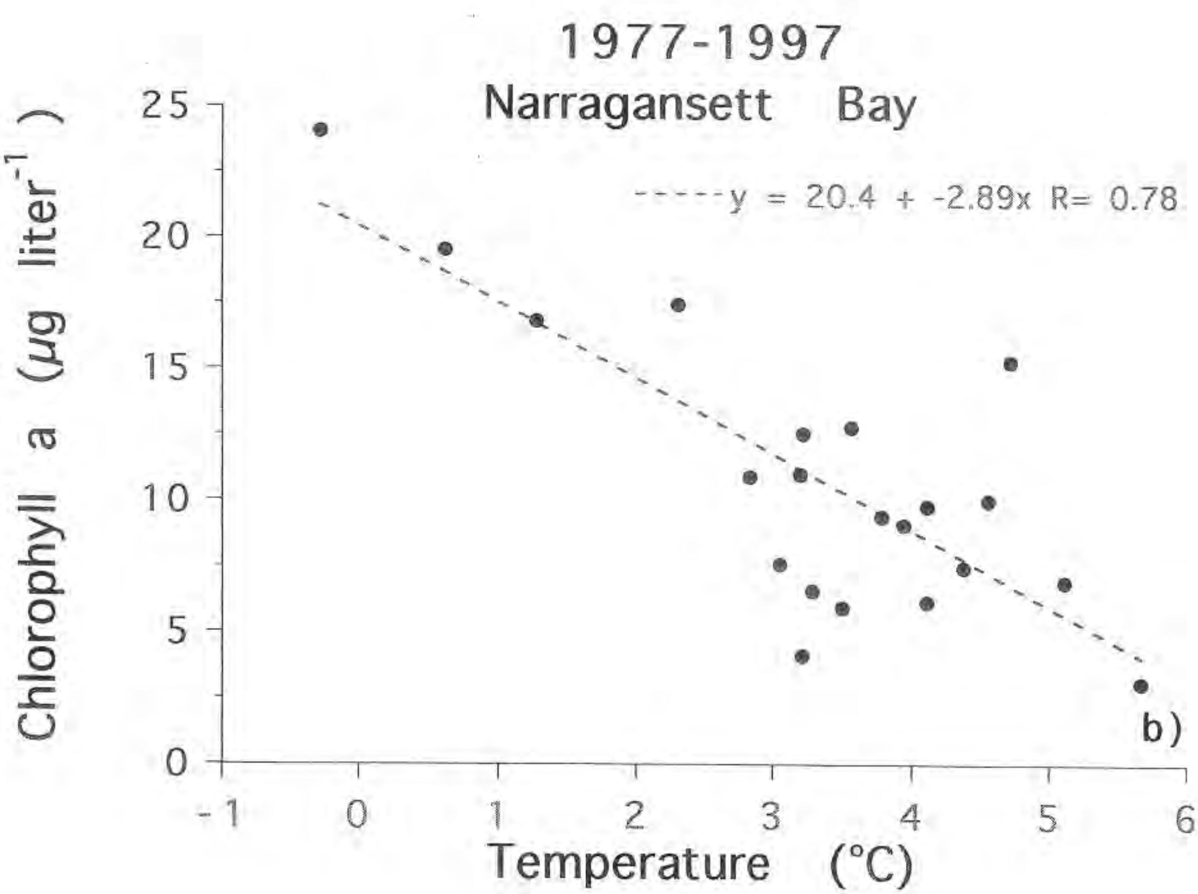

Photic Depth
F23
N04
N18
Depth (m)
0
3
6
9
12
15
0
10
20
30
40
50
0
5
10
15
20
25
30
J F M A M J J A S O N D
1998

304

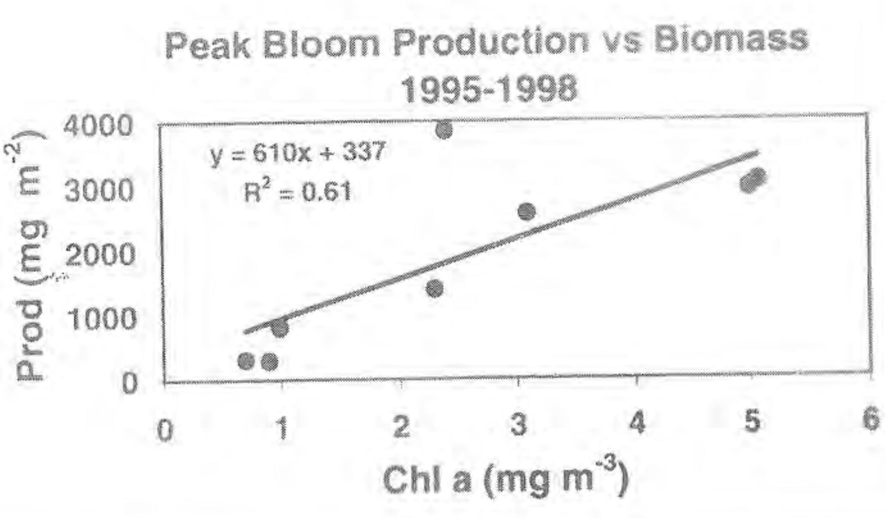
Mean Photic Depth (m) During Spring Bloom Period (Feb-Apr)

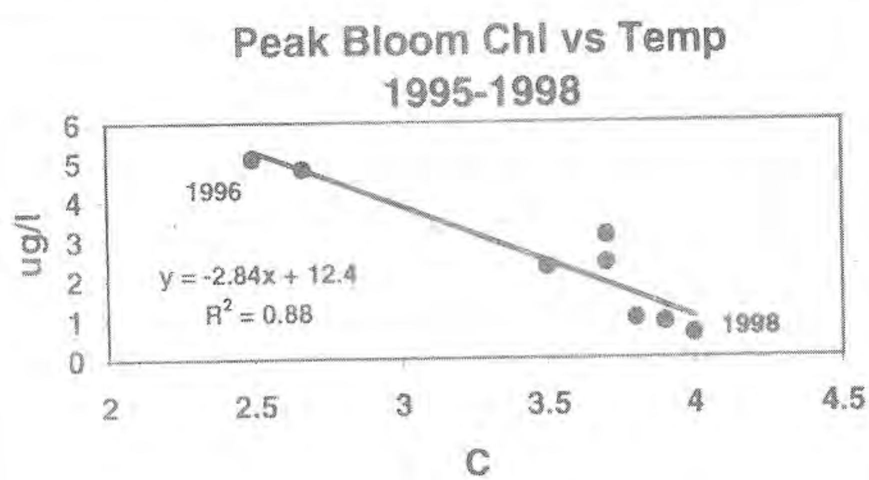
Year	F23	N04	N16-18
1995	18.7	42.6	33.6
1996	14.5	22.1	24.0
1997	15.3	26.6	26.8
1998	12.2	40.4	21.0

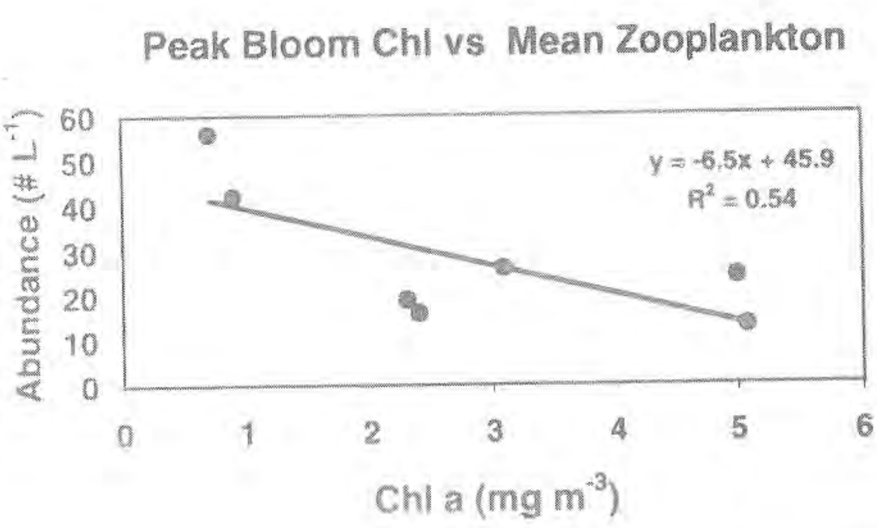

Temperature (NOAA)
Narragansett Bay
y = -146 + 0.075x R= 0.69
° C
Year
a)


1977-1997
Narragansett Bay
y = 20.4 + -2.89x R= 0.78
Chlorophyll a (µg liter⁻¹)
Temperature (°C)
b)

306


Peak Bloom Production vs Biomass
1995-1998
y = 610x + 337
R2 = 0.61
Prod (mg m-2)
Chl a (mg m-3)
0
1000
2000
3000
4000
0
1
2
3
4
5
6

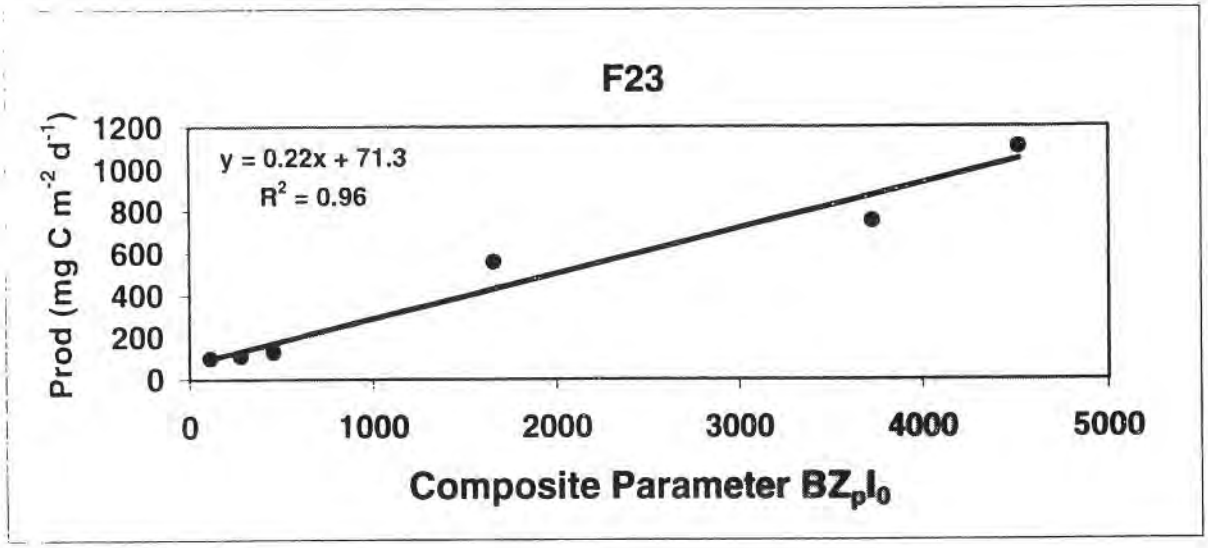

Peak Bloom Chl vs Temp
1995-1998
1996
1998
y = -2.84x + 12.4
R2 = 0.88
ug/l
C
0
1
2
3
4
5
6
2
2.5
3
3.5
4
4.5

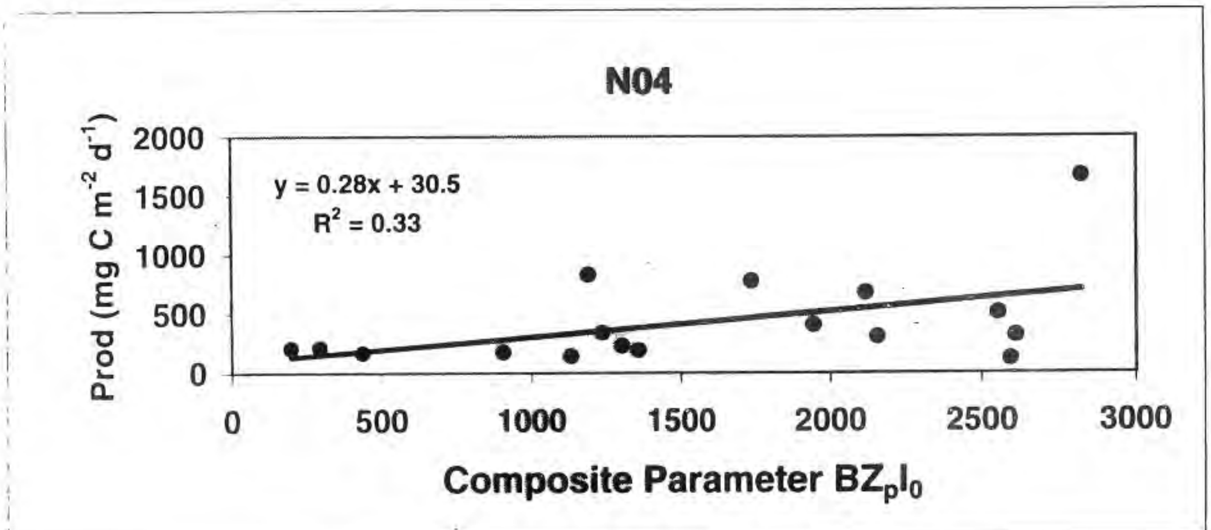

Peak Bloom Chl vs Mean Zooplankton
y = -6.5x + 45.9
R2 = 0.54
Abundance (# L-1)
Chl a (mg m-3)
0
10
20
30
40
50
60
0
1
2
3
4
5
6

