Summary of

MWRA
Water Quality Workshop

of
February 18, 1998

Prepared by
Stephen J. Cibik
Jessica E. Morton

ENSR
35 Nagog Park
Acton, MA 01720

ms-52

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citation:

Cibik, S.J. and J.E. Morton. 1998. **Summary of MWRA water quality workshop.** MWRA Enviro. Quality Dept. Misc. Rpt. No. ms-52. Massachusetts Water Resources Authority, Boston, MA. 200 pp.

OVERVIEW

The Water Quality workshop summarized in this document was held to present the results of 1997 water column monitoring data from the MWRA Harbor and Outfall Monitoring Program and to provide an initial forum to integrate results across the various disciplines. In addition the agenda included a review of data gathered thus far, a forum for hypotheses concerning post discharge status of the Boston Harbor and Massachusetts and Cape Cod Bays, and preparation for the new HOM monitoring team. Scientists were asked to make predictions relevant to their discipline for the upcoming year as well as for the post discharge period. The adequacy of current thresholds, appropriate dissolved oxygen threshold levels, and the effectiveness of the current monitoring program were discussed.

INTRODUCTION

The MWRA Harbor and Outfall Monitoring (HOM) Water Quality Workshop was held on February 18, 1998 at the Holiday Inn in Boxborough, MA. This workshop presented the 1997 baseline water column monitoring data and compared these results to previous data. There were approximately 45 attendees, including MWRA personnel, state and federal regulators, academics, nonprofit environmental groups, and project scientists (see Appendix A).

Steve Cibik (ENSR) and Mike Mickelson (MWRA) presented the overall goals and objectives of the workshop and project scientists presented summaries of water quality data and made interannual comparisons. Mike Connor (MWRA) moderated a general discussion at the end of the day to address new issues raised, monitoring thresholds and future predictions.

The objectives of the workshop were to:

1) Discuss how to use the baseline to understand ecological functions as well as infer impacts of proposed outfall
2) Rank public concerns
3) Evaluate trigger parameters
4) Discuss alternative thresholds (e.g., for DO)
5) Prepare for subsequent meetings for OMTF and Public.

The goals of the workshop were to:

1) Review baseline data
2) Consider tools
3) Discuss issues and concerns
4) Come to a consensus on issues
5) Evaluate thresholds and monitoring design.

MWRA Harbor and Outfall Monitoring (HOM) Water Quality Workshop
Wednesday, February 18, 1998
Holiday Inn, Boxborough, MA

Hosted by ENSR
35 Nagog Park , Acton, MA 01720
(978) 635-9500

AGENDA

SETUP 8:00 AM - 8:45 AM

8:45 AM **Goals and Objectives of workshop: Steve Cibik, ENSR/Mike Mickelson, MWRA**

- Review what we know of Mass Bay system from baseline studies
- Review the tools available to us to simulate and test for potential impacts from effluent relocation
- Debate "worst-case" scenarios and relevant processes
- Identify main issues of concern for relocation
- Evaluate thresholds and monitoring program

9:00 AM **Overview of Mass Bay Ecosystem: Steve Cibik**

- Annual cycle of events [winter nutrient setup; spring bloom; stratification; bottom water DO declines and inflections; upwelling events; turnover and fall bloom]
- Nuisance algae (*Alexandrium*, *Phaeocystis*, and *Pseudo-nitzschia*]
- Bottom water dissolved oxygen declines
- Worst-case scenarios [prolongation/enhancement of seasonal blooms; stimulation of nuisance algae; sub-pycnocline production; enhanced production due to upwelling; depressed DO, particularly in stratified bottom water; alteration of plankton assemblages]
- Review of monitoring thresholds [chlorophyll; DO concentration and depletion rate; nuisance algae; zooplankton assemblage shift; PSP extent]

9:45 AM **Bay Eutrophication Model: Jim Fitzpatrick (Hydroqual)**

- Model description and assumptions
- Applications of model (past and present)
- Model predictions for chlorophyll and dissolved oxygen
- Perspectives on zooplankton grazing and carbon flow
- Utility of model as interpretive tool

10:15 AM **Nearfield Carbon/Oxygen Balance: Mark Gerath (ENSR)**

- Objectives and approach to investigating carbon/oxygen balance
- Utility as interpretive tool

10:45 **BREAK**

11:00 AM Stratification, Advection, and Upwelling: Bernie Gardner (UMB)

- General circulation patterns in nearfield and farfield [relative to mixing and material transport]
- Development and integrity of pycnocline [seasonal onset; stability; etc.]
- Upwelling [both near-shore and in nearfield]
- Mitigative effects of advection on bottom water DO [perspectives on DO inflections]

11:30 AM Potential Implications of Altered Nutrient Field: Ted Loder (UNH)

- Overview of nutrient cycle and relocation of discharge into Mass Bay
- Winter setup [relocated discharge in well-mixed water column environment]
- Potential effects on spring bloom [relative change prior to "capping" by pycnocline based on nutrient mass and C:N:P:Si ratios]
- Perspectives on stratified bottom water nutrients and subsequent release during turnover

12:00 PM - 1:00 PM LUNCH (provided)

1:00 PMPrimary Productivity: Craig Taylor (WHOI)

- Overview of annual productivity cycle
- Vertical structure of water column productivity
- Potential enhancement of sub-pycnocline production during the stratified period
- Update on DCMU approach and alternative measurements of productivity

1:30 PMCarbon and Dissolved Oxygen: Brian Howes (CMAST)

- Overview of annual respiration cycle
- "Life-expectancy" of carbon in nearfield [locally-produced vs. effluent carbon quality, decomposition rates vs. advective transport]
- Sediment storage vs. water column recycling

2:00 PMPlankton Issues: Steve Cibik, Kristyn Lemieux (ENSR); Jack Kelly

- Nuisance algal issues [*Alexandrium*, *Phaeocystis*, and *Pseudo-nitzschia*; shellfish toxicity]
- Zooplankton retrospective [update, summary of findings, recommendations]
- Zooplankton food web conceptual model

2:45 PMBREAK

3:00 - 5:00 PM Monitoring thresholds and Contingencies: Mike Connor, Mike Mickelson (MWRA)

- Overview of water column monitoring thresholds [evolution of hypotheses over HOM 1 and 2; streamlining to encompass annual and seasonal chlorophyll; DO concentration and depletion rate; nuisance algae; zooplankton assemblage shift; PSP extent]
- Discussion of adequacy of thresholds [Are all issues covered? Are the thresholds appropriate? Does the monitoring program effectively provide the necessary data to test for significant change? Are modifications needed? Alternative DO threshold to be evaluated]

WORKSHOP REVIEW

Overview of Mass Bay Ecosystem: Stephen Cibik

An overview of Mass Bay and HOM baseline data focusing on annual cycles, baseline results, issues, and monitoring thresholds were presented.

1992-1997 results showed a highly variable system with complex interactions between chemical, physical, and biological processes. The annual cycle of events was described. Interannual comparisons of water column structure (T, S, and density) were used as premise for chemical and biological features/events.

Notable features:
1) spring freshets (especially in 1993 = year of biggest *Alexandrium* bloom)
2) upwelling during stratified period
3) nutrient cycling
4) seasonal blooms
5) DO minima

Focus on discussion on seasonal blooms:
- density plots
- cross sections
  - 1994: bimodal spring bloom
  - 1995: late winter/late April (two pulses)
  - 1996: biggest spring bloom ever in baseline record
  - 1997: long bloom period with mid-water bloom in April
- 1996 and 1997 provide an excellent contrast 1996 had a widespread centric diatom bloom, and 1997 was "pale" by comparison (only 10% of 1996 centric diatoms), but big *Phaeocystis* bloom.

- What is early-season role of stratification? May stabilize water column, induce thermal heating of shallow layer. Is inter-annual variability real or is it dependent upon the days we sample? Real, although timing of sampling, though consistent, may contribute.
- Why the difference between the two years? Likely a combination of both resource (nutrients, light) and predator based controls (grazing).
- Why interannual shift in POC and fl? *Phaeocystis* is carbon-rich due to polysaccharide envelope
- Analysis should focus on what is common in 1992 and 1997 to see why blooms of Phaeocystis occur

Focus on DO:

1994 and 1995 were the worst DO years (1994: 4.8 for DO)
'92, '93, and '96 each had bad starts but ended up comparably high in DO
1997 lowest ranked slope

- DO in bottom water capped by pycnocline – percent saturation may reveal physical controls on [DO]. B. Howes: Better to take concentration when initially capped and subtract numbers from it to calculate deficit (mass removal) over time.

Overview of monitoring thresholds concluded session.

Bays Eutrophication Model: Jim Fitzpatrick

A eutrophication model based on the combination of coefficients used for Long Island Sound and Chesapeake Bay, with modifications based on geographical location. Used to predict seasonal (yearly) highs and lows, but does not predict weekly minima or maxima; all variables are not accounted for.