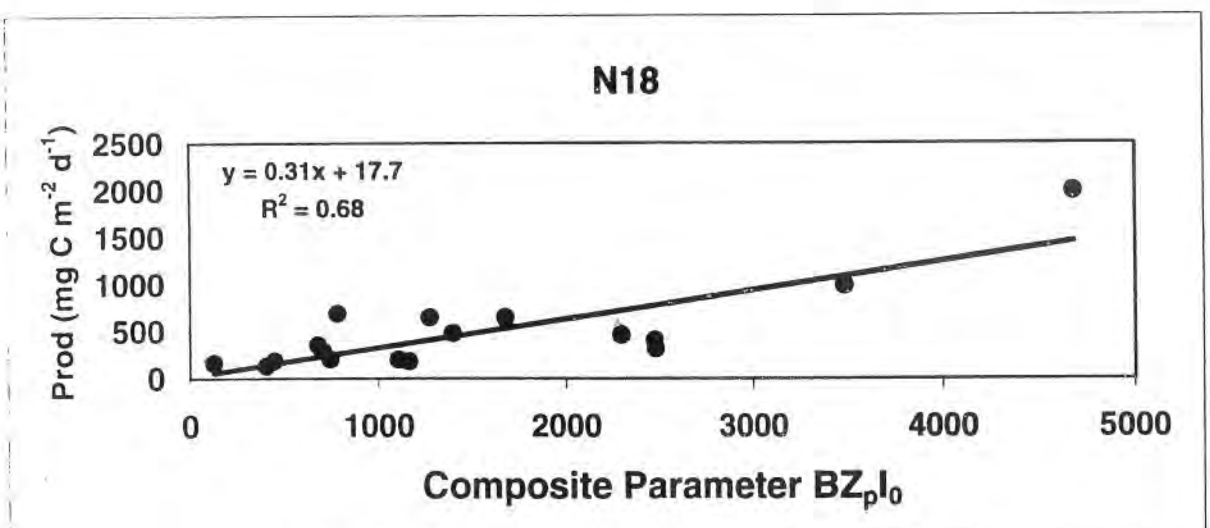
Modeling Production

$$P(^{14}C) = m\ B I_0 Z_p + b$$

$P(^{14}C)$=primary production (mg C m^{-2} d^{-1})
B = biomass (mg Chl *a* m^{-3})
I_0 = incident irradiance (E m^{-2} d^{-1})
Z_p= photic depth (m)
b = intercept
m = slope

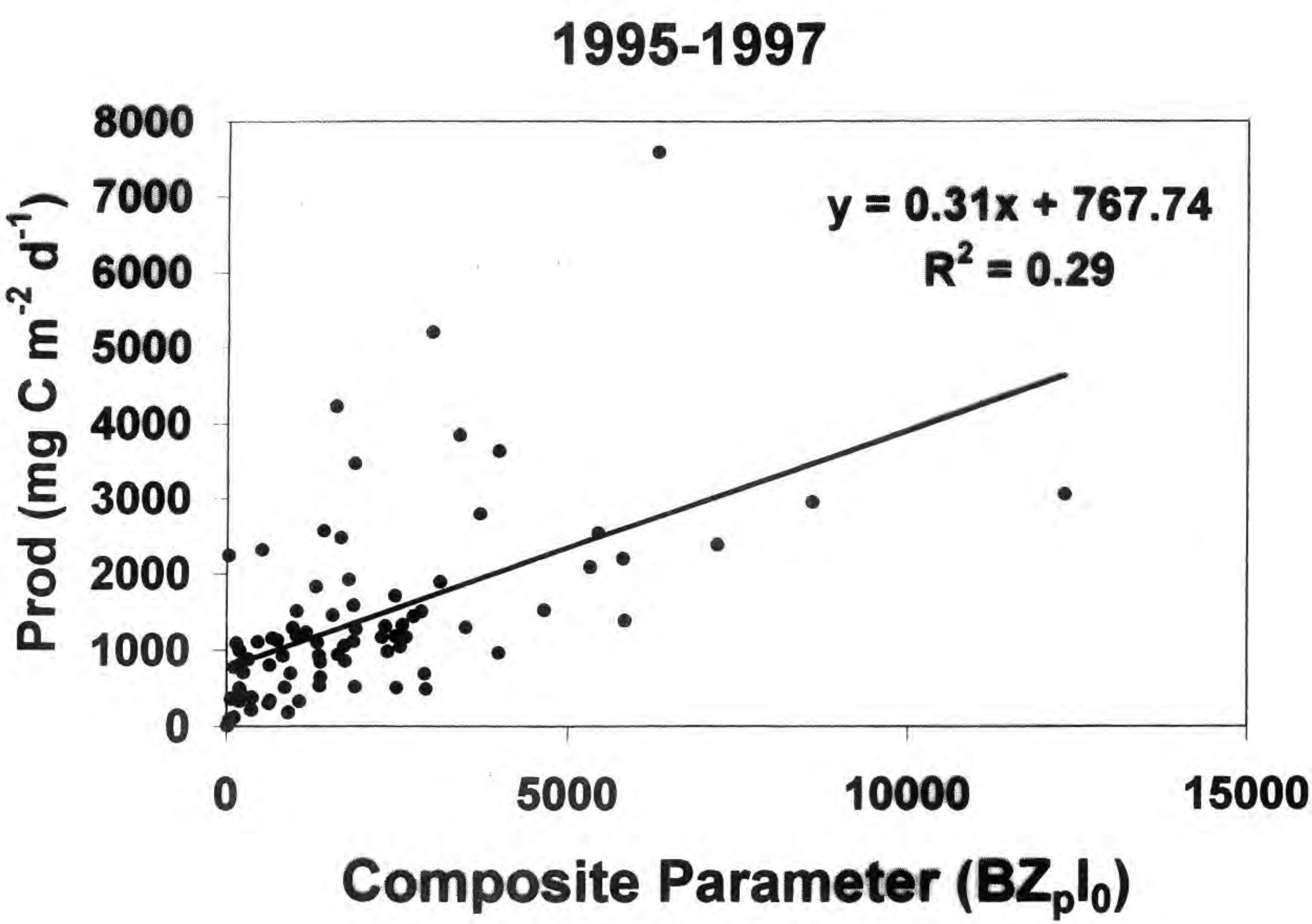

F23
y = 0.22x + 71.3
R^2 = 0.96
Prod (mg C m^{-2} d^{-1})
0
200
400
600
800
1000
1200
0
1000
2000
3000
4000
5000
Composite Parameter BZ_pI_0

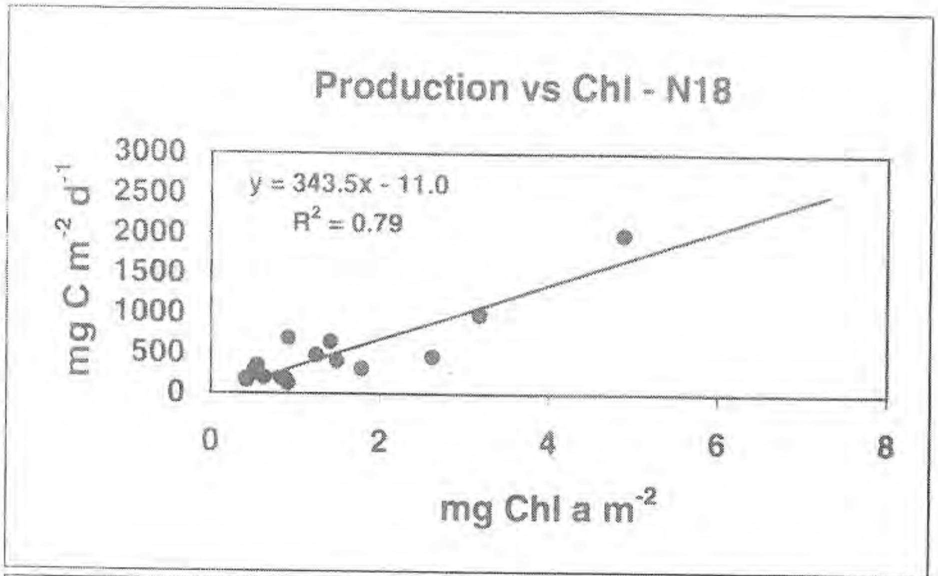

N04
y = 0.28x + 30.5
R^2 = 0.33
Prod (mg C m^{-2} d^{-1})
0
500
1000
1500
2000
0
500
1000
1500
2000
2500
3000
Composite Parameter BZ_pI_0


N18
y = 0.31x + 17.7
R^2 = 0.68
Prod (mg C m^{-2} d^{-1})
0
500
1000
1500
2000
2500
0
1000
2000
3000
4000
5000
Composite Parameter BZ_pI_0

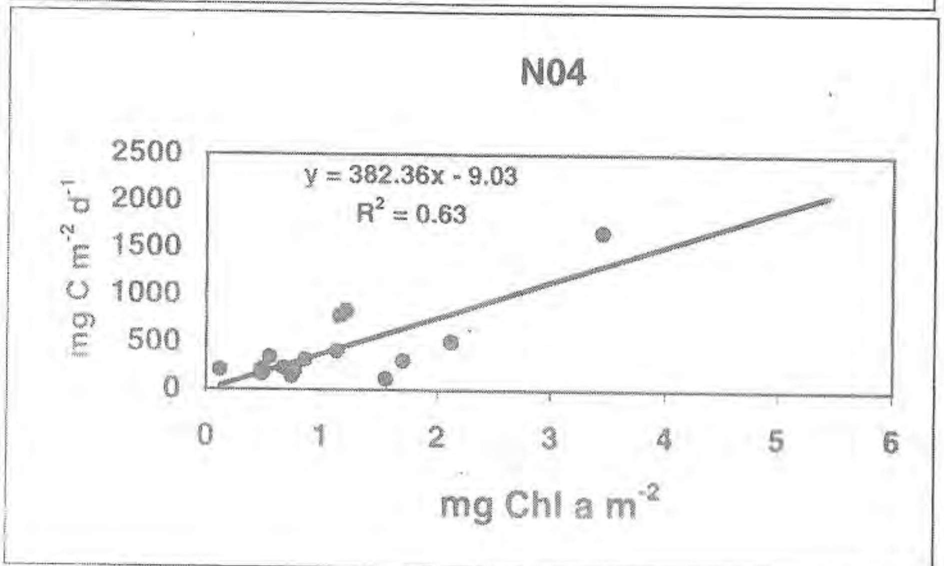
Slope of equation P=mBIOZp+b

Station	F23	N04	N16-18
1994	0.56	0.56	0.56
1995	1.87	0.39	0.64
1996	0.88	0.23	0.56
1998	0.22	0.28	0.31

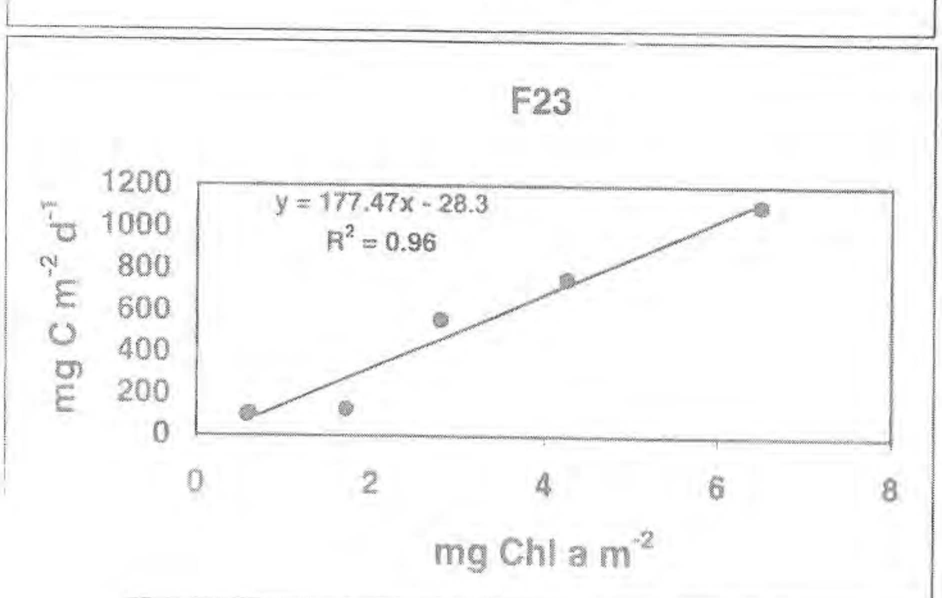

1995-1997
y = 0.31x + 767.74
R2 = 0.29
8000
7000
6000
5000
4000
3000
2000
1000
0
Prod (mg C m-2 d-1)
0
5000
10000
15000
Composite Parameter (BZpI0)