A modeling exercise with doubled or quadrupled nitrogen input from the MWRA outfall showed increased inorganic nitrogen near the outfall as expected. With distance from the outfall, inorganic nitrogen was consumed leading to increased chlorophyll. But farther yet, in Cape Cod Bay by phosphate and silicate prevented the winter diatoms from taking up the inorganic nitrogen so DIN levels were increased. Depending on the purpose of such exercises, other scenarios could be investigated, including increasing other effluent constituents besides just nitrogen, and altering the nutrient requirements of the phytoplankton.

Nearfield Carbon/Oxygen Balance: Mark Gerath

The C/O Mass Balance is based on data collected from the inner 9 stations during 1996 WC surveys to evaluate trends in Carbon and Oxygen to develop a semi-quantitative predictive tool.
Looks at survey-to-survey changes, incorporates salinity to quantify advection

- Discussion of strength of approach and need to "downsize" the NF box.
- Question was asked inquiring about the use of this tool and not a hydrodynamic model.
  - -M.Gerath: approach uses actual data and rates to differentiate effect of physics or biology.
  - -Spatial is less variable than temporal

Stratification, Advection, and Upwelling: Bernie Gardner

Salinity stratification evident prior to thermal stratification (often by 2+ weeks).
Oxygen inflections in Nearfield and Stellwagen appear to be from GOM intrusion (accompanied by salinity increase). Look further into boundary data record to confirm.
Upwelling occurs, but may be overstated in importance; both mixing (say from cooling surface water) and upwelling can affect primary production.

Potential Implications of Altered Nutrient Field: Ted Loder

Nearfield Nutrient Concentrations:The timing and rate of nutrient uptake in spring varies from year to year. Once uptake begins, all the nutrient forms decrease, often with one or more becoming limiting.
Winter "sets" up the initial bloom = nutrient replete; not all years show full depletion from spring bloom.
Mass balance was developed to project potential increases in carbon from nutrient resupply in post-relocation environment = potential for a local doubling of C biomass.

Primary Productivity: Craig Taylor

0-5m layer is light saturated for photosynthesis
High [temporal] resolution estimates of productivity developed from continuous light data; high [vertical] resolution estimates based on vertical light profiles.
A substantial amount of productivity (Carbon) happens below the pycnocline (in the light limited level); 20% of production during latter half of 1996 occurred at depth.
1997 harbor production down from previous two years, similar to 1994.
Why does the BzPIo model fail to reproduce the results?

- The model is a function of time, photosynthetic efficiency, and light.
- It assumes photosynthetic productivity is constant, and that production is light-limited..
- Three to four fold variations in photosynthetic efficiency over seasons
- Station F23 is subjected to high advection of water with different histories.

Carbon and Dissolved Oxygen: Brian Howes

Even though Stellwagen Basin is only sampled three times during the stratified period, the DO decline is linear March - October. It is not necessary to increase the number of surveys to monitor for dissolved oxygen in Stellwagen Basin. Stellwagen is deeper than NF - mid-depths are colder and thus more like bottom water.

Variability in the rate of bottom water declines could be due partly to resuspension of sediments, but primarily (50%) a result of the spring and fall bloom.

Plankton Issues: Steve Cibik, Kristyn Lemieux, Jack Kelly

Nuisance algae issues, the zooplankton retrospective and the proposed food-web model were discussed.

Nuisance algae (S. Cibik)

Phaeocystis, Alexandrium, and *Pseudo-nitzschia* are target species. Thresholds set based on abundance distributions. Issue:The statistical implication of inclusion of non-detects should be revisited.

Zooplankton Retrospective (K. Lemieux)

Scope of retrospective from Focus Group convened by the OMTF (in December 1996)
- discuss monitoring issues for zooplankton in the Bays and as a forage resource for the right whale.
Three main issues were to be addressed:

1) "Identify all relevant zooplankton data from region"
2) "Use all comparable data to distinguish Cape Cod Bay from other areas, if possible" (and identify any regional differences)
3)"Establish a longer and broader baseline data set for Cape Cod Bay (CCB) than is presently available from only the MWRA monitoring"

Extensive graphical and statistical analyses were undertaken. Statistical analyses were conducted according to guidance from Drs. Andrew Solow and. Cabell Davis.

Three main conclusions were presented.
1) CCB appears to have characteristics, which favor patch formation. There is evidence that patches also form in areas of MB and adjacent Gulf of Maine (GOM), however there are comparably few studies to document the extent. This makes the assessment of CCB unique qualities a bit more complex.
2) Patches and ambient samples appear to be similar in composition, but patches are significantly more dense.
3) given all statistical evidence it appears as if MB and CCB are similar. However, CCB is more similar to nearshore MB assemblages than offshore assemblages of MB. The presence of this nearshore/offshore gradient supports the MWRA zooplankton hypothesis

Issues raised:
Are Mass Bay and CC Bay really different systems, or just the same with a time lag due to circulation? ZP data would indicate they are the same (especially to the Mass Bay coastal assemblage), except for the presence of the patches. However, data are lacking which would fully document patch occurrence in Mass Bay.

Food-web model (J. Kelly)

Conceptual food web model for Mass and Cape Cod Bays was developed in response to permit requirement. It describes carbon flow from plankton to right whale, and illustrates physical, chemical, and biological modification of C flow.

Emphasis on transport mechanisms elicited the question as to why there is not more emphasis in monitoring program on water mass movement and circulation. Modeling and plume tracking are adequate to interpret this mechanism.
"Unattractiveness" of *Phaeocystis* to right whale is implicit in the conceptual model, both in terms of avoidance and exclusion of desirable species.

Discussion

General Discussion

Initially the discussion focused on photosynthesis and respiration below the pycnocline.

Cross-boundary fluxes of oxygen (GOM intermediate water) should be investigated

Assessments should be made to the yearly species composition in reference to Carbon respiration and productivity.

Why *Phaeocystis* in 1997? Pursue relationships with light and possibly turbulence in the water column.

Whale/Zooplankton model, Is enough being done?

One issue against the Eutrophication model… Nutrients are not a significant effect in CCB, Boston harbor only contributes 10 – 15% as is. Model also imparts constraints which may not be realistic for 4x scenario (e.g., silicate limitation cut off production, but wouldn't different assemblage character inputs release this restriction?)

New Issues raised:
1) Light below pycnocline
2) Early stratification, Nitrogen decline
3) Zooplankton/Nuisance Algae
4) What drives bottom DO inflections

Overview of the workshop provided for the 3/20/98 meeting of the Outfall Monitoring Task Force: Mike Mickelson (MWRA)

The presentations looked back over the 6 years of baseline monitoring to the present work in progress which in many cases did not cover all of the 1997 results. The scientific presentations reinforced earlier observations that Massachusetts Bay is a typical temperate coastal ecosystem with typical seasonal cycles and typical variability. The large seasonal and interannual variations in the climactic and hydrographic regimes drive the biological components of the system. Some years and some seasons within years do stand out however as being somewhat different from the average observed over the course of the monitoring. Noteworthy events include the lowest DO (1994) and the greatest spring bloom (1996). Phytoplankton species events were the highest Alexandrium bloom (1993) and Phaeocystis bloom (1997).

The meeting discussion focused on the following topics:

WATER COLUMN MONITORING

1) Variability. The system variability is well documented by the monitoring but more work is needed to improve our understanding of the complex interactions behind the variability. The Bays Eutrophication Model (Hydroqual's "BEM"), which had been run for 1992, will also be run for other years to help us understand the extremes of DO and chlorophyll.

2) Sensitivity to nitrogen. An interesting recent result from the Bays Eutrophication Model is that a hypothetical doubling of the nutrient load from MWRA would have little effect on the Bay. A hypothetical fourfold increase would be manifest in April as a doubling of chlorophyll near Scituate and surface inorganic nitrogen in Cape Cod Bay and in October as a 0.5 mg/L decrease in DO in the nearfield bottom waters with little effect elsewhere.

3) Importance of deep-water advection. Multiple efforts are underway to understand the seasonal decline of DO: quantifying advection (currents), estimating the carbon-oxygen balance, and of course running the Bays Eutrophication Model. The efforts are spurred by the observation of a steep initial decline in DO in early 1997 which was reversed before the usual low in October.

4) Temporary weak stratification. The transition from well-mixed winter conditions to the strong water column stratification of summer is often marked by a series of "false starts," with alternating layering and mixing depending on meteorological conditions. The discussion considered that understanding these events could be very important in understanding the nature of the spring bloom.

5) Outfall-induced mixing. The participants considered that the momentum of the outfall discharge could have a substantial effect on vertical mixing. If this occurs, it could physically delay the onset of stratification and the timing of the spring bloom. Delayed stratification could lead to warmer bottom waters and a lower initial DO concentration leading into the seasonal summer DO decline. Such mixing in autumn, however, might tend to actually increase the local ambient DO concentrations. The duration of the stratified period might decease.

6) Nutrient enrichment. The spring bloom terminates with nutrient depletion. Because the outfall might increase the initial (winter) nitrogen concentration the bloom might be more intense. The spring bloom might also last longer should mixing be enhanced in the nearfield by the outfall discharge. Furthermore, the summer bloom events which depend on the occasional mixing events might be sustained by the nitrogen from the outfall brought nearer to the surface by the force of mixing.