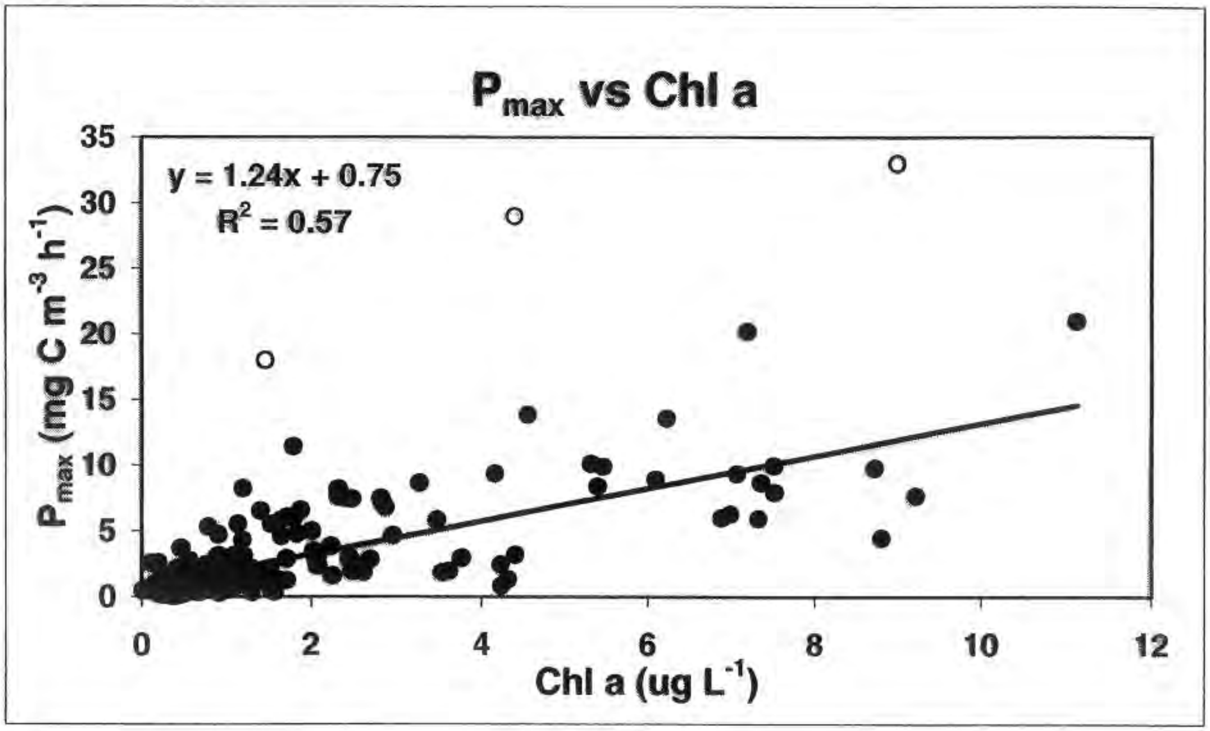
Production vs Chl - N18
y = 343.5x - 11.0
R^2 = 0.79
mg C m^-2 d^-1
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
mg Chl a m^-2



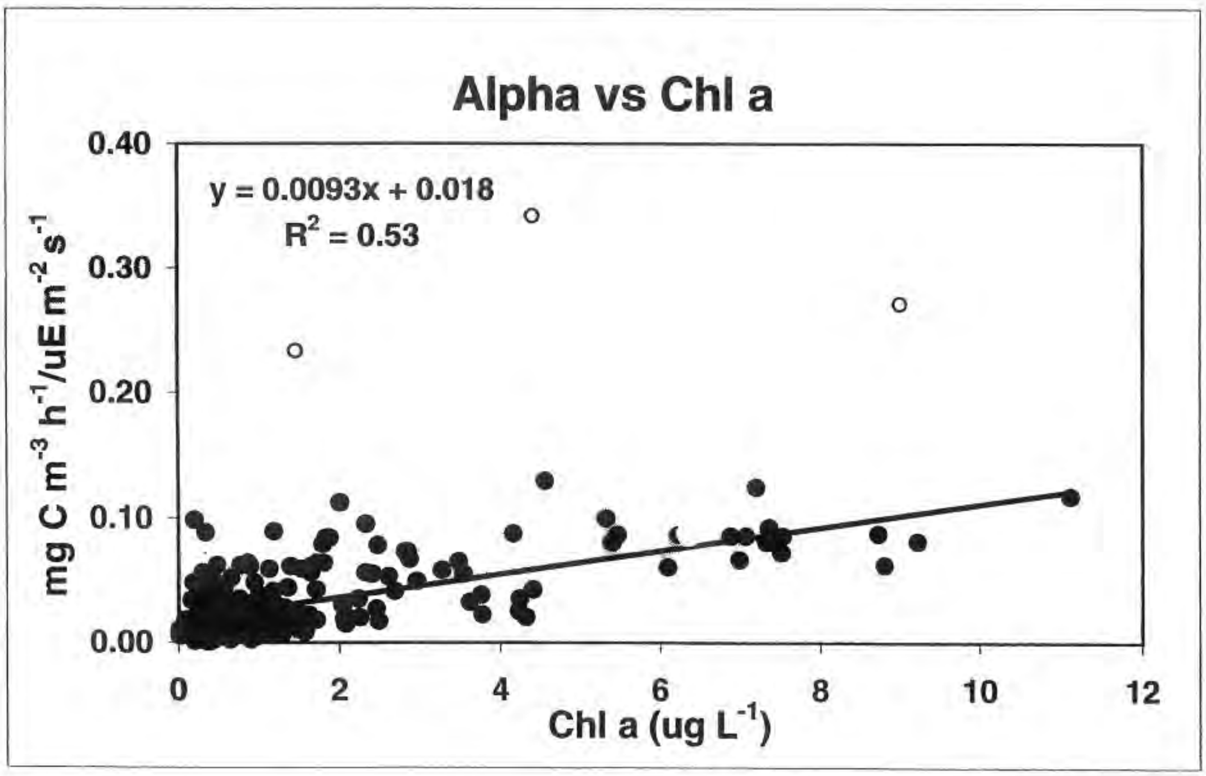
N04
y = 382.36x - 9.03
R^2 = 0.63
mg C m^-2 d^-1
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
mg Chl a m^-2



F23
y = 177.47x - 28.3
R^2 = 0.96
mg C m^-2 d^-1
1200
1000
800
600
400
200
0
0
2
4
6
8
mg Chl a m^-2



Pmax vs Chl a
y = 1.24x + 0.75
R2 = 0.57
Pmax (mg C m-3 h-1)
Chl a (ug L-1)
0
5
10
15
20
25
30
35
0
2
4
6
8
10
12



Alpha vs Chl a
y = 0.0093x + 0.018
R2 = 0.53
mg C m-3 h-1/uE m-2 s-1
Chl a (ug L-1)
0.00
0.10
0.20
0.30
0.40
0
2
4
6
8
10
12

CONCLUSIONS
1998

- Annual production at N04, N18 and F23 lower than in prior years
- Seasonal productivity pattern dominated by fall bloom
- No winter-spring bloom despite increased chlorophyll-specific production during typical bloom period
- Bloom failure not correlated with nutrient availability or light limitation
- Bloom failure may be related to warm winter temperatures and increased grazing by zooplankton
- Productivity significantly correlated with composite parameter (but variable across years)

E nthic Fluxes

ing in Harbor only

diment nutrient recycling to
oduction

ng affect nutrient ratios

he sediment in nutrient
nitrification and burial

delling – calibration and

d sediment-water nutrient

grain size

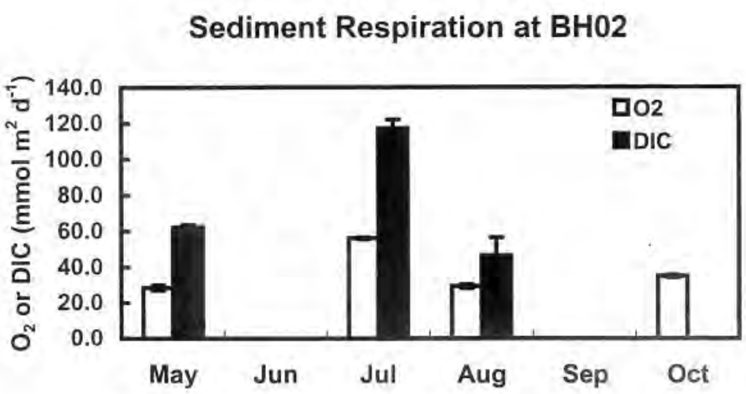
Conclusions

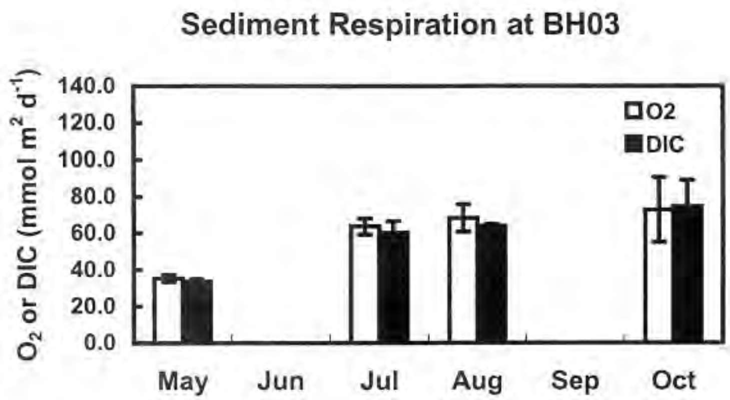
1) Long term trends – It's a bit early (and stations have changed) but sediments in the highly impacted sites in the Northern Harbor may be showing some decrease in fluxes even with the amphipods present.

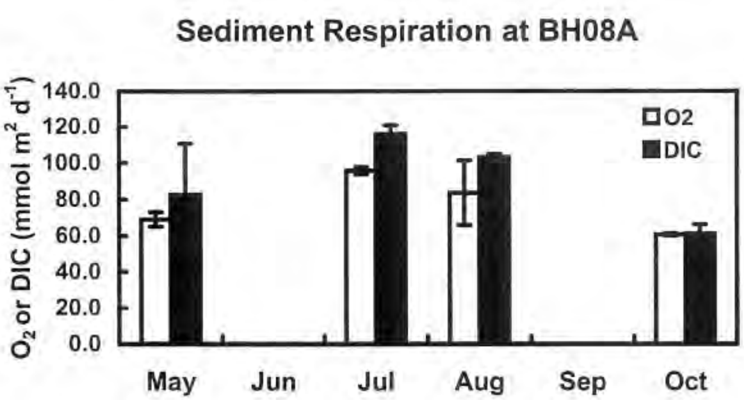
2) Denitrification rates have gone up and down a bit with amphipod colonization but still not a major factor in removing anthropogenic N.