7) Primary production. Scientists have recognized the balance of light and nutrient limitation in algal growth and that the future subpycnocline effluent discharge would generally stimulate less algal growth than the present discharge. But there has been some debate about the algal response at the small area around the future outfall. The workshop discussed the substantial deep water production that occurs now and speculated that it may be enhanced by the outfall. This could be further enhanced by the clearing of surface waters expected when the surface discharge ceases.

8) Respiration. Bottom water and sediment respiration during the stratified period are largely sustained by earlier deposition of material produced during the spring bloom. Thus the factors affecting the spring bloom are indirectly important for interpreting low DO months later.

9) Phytoplankton. The large bloom of Phaeocystis was the defining event of 1997. This bloom, like the less intense bloom of 1992, was widespread.

10) Zooplankton. Cape Cod Bay and nearshore Mass Bay have has a similar zooplankton assemblage. It is not know whether patch formation is unique to Cape Cod Bay. Patches are simply higher concentrations of the ambient species rather than of one species, suggesting a physical origin.

11) Conceptual food web model. The path of nitrogen to right whales involves a number of steps in the food chain with alternate paths. The paths are affected by environmental factors. The MWRA outfall could conceivably affect the whales if there was transport of altered nearfield populations, of nutrients, or of toxics to whale foraging areas.

The following abstracts were not available at the time of printing:

- Stratification, Advection and Upwelling: Bernie Gardner (UMB)
- Potential Implications of Altered Nutrient Field: Ted Loder (UNH)
- Primary Productivity: Craig Taylor (WHOI)

Overview of Massachusetts Bay Ecosystem
MWRA HOM Water Quality Workshop 2/18/98
Stephen J. Cibik

The Massachusetts Water Resources Authority (MWRA) initiated water quality monitoring in Massachusetts and Cape Cod Bays in 1992. Six years of data have now been collected to characterize the physical, chemical, and biological processes of the ecosystem. These data will serve as a baseline for the evaluation of potential change following relocation of the MWRA's treated wastewater discharge from Boston Harbor to a point 15 km out into Massachusetts Bay, scheduled for late 1998. The overview of these data which was provided for the workshop summarized the typical seasonal cycle of the ecosystem, and discussed the influence of climatic and hydrographic regimes on the biological processes. This information prompted discussion on issues of concern for monitoring of post-relocation effects, and concluded with an overview of existing monitoring thresholds intended for use in contingency planning.

The water column at the future outfall site is seasonally stratified and exhibits an annual progression of events which is closely related to the water column structure. The annual cycle begins with a well-mixed, nutrient-rich, but light-limited water column. Winter nutrient concentrations are depleted throughout the water column by a phytoplankton bloom in late winter and spring. Spring discharges from riverine systems to the north, combined with increasing temperatures initiate seasonal water column stratification. Nutrient concentrations remain low in the surface water during the stratified summer period, while bottom water concentrations increase from remineralization of the spring bloom and advection of deeper offshore water. Bottom water dissolved oxygen (DO) concentrations decline throughout the summer stratified period. Late season cooling of surface water, coupled with wind energy from storms, releases bottom water nutrients which trigger a fall phytoplankton bloom.

The ecosystem has exhibited substantial temporal and spatial variability, but the six-year monitoring program has provided a powerful baseline dataset for use in evaluating post-relocation effects. Noteworthy departures from the baseline may yet reveal themselves in pre-relocation monitoring. One example was the system-wide bloom of the nuisance algae *Phaeocystis pouchetii* during late winter and spring of 1997, an event which surpassed in magnitude the only previous occurrence within the baseline during 1992. The demise of this bloom produced elevated water column respiration which appeared to set the stage for significant depression of seasonal bottom water dissolved oxygen concentrations. However, it became apparent that physical processes during mid-summer mitigated this potential by infusing oxygen-rich water from deep offshore into the system. These events demonstrate the need for refinement of our understanding of the complex interactions in the ecosystem in order to fully interpret potential effects from the outfall relocation.

Massachusetts Bays Eutrophication Model
Jim Fitzpatrick (Hydroqual)

An overview of the Massachusetts Bays Eutrophication Model (MBEM) will be presented, together with model calibration to a composite water quality data set collected by various researchers from 1989 through 1991 and to the first year (1992) of the harbor outfall monitoring program . This overview will include a brief description of its linkage to a hydrodynamic model of the Massachusetts Bay and Cape Cod Bay developed by Rich Signell of the USGS, as well as a more detailed description of the kinetic framework used to relate nutrients, phytoplankton biomass and dissolved oxygen in the Bays system. Included will also be a brief description of the sediment nutrient flux sub-model and a description of how zooplankton grazing is parameterized within the model.

The final part of the presentation will include some projection results for expected water quality in the Massachusetts Bays system once the outfall goes online. Also included will be projection results for a 2X and 4X increase in the MWRA effluent nitrogen load to the system.

Nearfield Carbon/Oxygen Budget

Mark Gerath, Mel Higgins, Brian Howes, Bernie Gardner, Steve Cibik, Craig Taylor.

An alternative to numerical modeling of the carbon and oxygen dynamics in the nearfield region is the evaluation of the data collected over the last number of years. Such an empirical approach to the problem can help to identify weaknesses in the data set as well as identify important processes. The data collected by the MWRA are a very substantial especially when compiled with information collected by other agencies (e.g, the USGS). The data provide a detailed picture of water quality parameters, currents, and biological processes in space and time. One of the major challenges of such an empirical approach is the reconciliation of data collected at different space and time scales. In particular, data on currents is collected only at one location but has very high temporal resolution. Conversely, data on water quality is collected relatively infrequently but over a wide area and at relatively high spatial resolution. In order to use these different data to evaluate the carbon and oxygen balance of the nearfield, a simple solution to the advection-dispersion equation has been derived.

The resulting expression will be solved for the mass balance of salinity in the nearfield. The processes affecting salinity are all physical ones, simplifying the solution of the equation. Following validation of the approach (including parameter definition) based on salinity, the other processes (i.e., productivity, respiration, and settling) will be evaluated for the carbon and oxygen budget.

This presentation will introduce the concept and utility of the carbon/oxygen budget as well as describe the progress to date.

Oxygen and Carbon Dynamics in Massachusetts Bay, 1997

Brian L. Howes
Center for Marine Science and Technology, UMass-D.
706 Rodney French Blvd
New Bedford, MA 0274

Rates of bottom water oxygen decline throughout the Nearfield during stratification in 1997 were similar to previous years. However, early season D.O. declines were higher than average with the overall rate mediated by a mid-summer physical "reaeration" event. Vertical profiles of watercolumn respiration within the Nearfield were similar to previous years (1995-96). During the spring and fall when the watercolumn was well mixed, respiration rates at the surface and mid depth were only slightly higher than bottom water values. In contrast, during stratification surface and mid water respiration rates were 4 to 6 times higher than observed in bottom waters. The observed vertical gradient in respiration resulted from both the higher temperatures and organic matter quality in the surface versus bottom waters. Analysis of rates of oxygen decline in Stellwagen Basin bottom water using watercolumn and benthic survey data from 1995-97 suggests that additional surveys are not needed to adequately capture this rate. However, the annual oxygen minimum may not always be captured under the present coarse fall sampling schedule due to inter-annual variations in the timing of the breakdown of stratification.

During stratification detailed vertical profiles of watercolumn respiration indicated relatively constant rates below the pycnocline. These data were collected for the first time in 1997 in order to improve the vertical integration of system respiration for oxygen-carbon balance calculations. This vertical profile was observed in both Nearfield and Stellwagen Basin stations. Integration of primary production and respiration measurements in the Nearfield indicted that about 85% of the carbon fixed during the stratified interval was remineralized within the watercolumn. Based upon the observed rates of production and respiration it appears that the watercolumn POC pool has an average turnover of ca. 7 days. Preliminary data on carbon sedimentation rates from moored sediment traps (USGS) are consistent with system carbon remineralization dominated by watercolumn processes. Sediment respiration appears to be significantly supported by organic matter stored from deposition prior to stratification, most likely from the spring bloom. Higher sediment chlorophyll concentrations were observed in late spring 1997 compared to previous years were consistent with the higher observed SOD in the Nearfield in 1997 and possibly resulted from deposition of the *Phaeocystis* bloom.

Although total system organic matter remineralization is dominated by respiration in the upper watercolumn, bottom water oxygen depletion during stratification is driven by sub-pycnocline watercolumn respiration and sediment oxygen uptake. During stratification both of these processes appear to be organic matter limited indicating that the input of additional labile organic matter without coupled oxygenation may potentially enhance oxygen depletion. An analysis of the effect of CBOD in future effluent discharged below the pycnocline indicates that even at 200 fold dilution, the potential enhancement of oxygen depletion is on the order of 2-5% over current "natural" levels.

Nuisance/Toxic Algae
MWRA HOM Water Quality Workshop 2/18/98
Stephen J. Cibik

Water quality monitoring thresholds developed for the Massachusetts Water Resources Authority monitoring program include three phytoplankton species due to their potential to produce harmful algal blooms. The three taxa are *Alexandrium tamarense*, *Phaeocystis pouchetii*, and *Pseudo-nitzschia multiseries*. The distribution and abundance of these three taxa as documented by baseline monitoring over the past six years were summarized for the workshop.