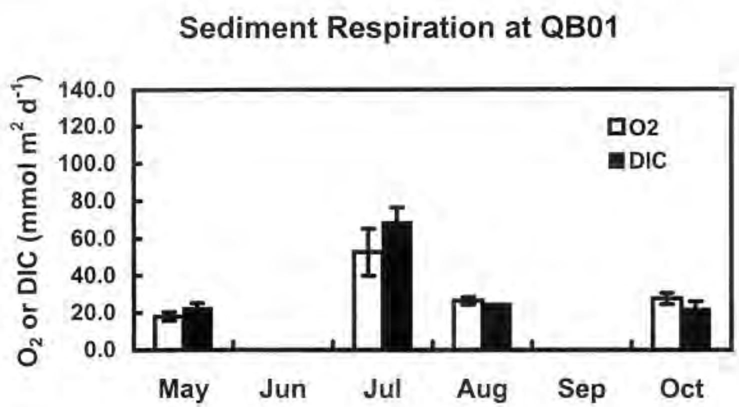
3) DIN/DIP ratio may have shifted up but majority of 1998 data still shows benthic fluxes still less than 16 (i.e. would contribute to N limitation)

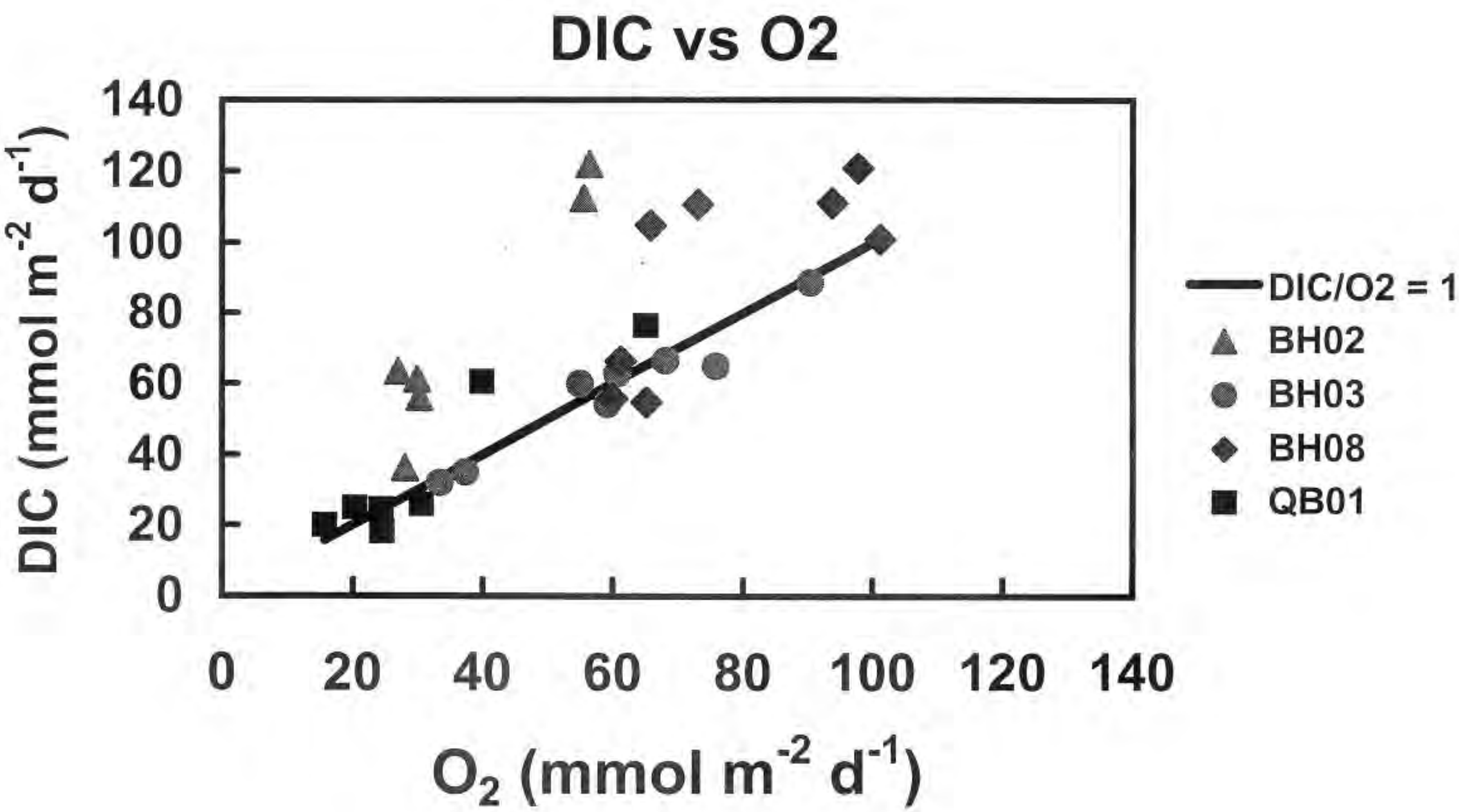
4)

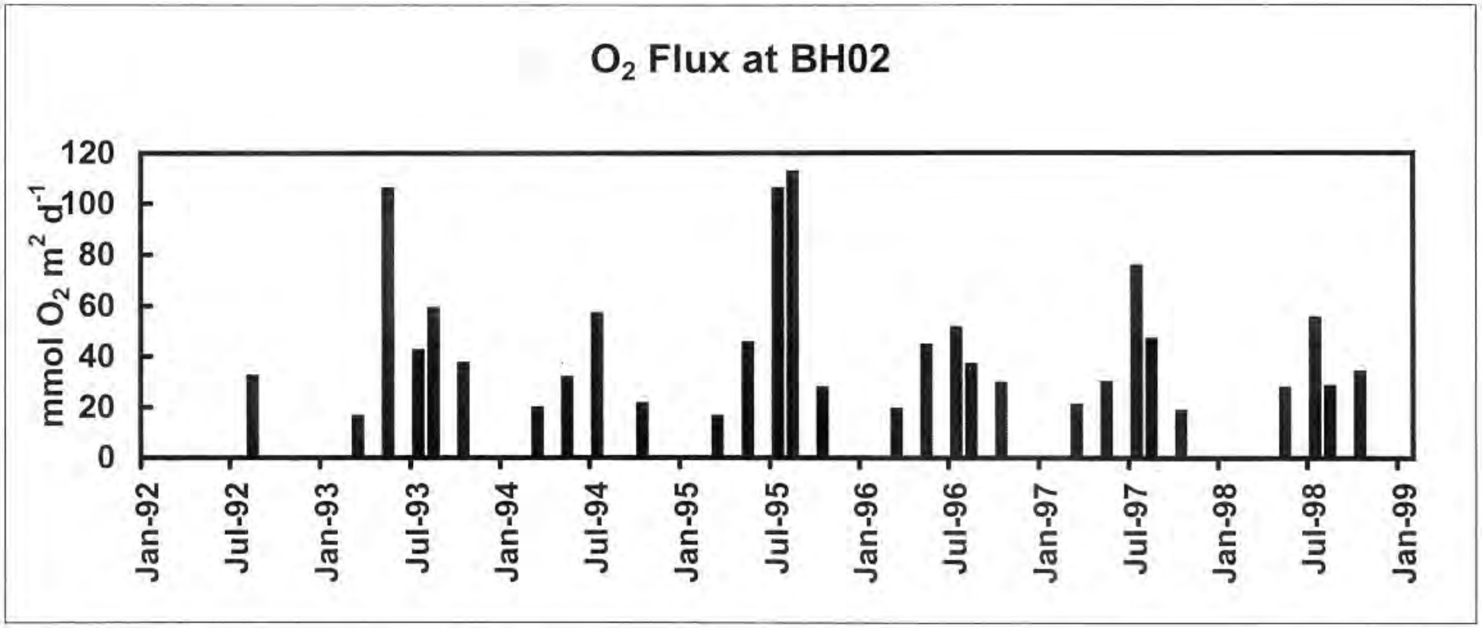

Sediment Respiration at BH02
O2
DIC
O_2 or DIC (mmol m^2 d^{-1})
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
May
Jun
Jul
Aug
Sep
Oct

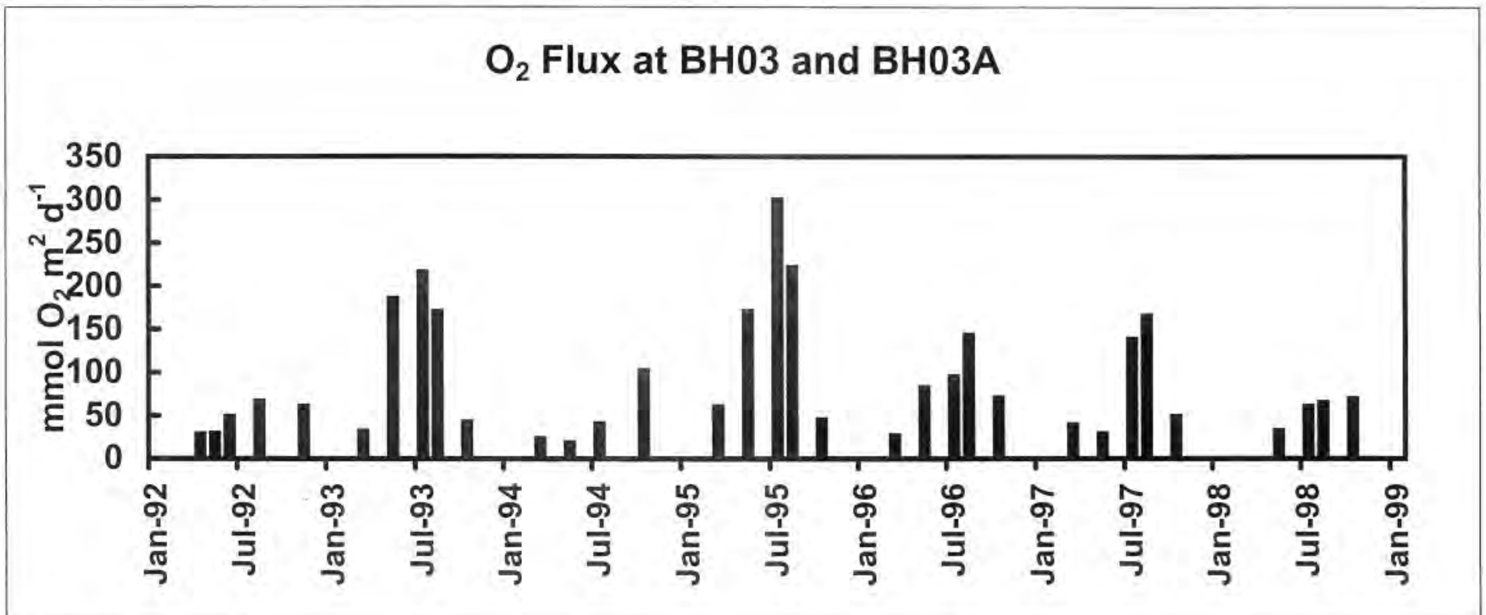

Sediment Respiration at BH03
O2
DIC
O_2 or DIC (mmol m^2 d^{-1})
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
May
Jun
Jul
Aug
Sep
Oct

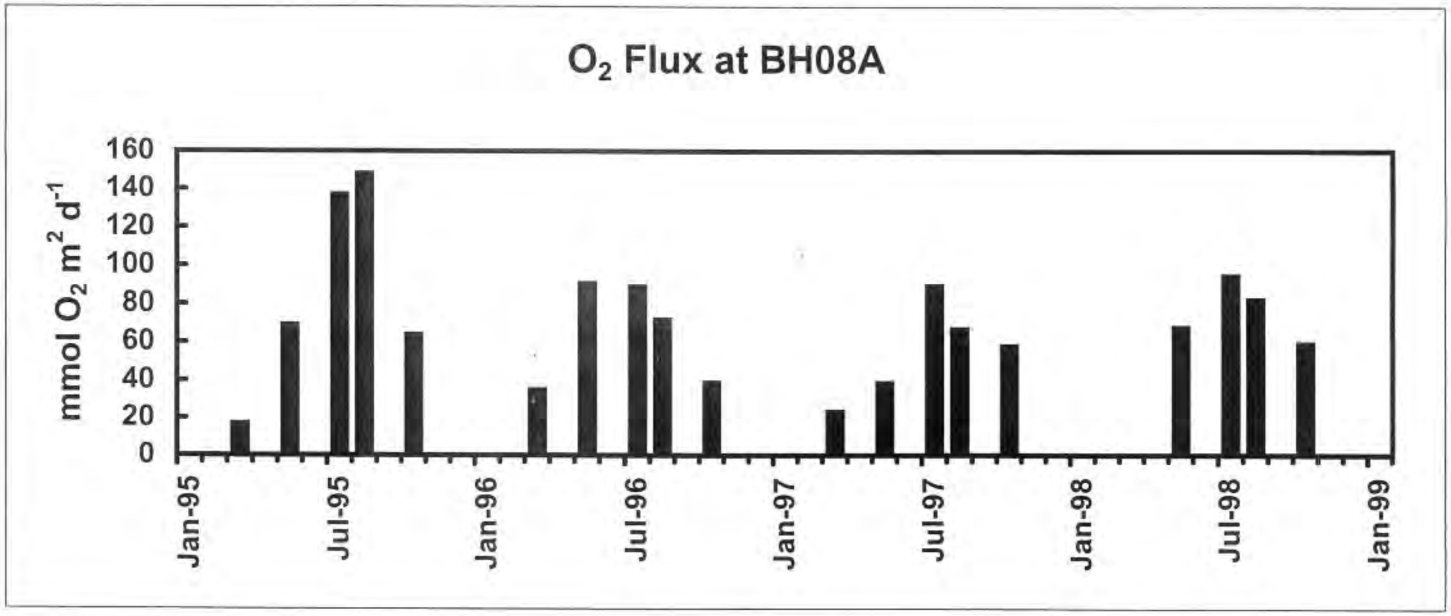

Sediment Respiration at BH08A
O2
DIC
O_2 or DIC (mmol m^2 d^{-1})
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
May
Jun
Jul
Aug
Sep
Oct