Alexandrium tamarense has been detected sporadically during the spring period over the monitoring baseline. It produces a neurotoxin which causes paralytic shellfish poisoning it humans when shellfish which have accumulated the toxin are consumed. It was found in greatest abundance during 1993, the only year this decade which has produced significant shellfish toxicity in Massachusetts waters. Its occurrence in the study area is primarily a function of physical processes which transport the organism into Massachusetts Bay from the north. Monitoring of these processes through satellite imagery (sea surface temperature and chlorophyll concentration) can aid in interpretation of occurrences of *Alexandrium*.

Phaeocystis pouchetii is a typical component of the late winter/spring phytoplankton assemblage in the Massachusetts Bay system. It is a small flagellate which is capable of forming large colonies which can clog nets and foam beaches. Two years within the baseline monitoring period, 1992 and 1997, have produced substantial, system-wide blooms. In both years, densities reached several million cells per liter, but the bloom in 1997 was of greater duration, spanning several surveys during the months of February through April. Blooms of this magnitude can impart substantial changes on carbon flux through the food web, and can ultimately affect water quality. Further investigation of the relationships with the climatology and water column characteristics of the two bloom years is needed to fully understand their occurrences.

Pseudo-nitzschia multiseries is a component of the fall and winter assemblage in Massachusetts Bay. It typically exhibits its seasonal maximum densities around November. Its production of domoic acid has been linked to amnesic shellfish poisoning in humans who consume shellfish exposed to water column high densities of the organism. However, six years of monitoring have shown the densities are typically below the threshold of 100,000 cells per liter being used by the program.

Zooplankton Retrospective
MWRA HOM Water Quality Workshop 2/18/98
Kristyn B. Lemieux

The principal goal of the Zooplankton Retrospective is to characterize the baseline of the zooplankton communities in the Massachusetts Bay and Cape Cod Bay system and adjacent Gulf of Maine waters prior to relocation of the Massachusetts Water Resources Authority (MWRA) effluent discharge approximately 15km offshore. The scope of the retrospective came from the Focus Group convened by the Outfall Monitoring Task Force (in December 1996) to discuss issues surrounding the monitoring of the zooplankton communities in the Bays and as a forage resource for the right whale. It was concluded that three main issues be addressed: 1) "Identify all relevant zooplankton data from region", 2) "Use all comparable data to distinguish Cape Cod Bay from other areas, if possible" (and identify any regional differences), and 3)"Establish a longer and broader baseline data set for Cape Cod Bay (CCB) than is presently available from only the MWRA monitoring". The Zooplankton Retrospective addresses these issues.

Statistical analyses were conducted following guidance provided by Drs. Andrew Solow and Cabell Davis of Woods Hole Oceanographic Institution (WHOI). Three main conclusions were established: 1) Cape Cod Bay and nearshore Massachusetts Bay have a similar zooplankton assemblage, 2) patches appear to be higher concentrations of the ambient species rather than of one species, and 3) it is not known whether patch formation is unique to Cape Cod Bay.

APPENDIX A
Attendance

1998 MWRA/ENSR Workshop Attendees

February 18, 1998
Water Column

Name	Organization
Mike Mickelson	MWRA
Steve Cibik	ENSR
Wendy Leo	MWRA
David Dow	NMFS/NEFSC
Craig Taylor	WHOI
Mel Higgins	ENSR
Don Galya	ENSR
Mark Gerath	ENSR
Peter Ralston	MWRA
Jessica Morton	ENSR
Stephanie Kelly	ENSR
Joan Tracey	ENSR
Jim Blake	ENSR
Gavin Gong	ENSR
Jennifer Sullivan	ENSR
Julie Early	MWRA
David Borkman	URI/GSO
Cathy Coniaris	OMTF Asst.
Doug Hersh	MWRA
Jeff Simpson	
Kelly Coughlin	MWRA
Josh Lieberman	ENSR
Anne Giblin	MBL
Jeff Rosen	TPMC
Ed Shoncair	Planners
Collaborative	
Russ Gaulin	ENSR
Matthew Liebman	EPA Regional
Eugene D. Gallagher	UMass/Boston
Jennifer Chiapella	ENSR
Peggy Murray	SAIC
Carlton Hunt	Battelle
Brad Butman	USGS
Kristyn Lemieux	ENSR
Norb Jaworski	Retired (EPA)
Rocky Geyer	WHOI
Jonathon Garber	USEPA
Christian Krahforst	MCZM
Bernie Gardner	UMass/Boston
Diane Gould	
Joseph Lobuglio	MWRA
(ENQUAD)	
Jim Fitzpatrick	HydroQual Inc.
Dave Tomey	EPA
Dave Mitchell	ENSR
Brian Howes	UMass/Dart.
Craig Taylor	WHOI

APPENDIX B
Overheads, Graphics and Presentations

APPENDIX B-1
Overview of Massachusetts Bay Systems: Steve Cibik

ENSR

Goals of Workshop

- Review Baseline Data
- Consider Available "Tools"
- Discuss Issues and Concerns
- Come to a Consensus on Issues
- Evaluate Thresholds and Monitoring Design

ENSR

Overview of Mass Bay and HOM Baseline

- Annual Cycle
- Baseline Results
- Issues
- Monitoring Thresholds

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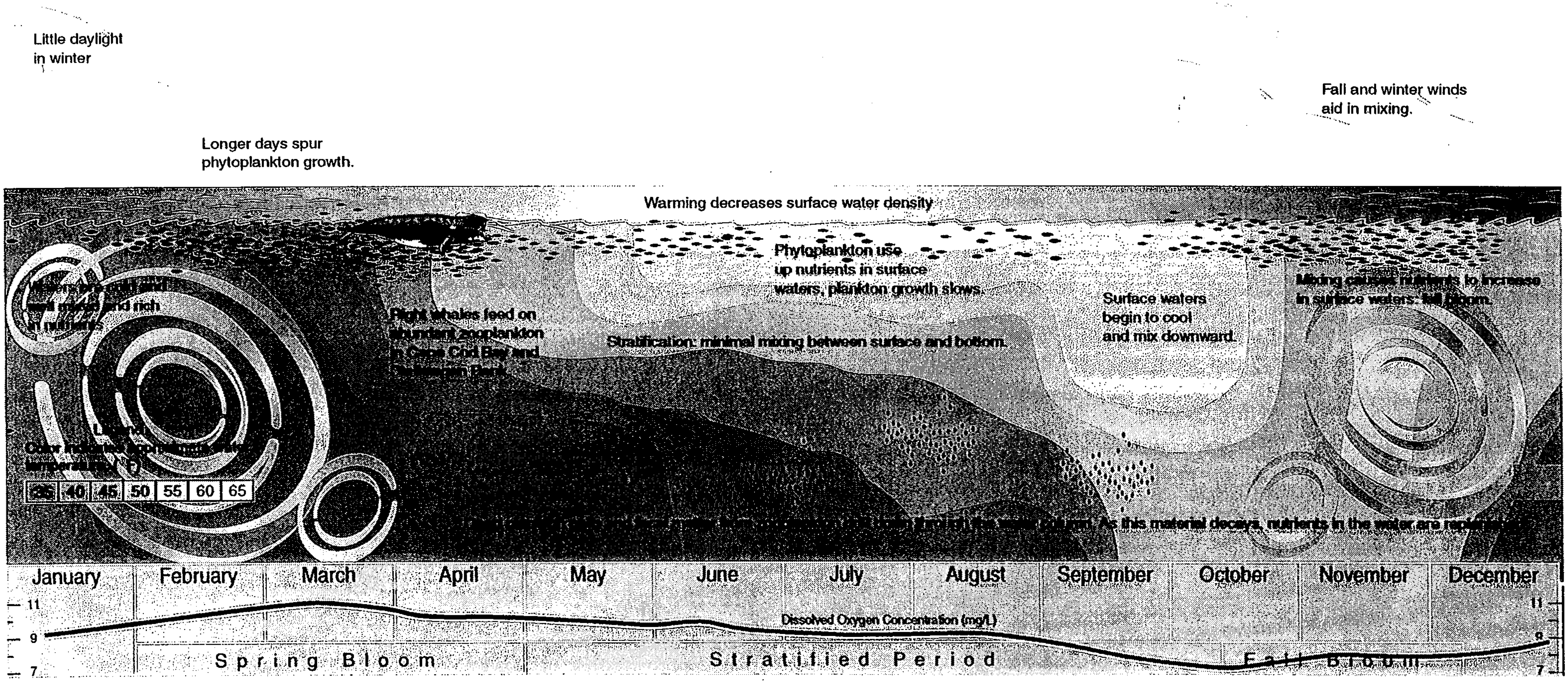
Mass Bay's Annual Cycle

- Winter Setup
  - Well-mixed water column
  - Ample nutrients
  - Light-limited primary production
- Spring Bloom
  - System-wide, but not synchronized
  - Diatom assemblage typical
  - Nutrients frequently stripped from water column

Mass Bay's Annual Cycle (Cont'd)

- **Stratified Period**
  - Late Spring through early Fall
  - Strong pycnocline = bilayered water column
  - Productive surface mixed-layer
  - Bottom layer DO typically declines, nutrients increase
- **Fall Turnover**
  - Caused by cooling surface water and wind
  - Released bottom water nutrients trigger fall bloom
  - Diminishing light terminates bloom



Little daylight in winter
Longer days spur phytoplankton growth.
Fall and winter winds aid in mixing.
Warming decreases surface water density
Phytoplankton use up nutrients in surface waters, plankton growth slows.
Right whales feed on abundant zooplankton
Stratification: minimal mixing between surface and bottom.
Surface waters begin to cool and mix downward.
Mixing causes nutrients to increase in surface waters: fall bloom.
As this material decays, nutrients in the water are replenished.
35 40 45 50 55 60 65
January February March April May June July August September October November December
Dissolved Oxygen Concentration (mg/L)
11
9
7
Spring Bloom
Stratified Period
Fall Bloom

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Overview of Baseline Monitoring Results

- Summary of Monitoring Protocol
- 1992-1997 Results Show:
  - Highly variable system
  - Complexity of interactions between physical, chemical, and biological processes
  - Each year has had at least one "signature event"
  - How fortunate we are to have six years of baseline data

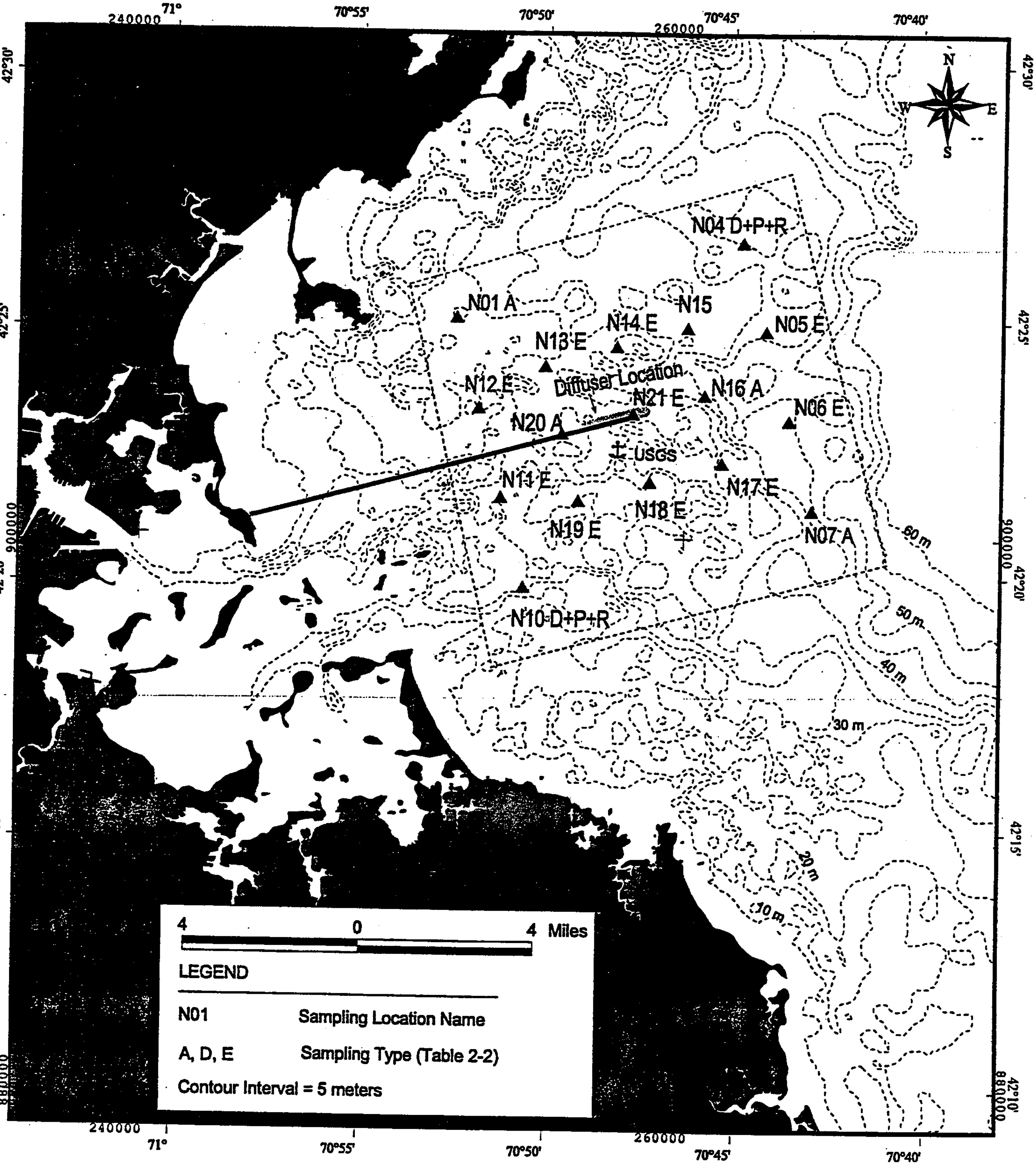
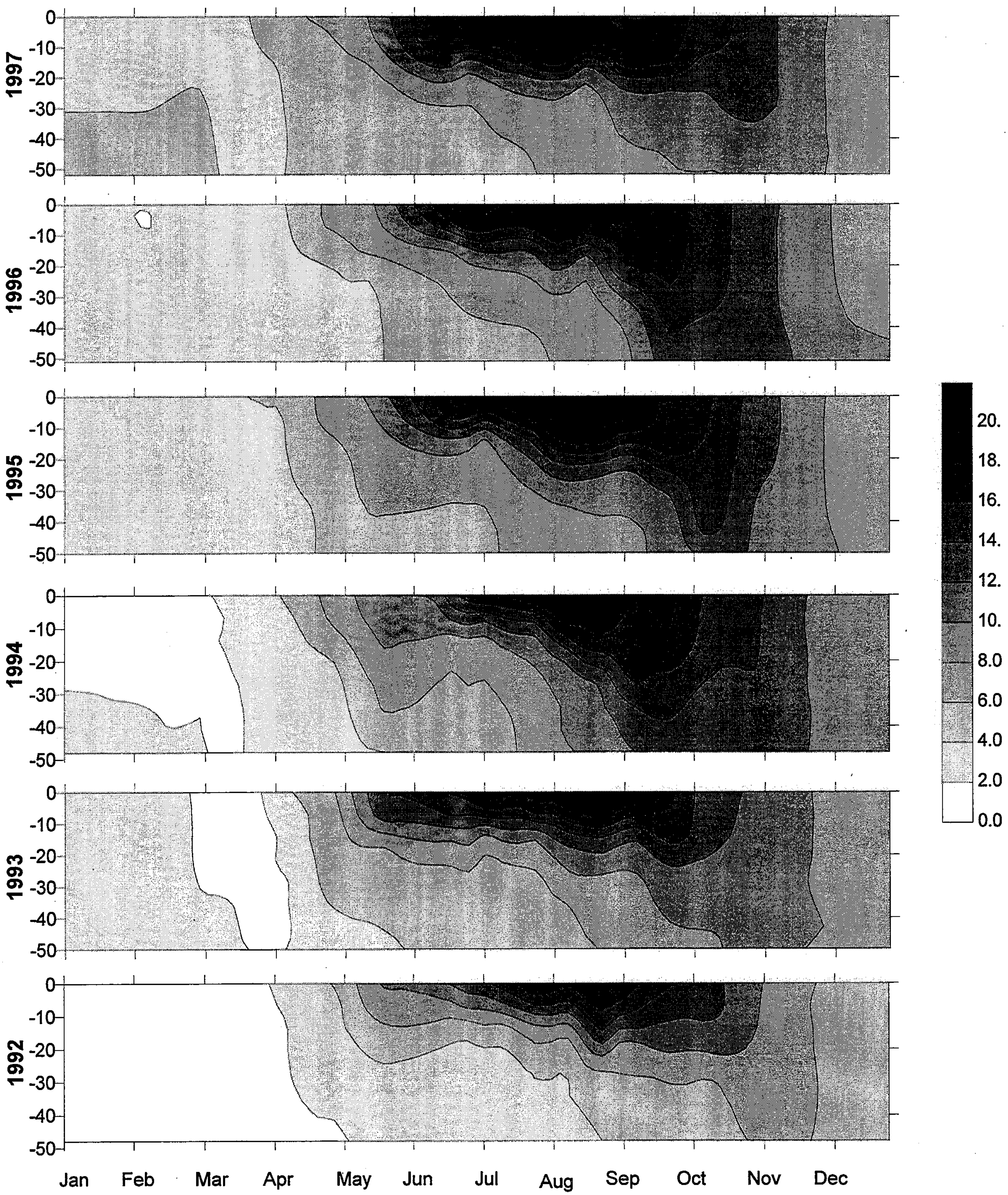