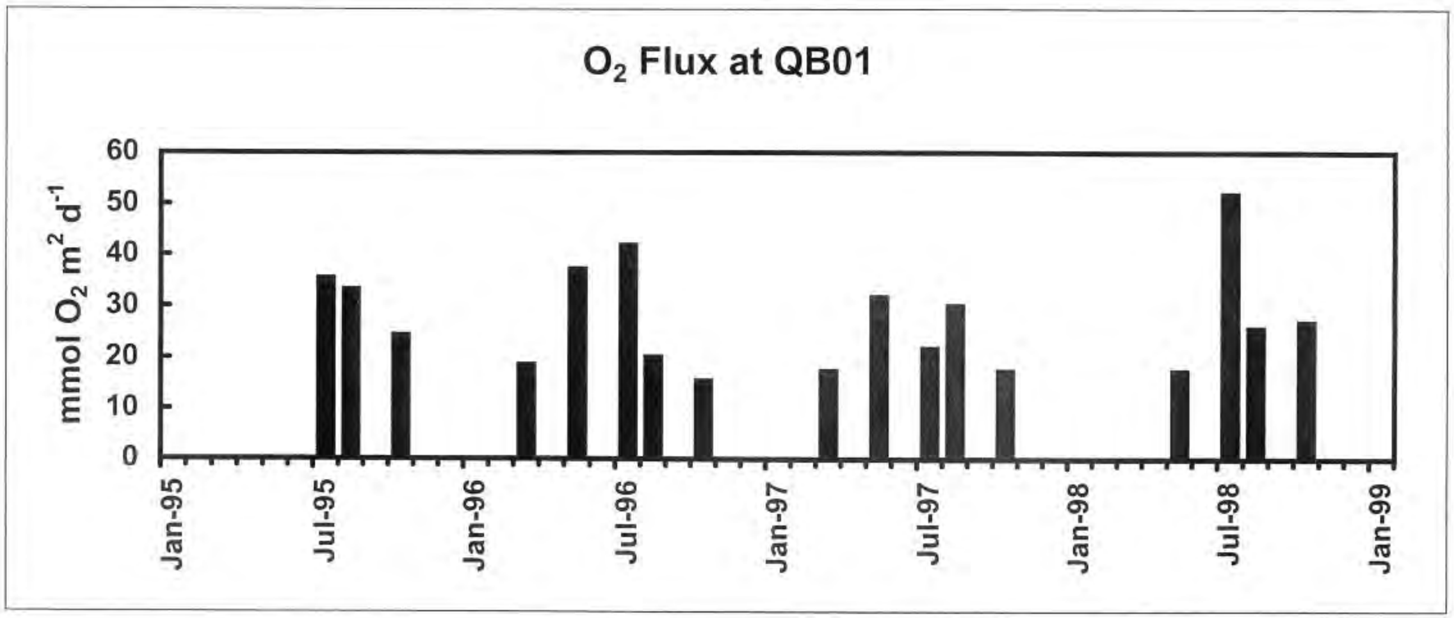

Sediment Respiration at QB01
O2
DIC
O_2 or DIC (mmol m^2 d^{-1})
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
May
Jun
Jul
Aug
Sep
Oct

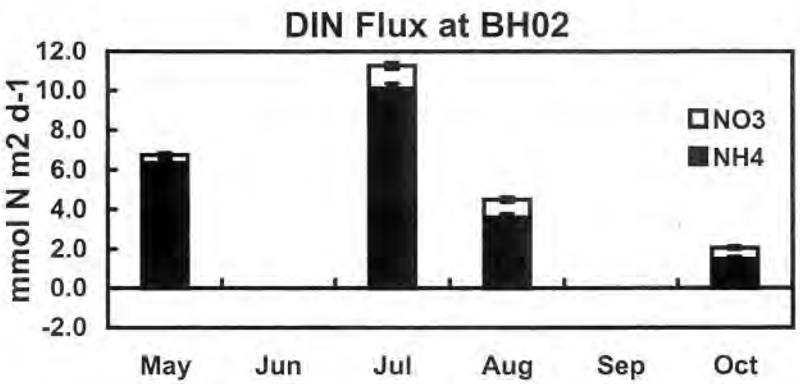

DIC vs O2
DIC (mmol m-2 d-1)
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
O2 (mmol m-2 d-1)
DIC/O2 = 1
BH02
BH03
BH08
QB01

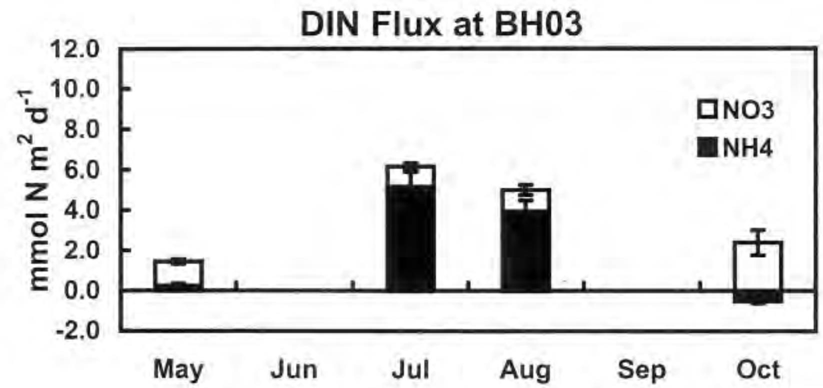

O_2 Flux at BH02
mmol O_2 m^2 d^{-1}
120
100
80
60
40
20
0
Jan-92
Jul-92
Jan-93
Jul-93
Jan-94
Jul-94
Jan-95
Jul-95
Jan-96
Jul-96
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99

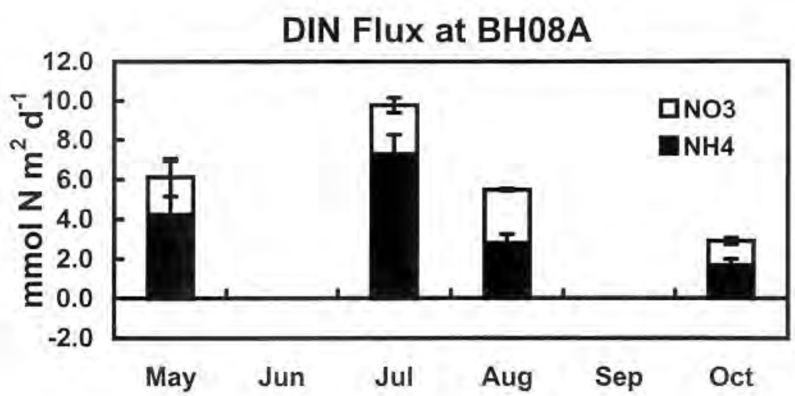

O_2 Flux at BH03 and BH03A
mmol O_2 m^2 d^{-1}
350
300
250
200
150
100
50
0
Jan-92
Jul-92
Jan-93
Jul-93
Jan-94
Jul-94
Jan-95
Jul-95
Jan-96
Jul-96
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99

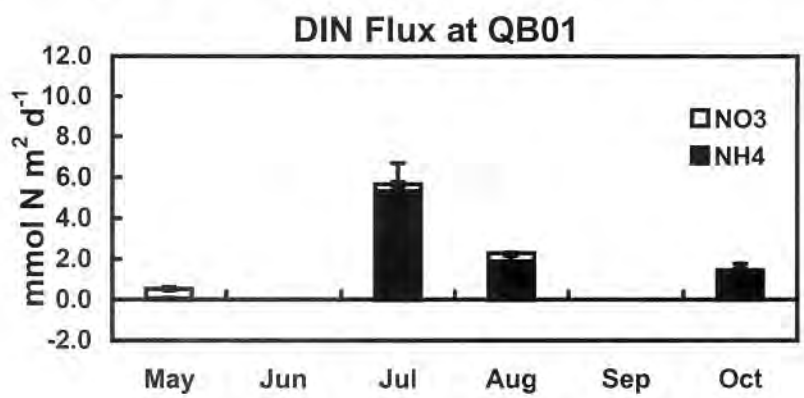

O2 Flux at BH08A
mmol O2 m2 d-1
160
140
120
100
80
60
40
20
0
Jan-95
Jul-95
Jan-96
Jul-96
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99


O2 Flux at QB01
mmol O2 m2 d-1
60
50
40
30
20
10
0
Jan-95
Jul-95
Jan-96
Jul-96
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99

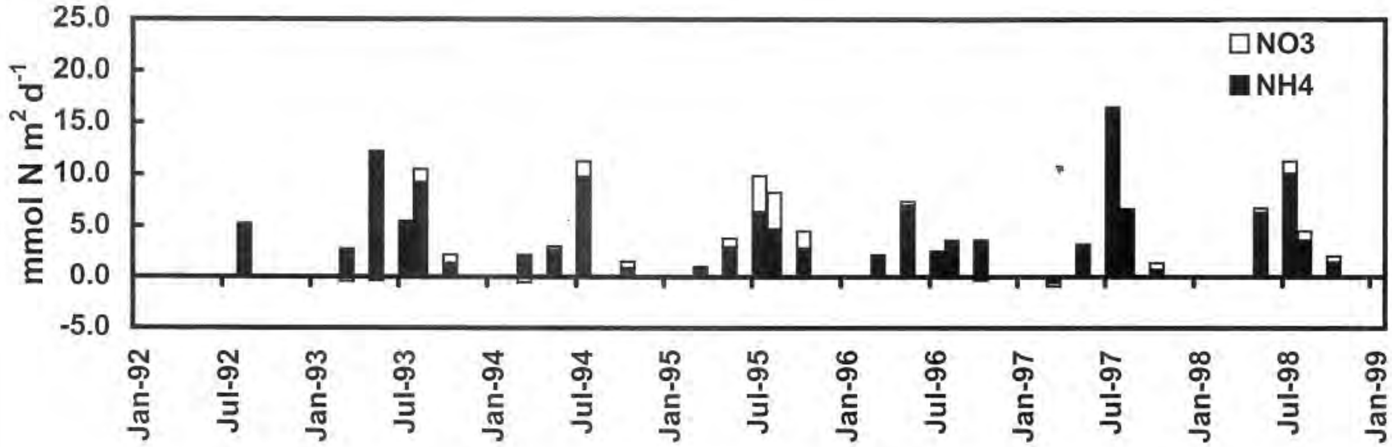

DIN Flux at BH02
mmol N m2 d-1
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
NO3
NH4
May
Jun
Jul
Aug
Sep
Oct


DIN Flux at BH03
mmol N m^2 d^-1
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
NO3
NH4
May
Jun
Jul
Aug
Sep
Oct

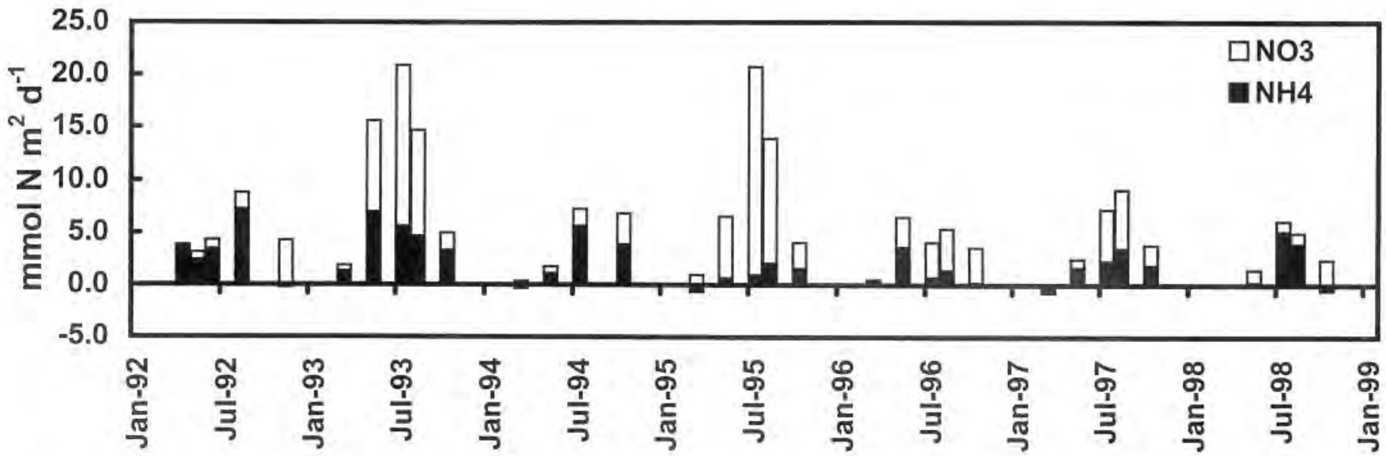

DIN Flux at BH08A
mmol N m^2 d^-1
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
NO3
NH4
May
Jun
Jul
Aug
Sep
Oct