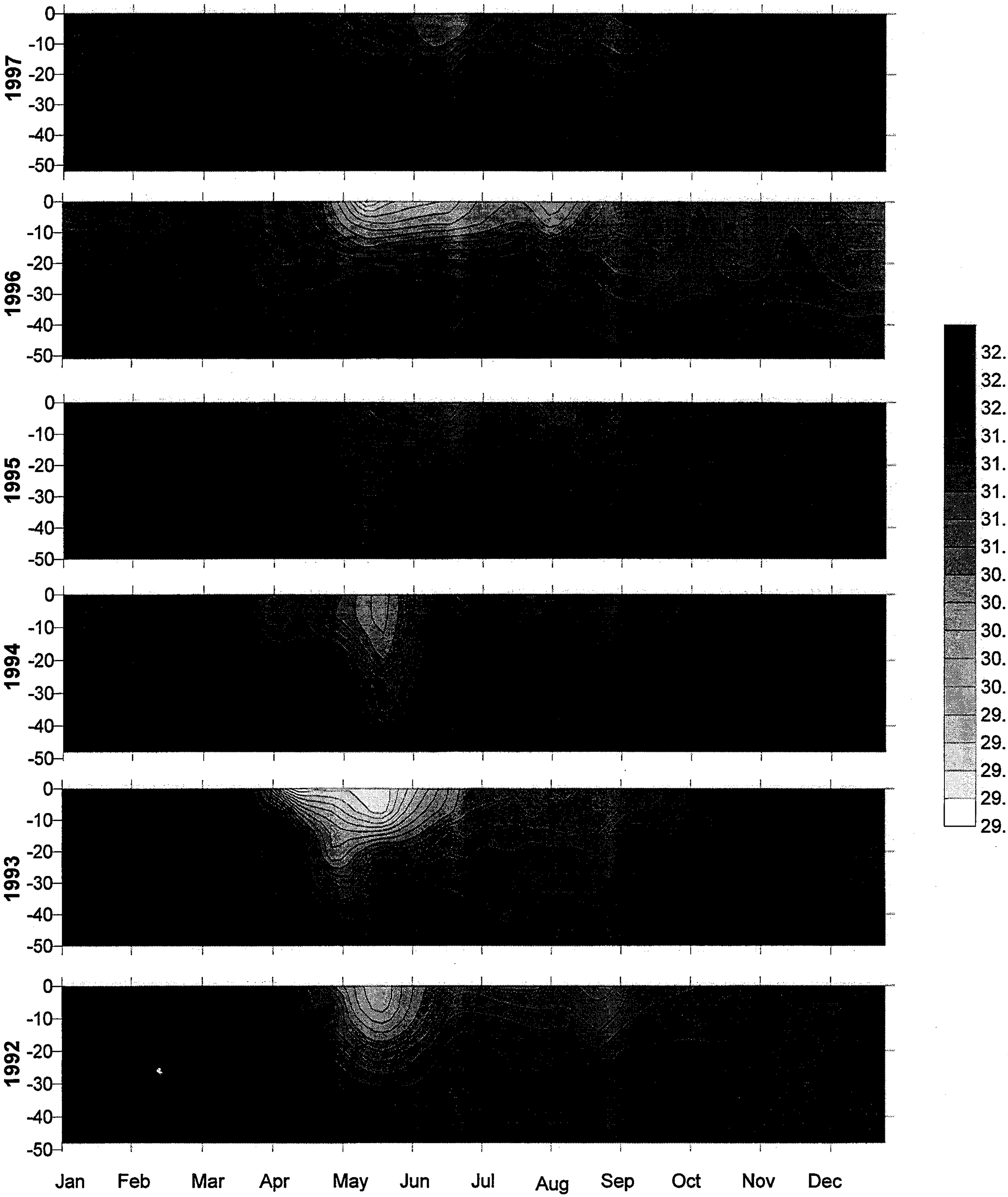
FIGURE 1-1

Location of Nearfield Stations

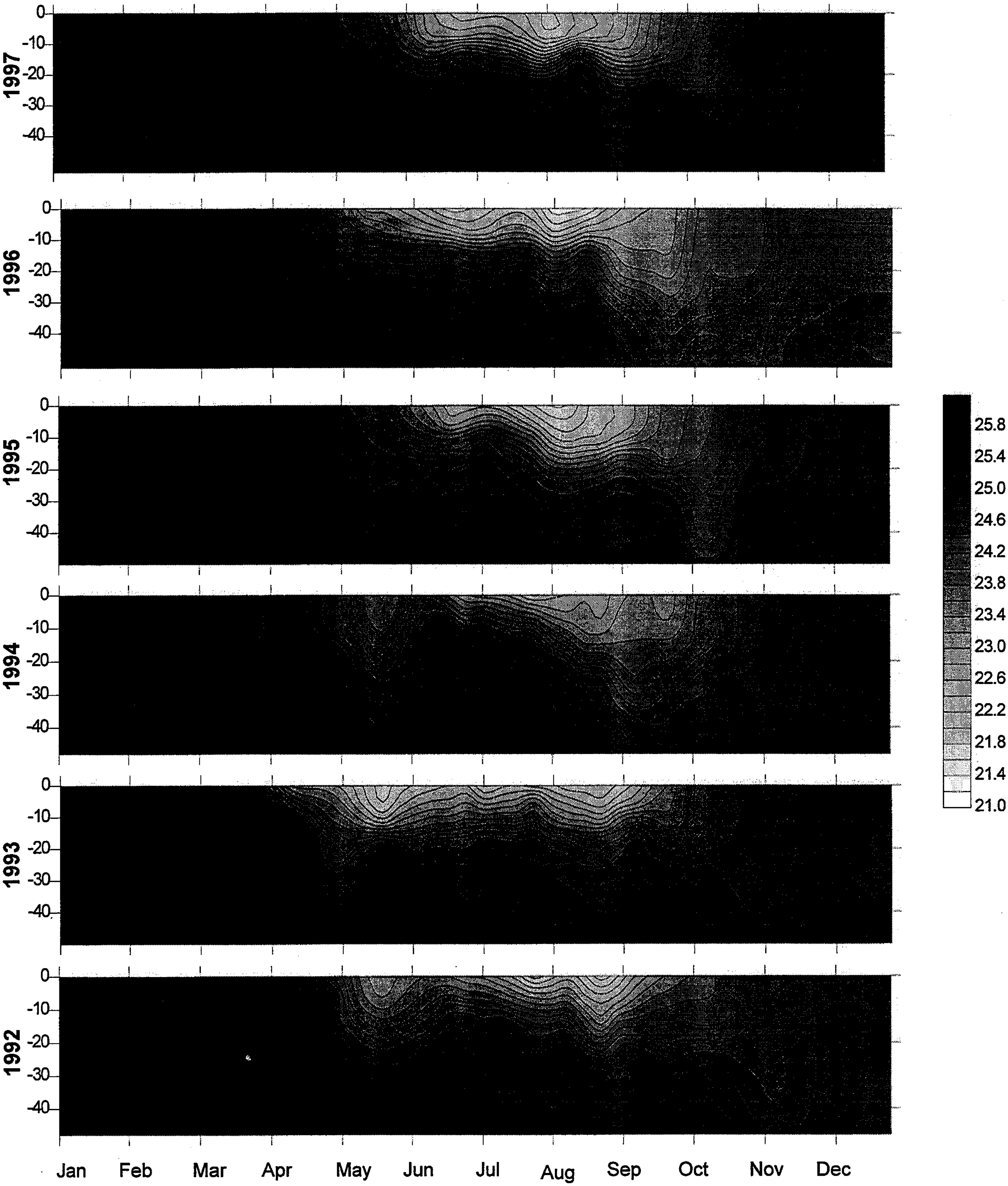
Temperature at N04, N07, N16, N20
(Degrees Celsius)



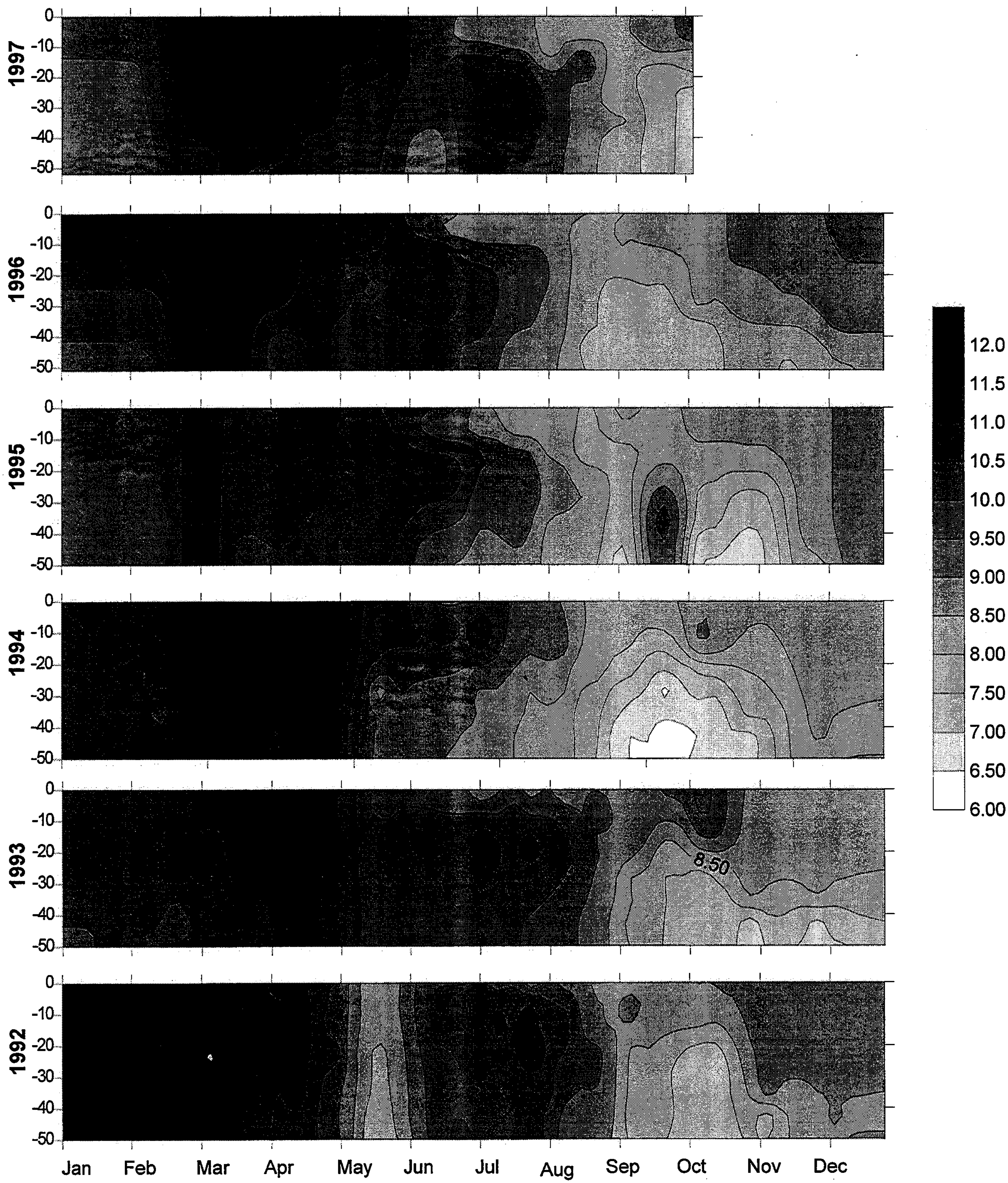
Salinity at N04, N07, N16, N20
(psu)



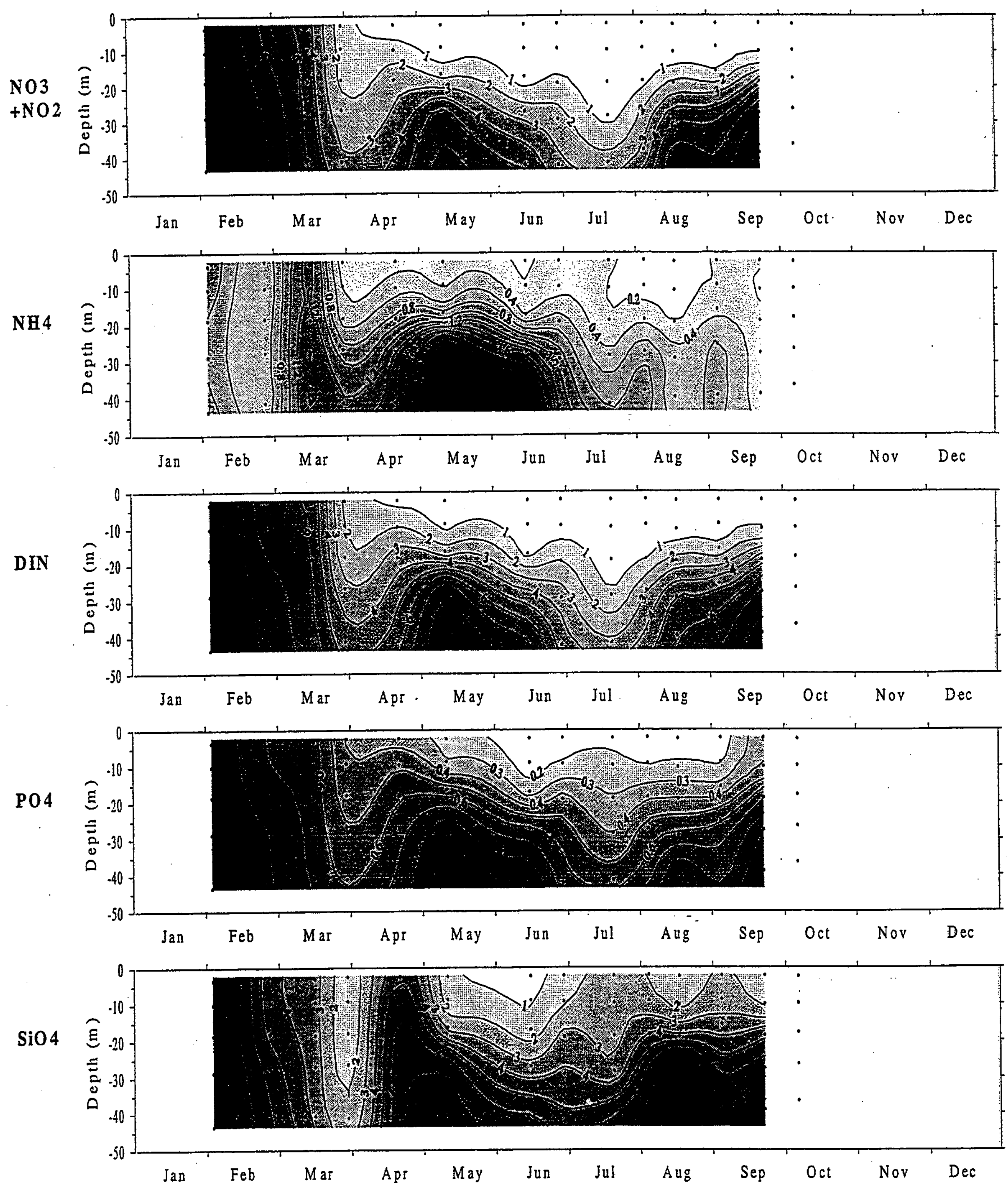
Density at N04, N07, N16, N20
(Sigma-T, kg/m3)



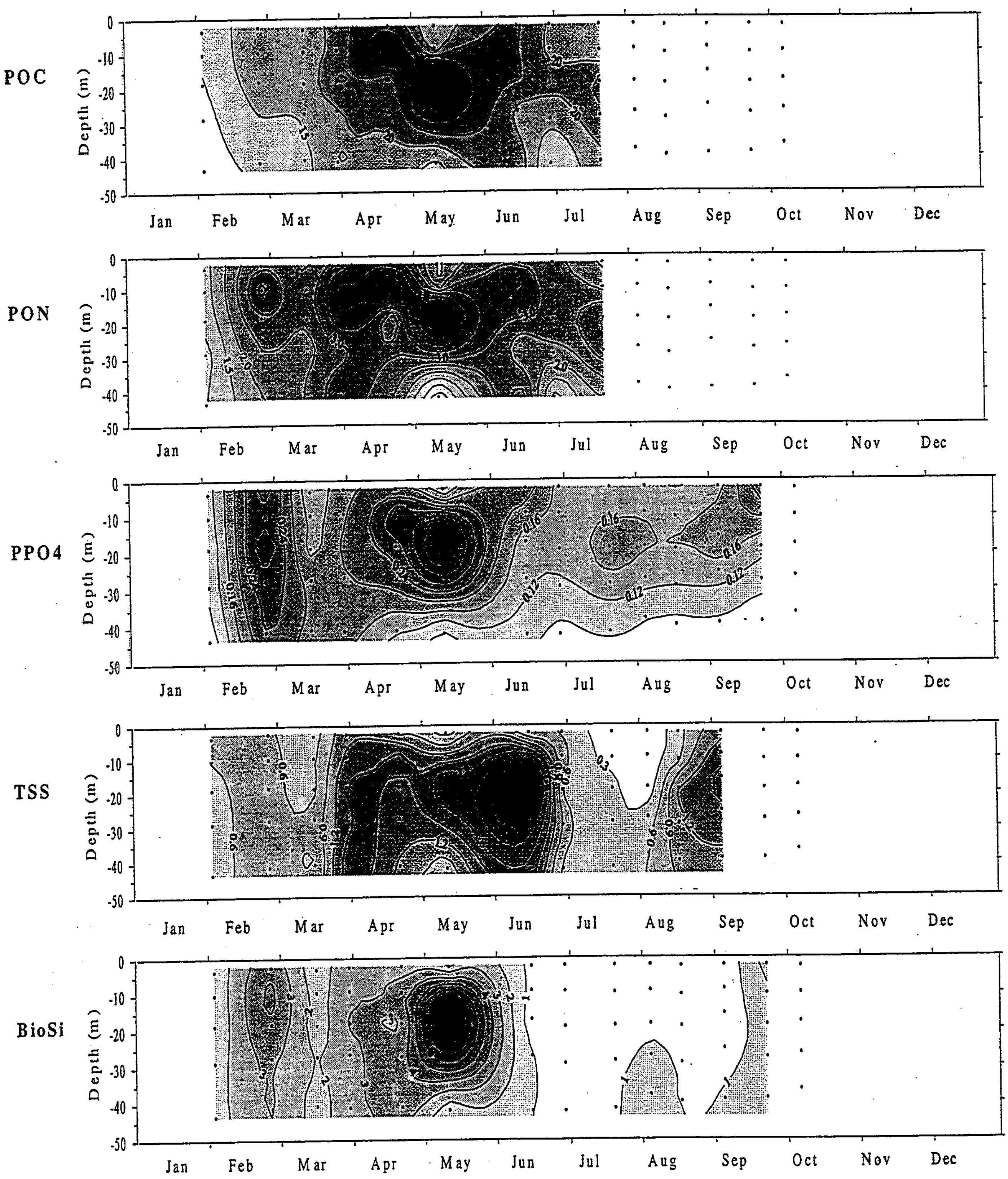
Dissolved Oxygen at N04, N07, N16, N20
(mg/L)