DIN Flux at QB01
mmol N m^2 d^-1
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
NO3
NH4
May
Jun
Jul
Aug
Sep
Oct

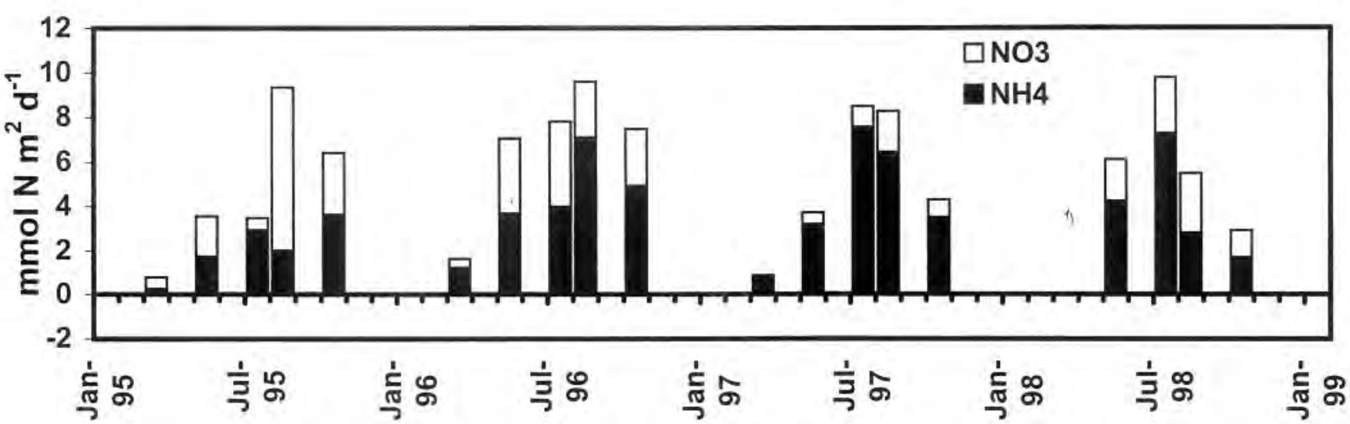
DIN Flux at BH02



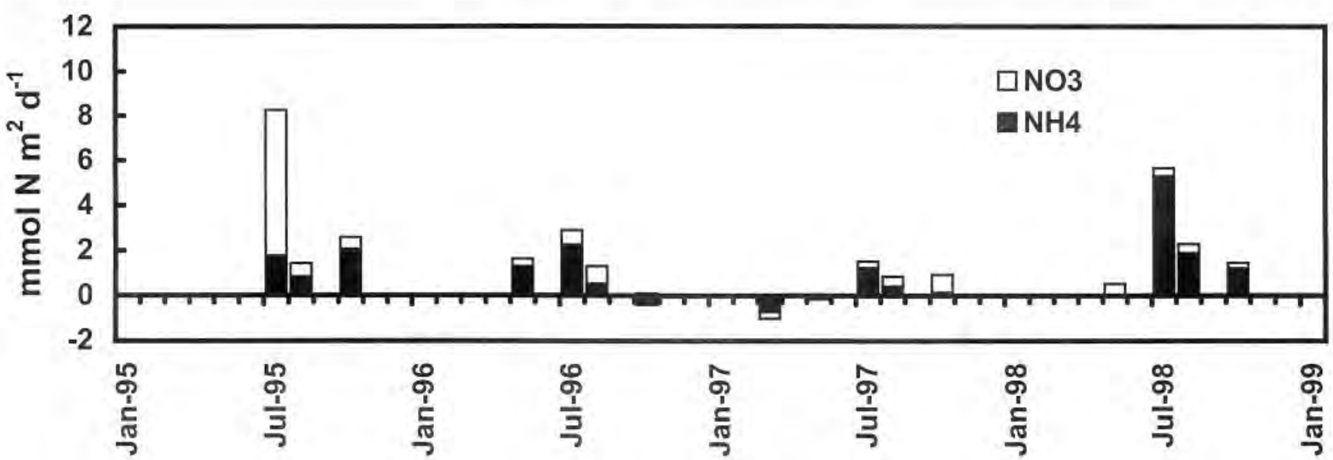
DIN Flux at BH03 and BH03A

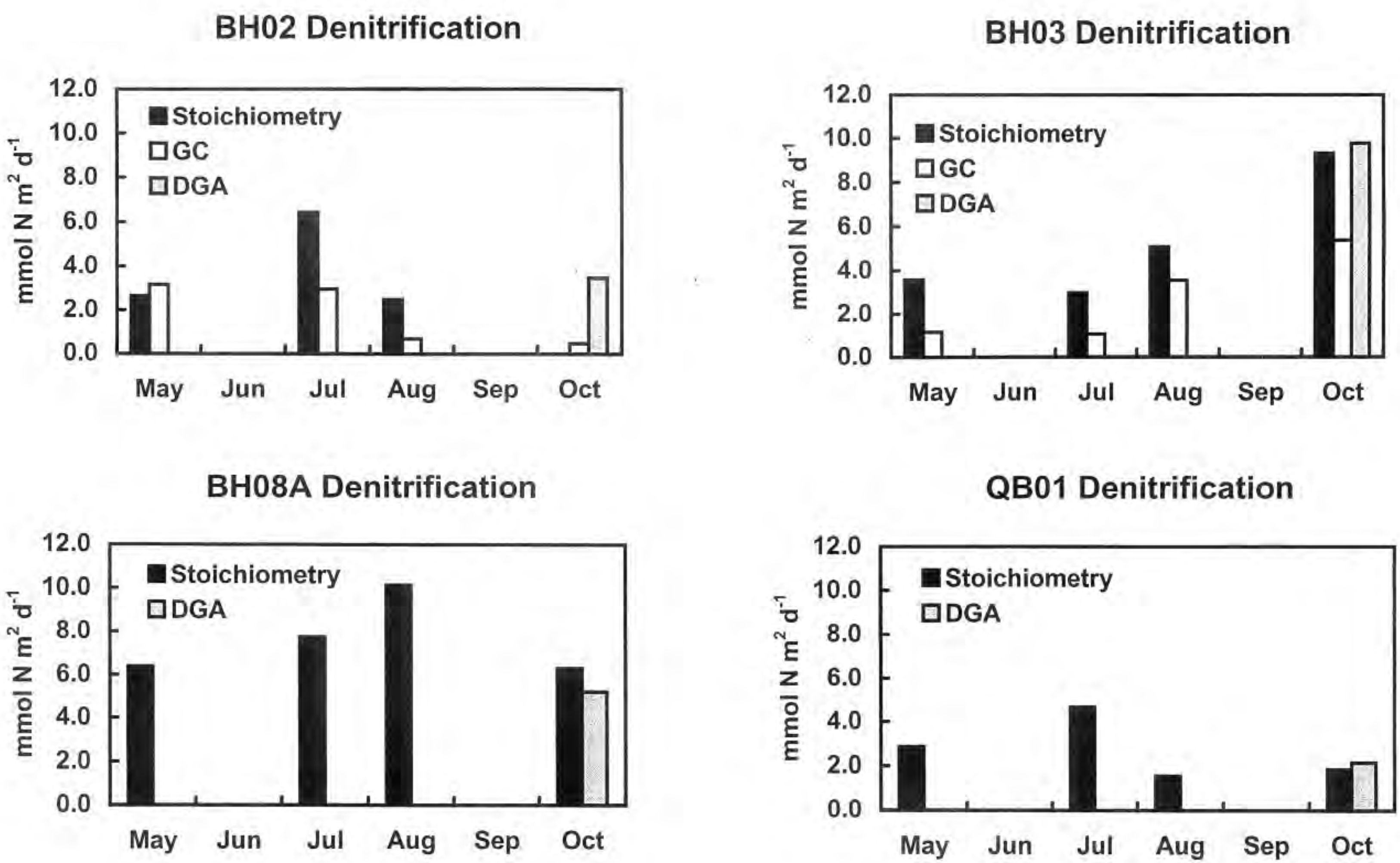


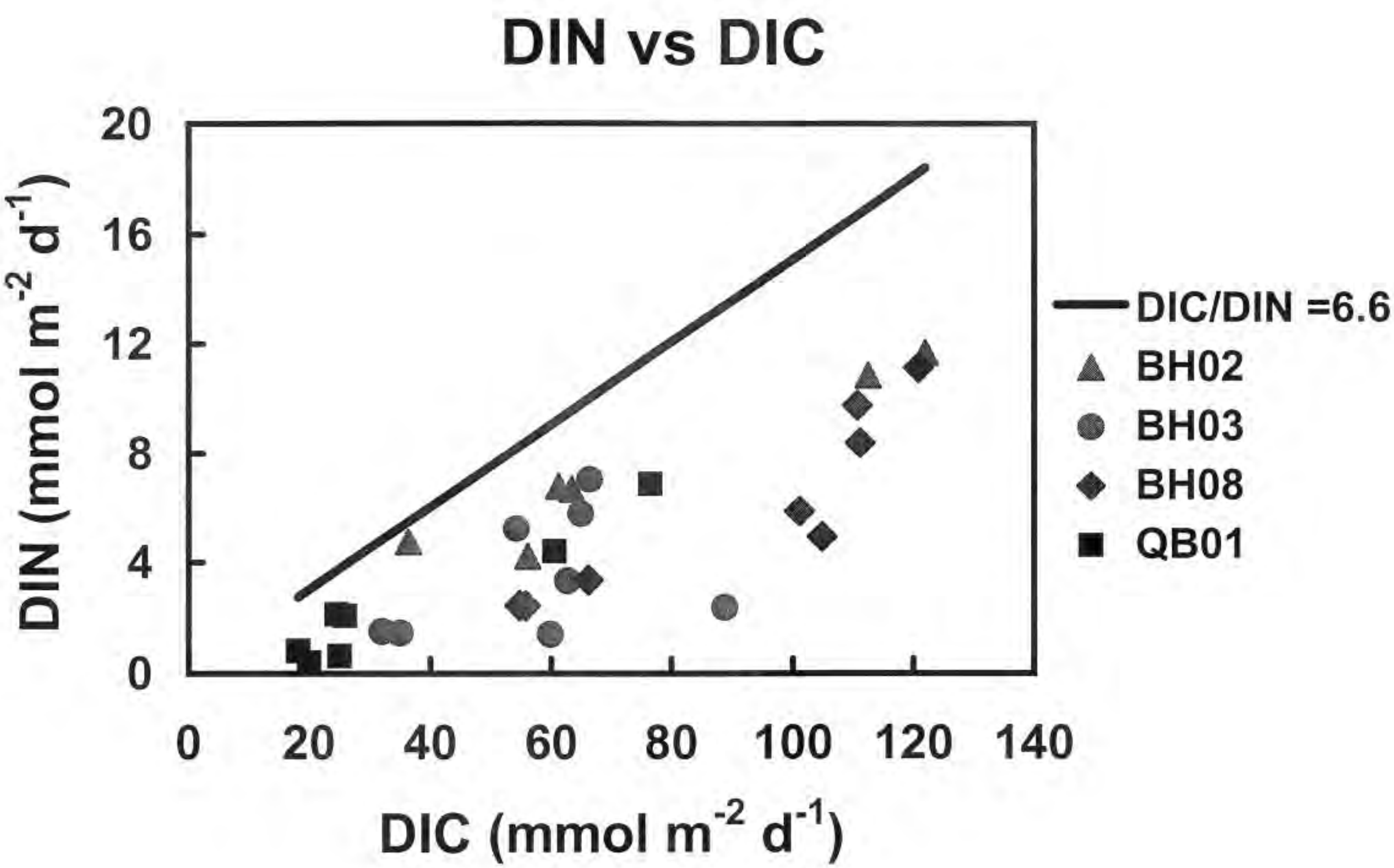
DIN Flux at BH08A

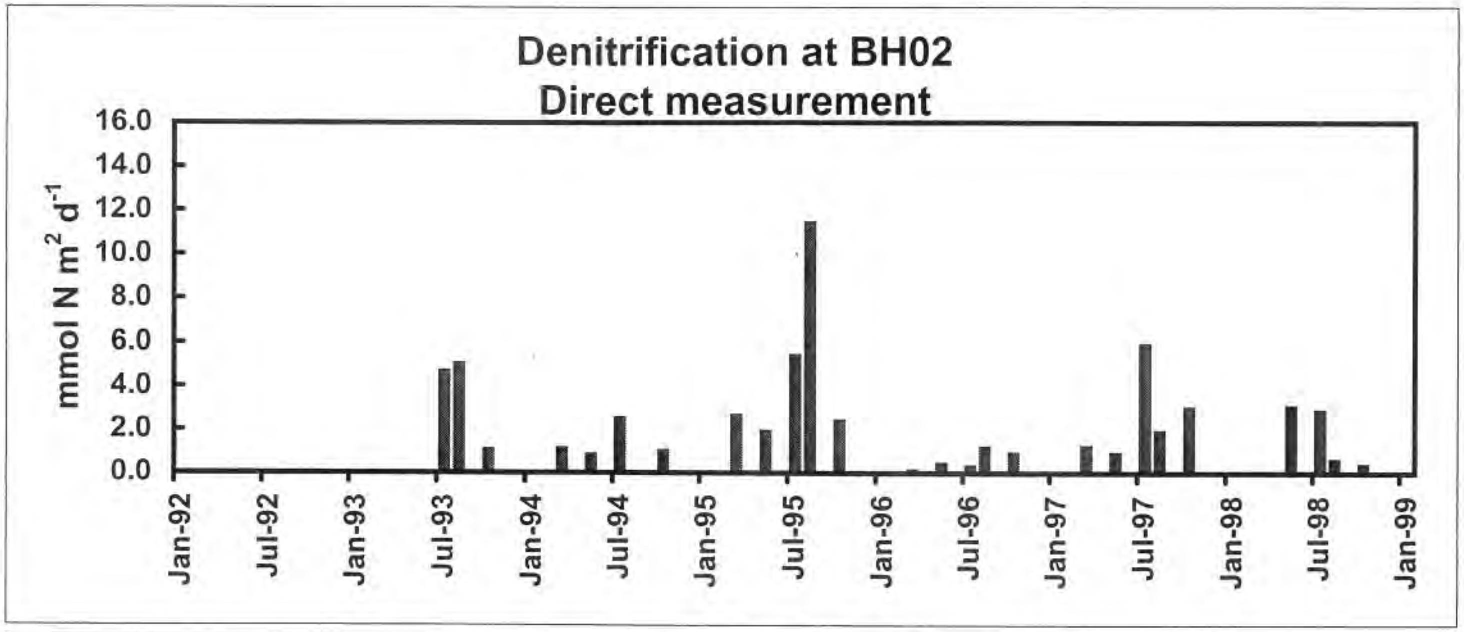


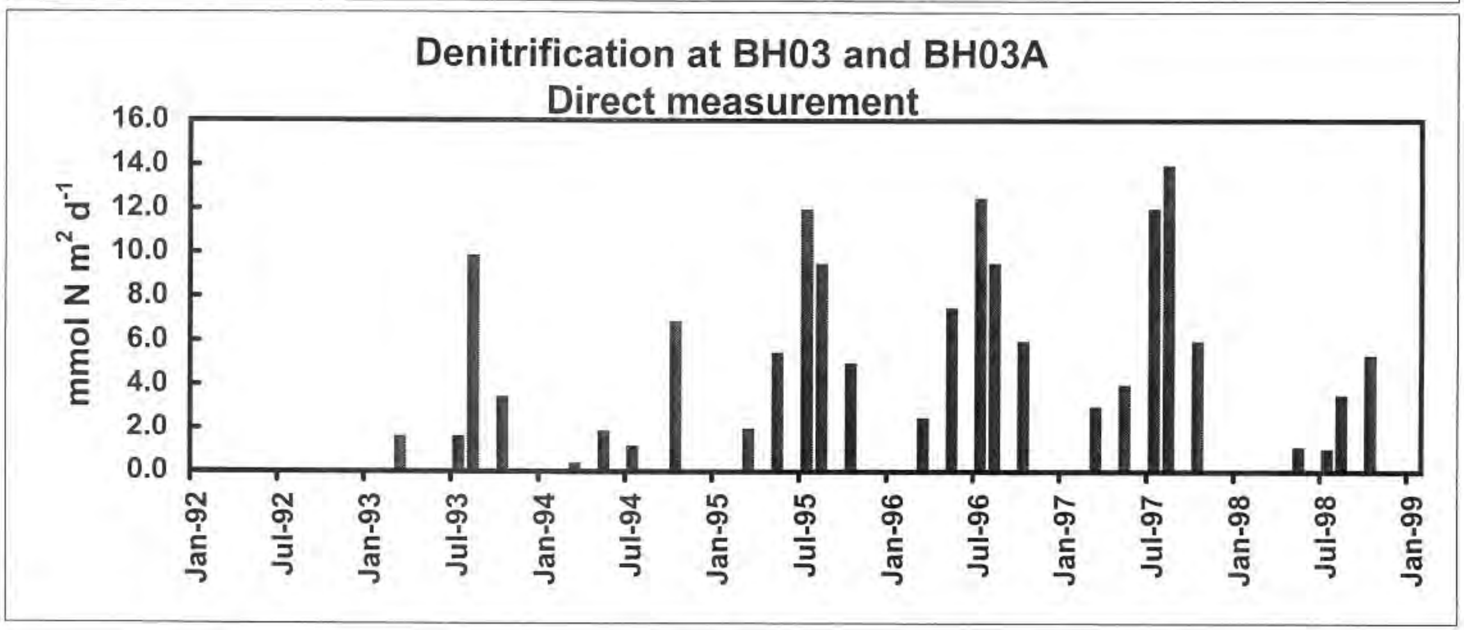
DIN Flux at QB01



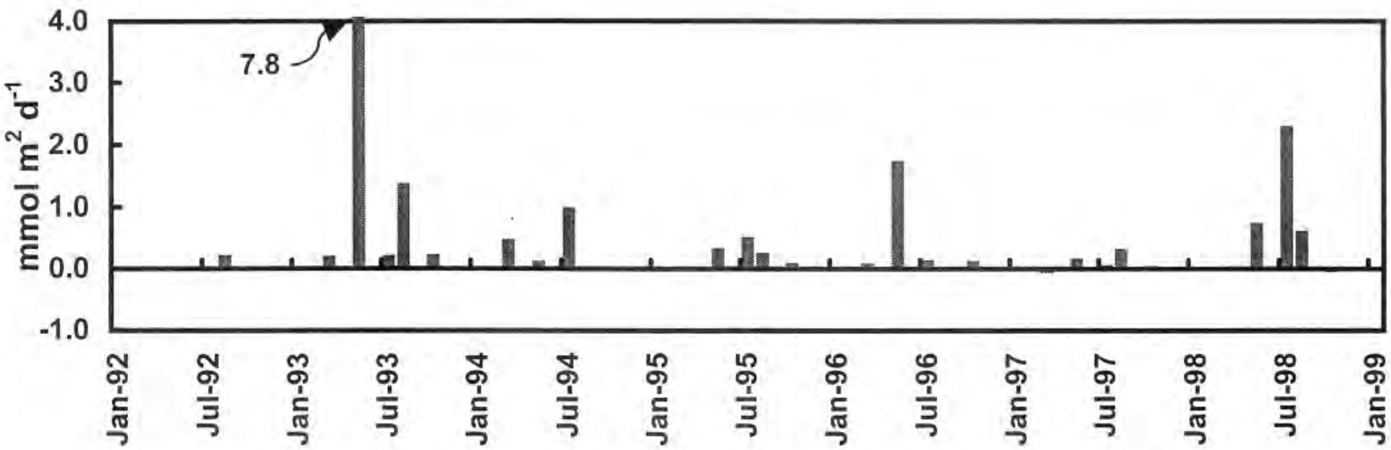

BH02 Denitrification
Stoichiometry
GC
DGA
mmol N m2 d-1
12.0
10.0
8.0
6.0
4.0
2.0
0.0
May
Jun
Jul
Aug
Sep
Oct
BH03 Denitrification
Stoichiometry
GC
DGA
BH08A Denitrification
Stoichiometry
DGA
QB01 Denitrification
Stoichiometry
DGA


DIN vs DIC
DIN (mmol m-2 d-1)
20
16
12
8
4
0
0
20
40
60
80
100
120
140
DIC (mmol m-2 d-1)
DIC/DIN =6.6
BH02
BH03
BH08
QB01

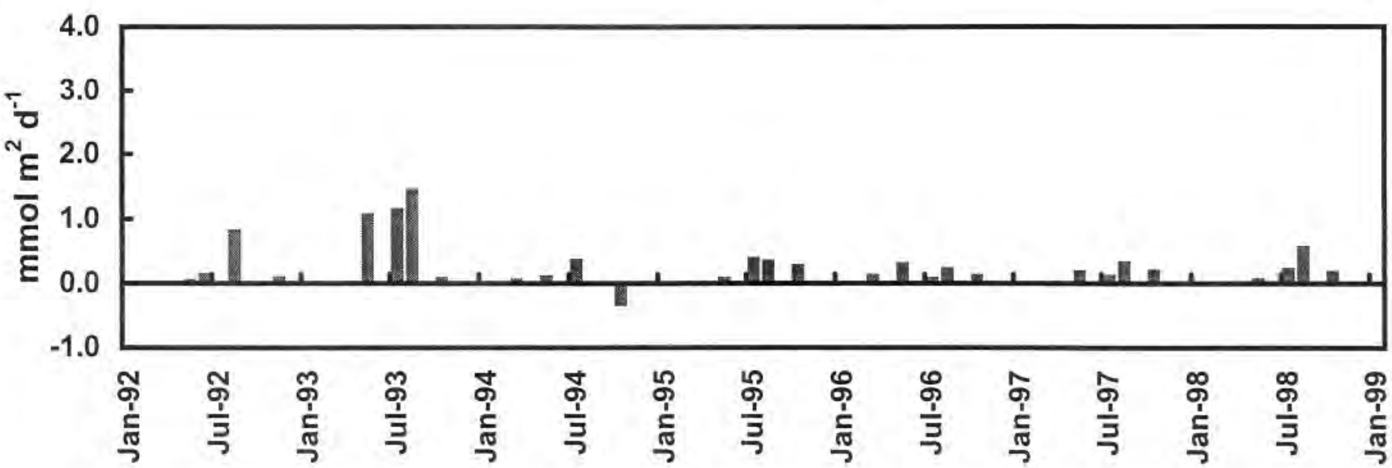

Denitrification at BH02
Direct measurement
mmol N m^{2} d^{-1}
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Jan-92
Jul-92
Jan-93
Jul-93
Jan-94
Jul-94
Jan-95
Jul-95
Jan-96
Jul-96
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99

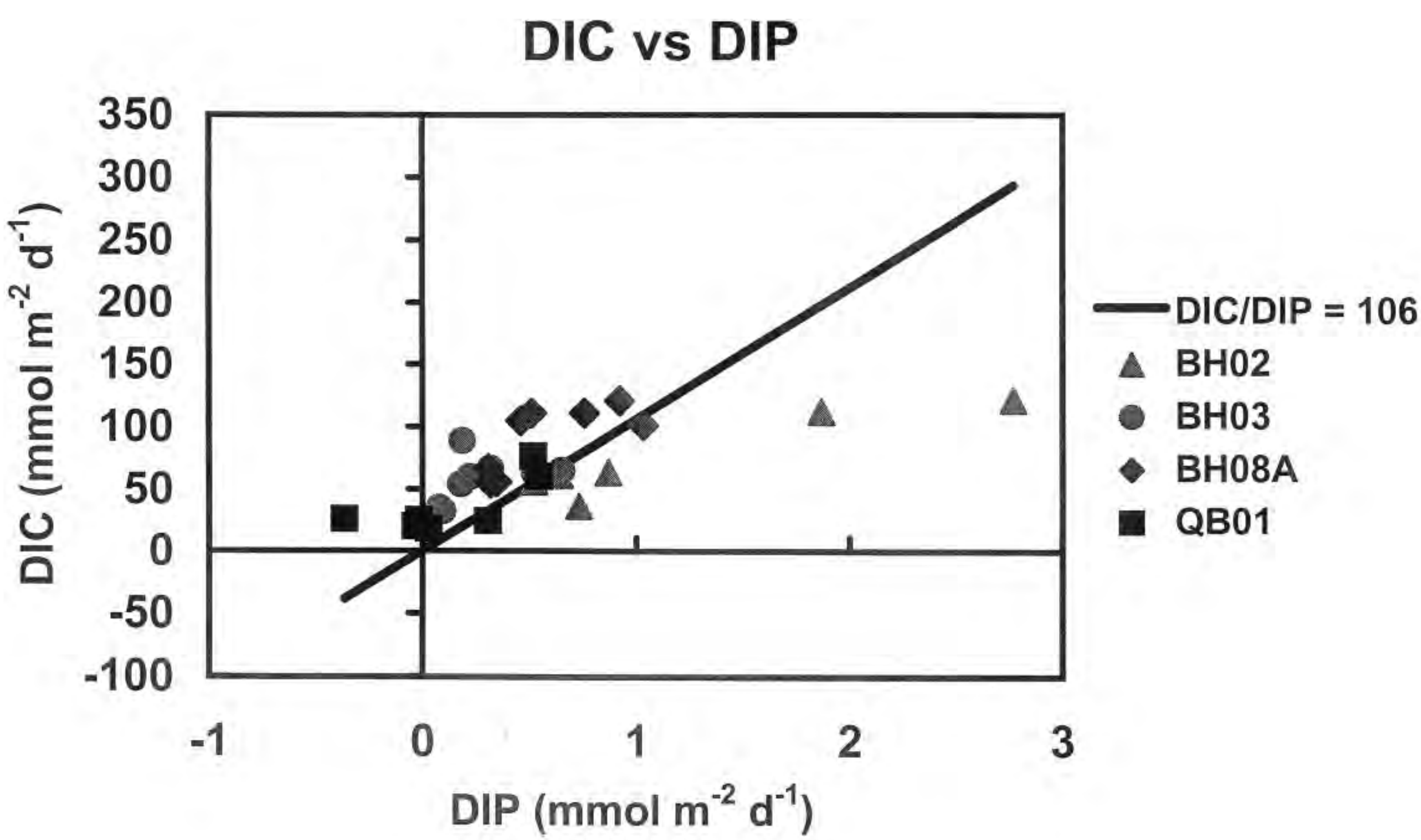

Denitrification at BH03 and BH03A
Direct measurement
mmol N m^{2} d^{-1}
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Jan-92
Jul-92
Jan-93
Jul-93
Jan-94
Jul-94
Jan-95
Jul-95
Jan-96
Jul-96
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99

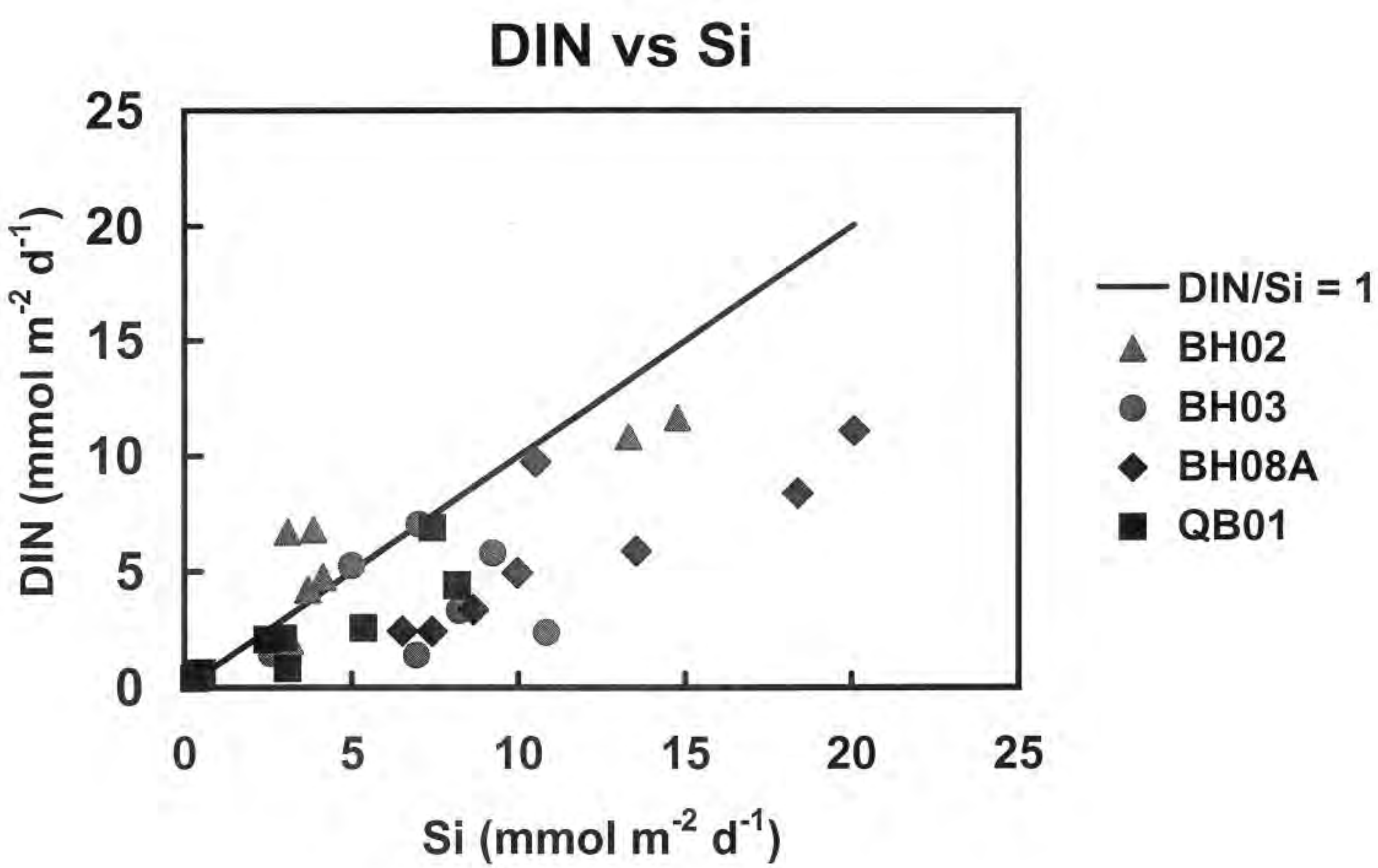
PO4 Flux at BH02



PO4 Flux at BH03 and BH03A




DIC vs DIP
DIC (mmol m-2 d-1)
350
300
250
200
150
100
50
0
-50
-100
-1
0
1
2
3
DIP (mmol m-2 d-1)
DIC/DIP = 106
BH02
BH03
BH08A
QB01


DIN vs Si
DIN (mmol m-2 d-1)
Si (mmol m-2 d-1)
0
5
10
15
20
25
DIN/Si = 1
BH02
BH03
BH08A
QB01

Water Column Monitoring and Nutrient Cycling
Statistical Approach to Threshold Testing and Rule Setting *(Dr. Jeff Rosen, TPMC)*

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Developing Protocols to apply the Thresholds

Automating the evaluation of the Outfall Monitoring Data

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What are the issues?

- Should the variability in the monitoring results (or the baseline) be considered in the evaluation relative to the threshold?
- If the variability is considered how should the results be aggregated before calculating the confidence intervals?
- Should all parameters be handled the same way?

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Proposed Approach

- Calculate one sided confidence intervals (the relevant direction).
- Evaluate if threshold is within the one sided confidence interval
- If it is within the confidence interval then threshold is not exceeded

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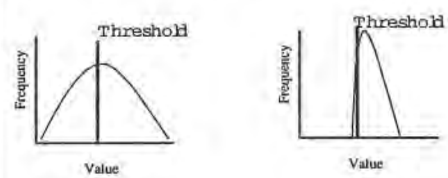
Should the variability in the monitoring results (or the baseline) be considered in the evaluation relative to the threshold?



As an example: Should these two results both trigger the same response?

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Propose that variability be considered in some of the response parameters.

- Establish thresholds based on baseline data or levels which have demonstrated ecological or resource management foundations. e.g. State action levels, ER-L, ER-M values, etc.
- Decide on direction of comparison, DO < threshold, Arochlor>threshold
- Calculate a one sided 95% confidence interval (t distribution)

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Comparison

- Trigger $\leq$ lower confidence limit (e.g. for DO)
- Trigger $\geq$ upper confidence limit (e.g. for Arochlor)
- Yes → Trigger Response
- No → No response

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Example

	Dissolved Oxygen
Station	mg/l
1	6.5
2	5.3
3	6.4
4	5.6
5	5.0
6	6.1
7	5.4
8	4.6
9	7.6
10	4.8
11	4.2
12	7.2
13	6.5
14	4.6
15	7.6
16	6.1
17	6.0
Mean	5.96
Std. Dev	1.12

- Fabricated Data - seventeen stations sampled on one day.
- If the warning threshold is set at 6.0 then these results would trigger a warning when it is probably not appropriate.
- Detectable difference for these results is .96 mg/liter. Any value between 5.52 < DO < 6.48 are not distinguishable from the threshold
- Do you want this to trigger a response?

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Aggregation Issues

- Data collection for each parameter will occur over a wide range of spatial and temporal scales
- The monitoring plan needs to specify how the data will be evaluated relative to each established threshold
- The method of aggregation and comparison to the threshold can have significant effects on the actions required

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Example

Detectable Differences Using	All Depths	Means of Depths	
Mean	5.96	5.96	Same as expected
Standard Deviation	2.12	1.12	Different as expected
count	85	17	Different as expected
Detectable Difference	0.81	0.96	

$$\delta = \sqrt{6.2 * (2\sigma^2) / n}$$

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Conclusion

- The way we aggregate the results will have an effect on the comparison between monitoring results and the thresholds.
- We need to decide on how to aggregate the results to do the comparison with the thresholds.
- These steps need to be define in great detail
- Ultimately these comparisons should be automated.

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Progress Made

- Detailed descriptions of the approaches have been proposed for many parameters.
  - Total Nitrogen, Toxics, Effluent Toxicity, cBOD, Fecal Coliform,Total Suspended Solids, Floatables, Dissolved Oxygen, DO depletion rate, fish and shellfish tissue concentrations, RPD depth
- More work is required to define detailed approaches for Chlorophyll a, Zooplankton, Nuisance algae, Benthic Communities

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Evaluating approaches for Chlorophyll a Data

- Two Thresholds to evaluate -
  - Annual mean < 1.5 (2.0) * baseline Mean
  - Seasonal Mean < 95th%ile baseline Seasonal mean
- Evaluating approaches of aggregation
  - Pooling Depths at a station
  - Pooling stations for a survey
  - Pooling surveys over seasons

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Evaluating Detectable Differences

- Will vary depending on variance estimates included in calculations?
- What are the intended Sampling units?
  - Each depth at a station for each survey?
  - The overall station for each survey (over all depths)?
  - The Near Field (over all stations and depths) for a survey?

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Power

Null Hypothesis		Null Hypothesis: Accepted	Null Hypothesis: Rejected	
	True	Correct	Type I Error	
	False	Type II Error	Correct	POWER OF THE TEST
		Trigger	No Trigger	

H_0: Measured Value = Threshold - Trigger a response

H_A: Measured Value is > (or <) Threshold - No Response

$\alpha = .05$ Probability of rejecting null hypothesis when it is True. We would not trigger a response when it should be triggered.

Power = $1 - \beta = .80$. The probability of rejecting the null hypothesis when it is false. The probability of not prompting a response when in fact there is no need for a response. (Prevents false alarms 80% of the time)

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Detectable Difference

What is the difference which can be detected with a given sample size (n), Variance (σ^2), $\alpha = 0.5$, $\beta = .20$?

For one tailed test calculated from:

$$n = (Z_\alpha + Z_\beta)^2 * 2\sigma^2/\delta^2 \quad \text{where}(\delta = \mu_A - \mu_0)$$

solve for δ

$$\delta = \sqrt{(Z_\alpha + Z_\beta)^2 * 2\sigma^2/n}$$

δ is the detectable difference. The difference which can be detected with the probabilities of α and β specified

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Products

- Summary of distributional properties for different aggregation strategies
- Detectable differences with $\alpha = .05$ and $\beta = 0.2$ for each aggregation strategy *(assumes that variance estimates for the baseline are representative of the variances that will be observed post outfall relocation).*
- Recommendations for the logistics of evaluating the Chlorophyll a Thresholds.