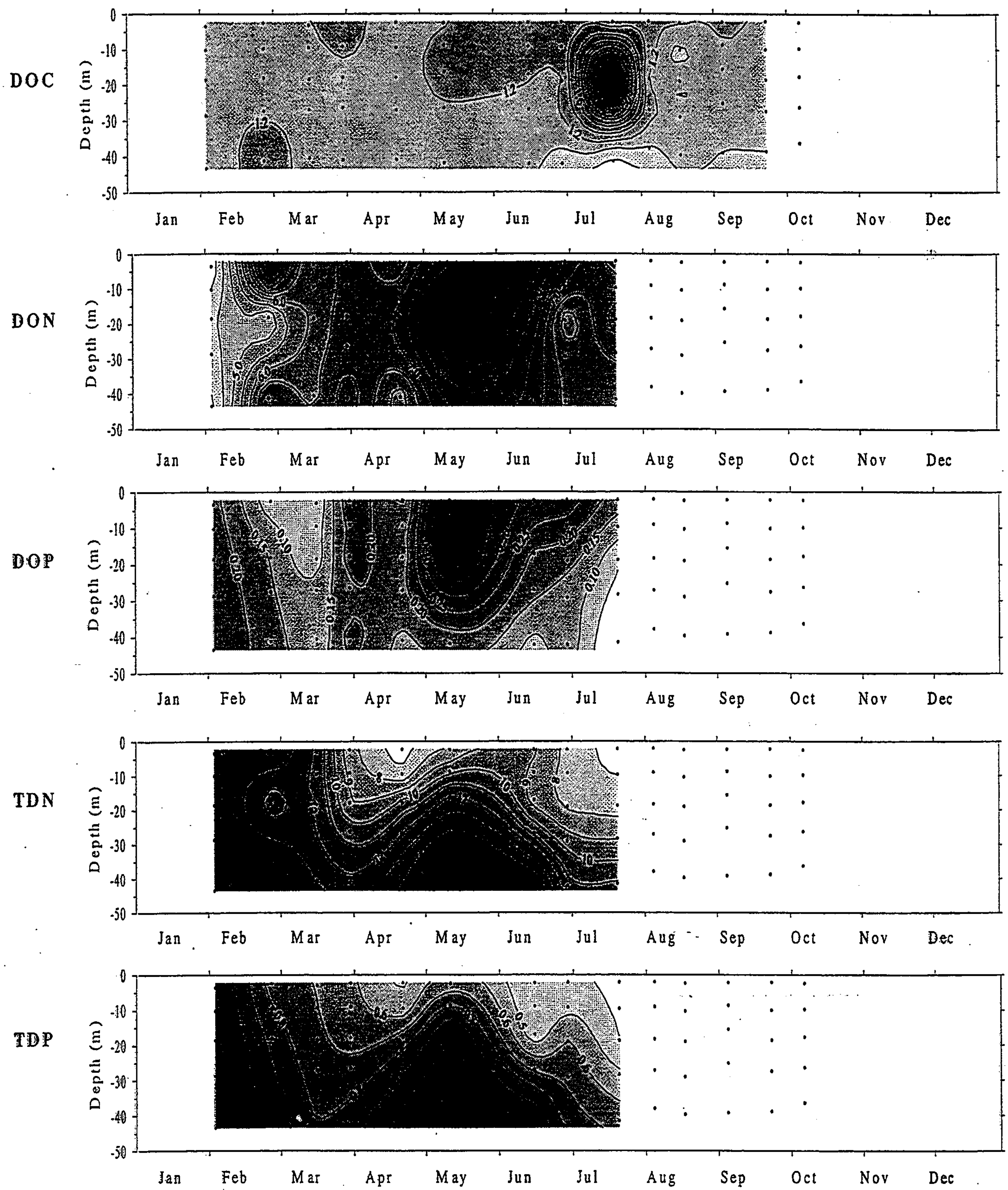
1997 Nearfield (N04, N07, N16, N20)



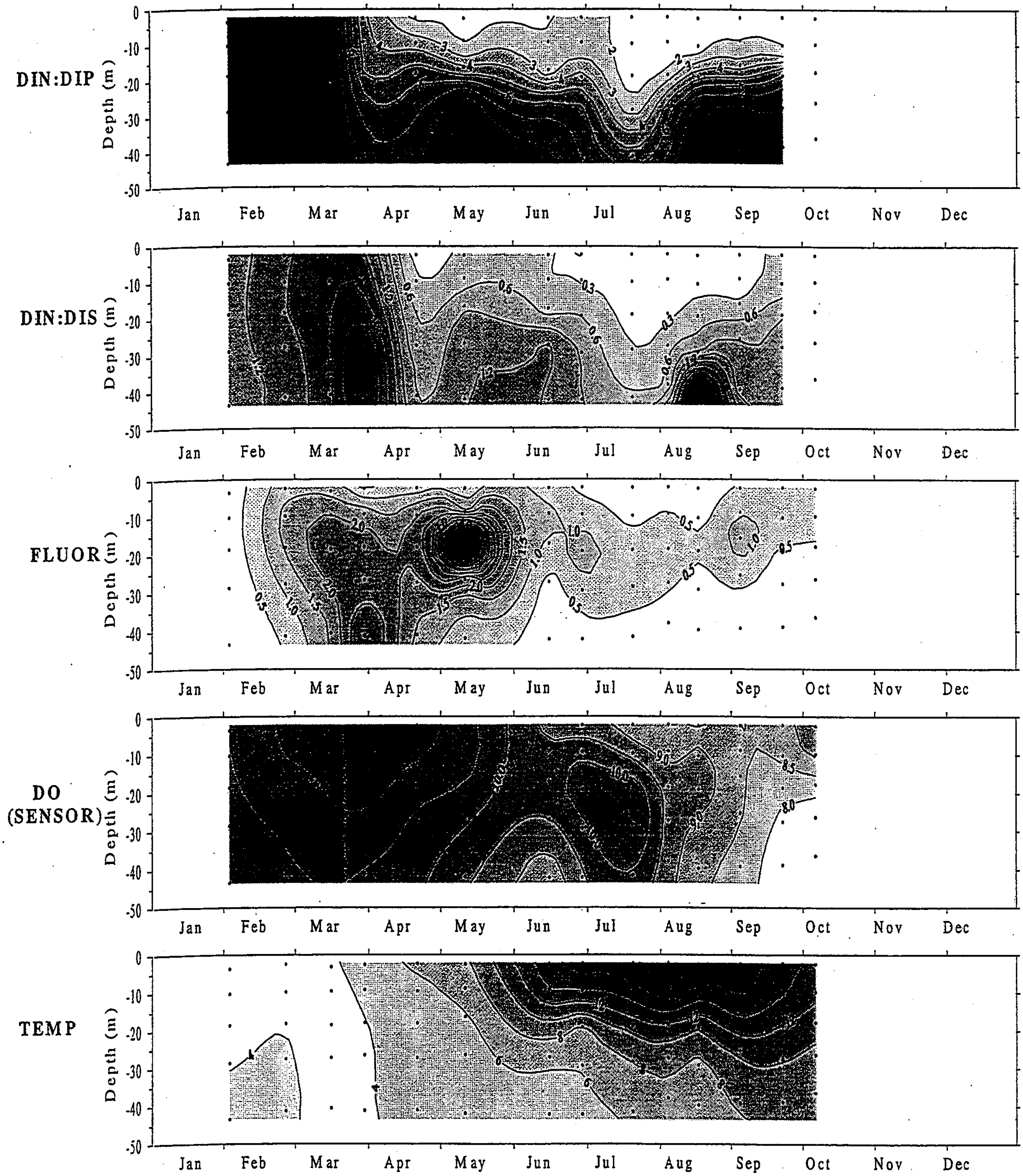
1997 Nearfield (N04, N07, N16, N20)



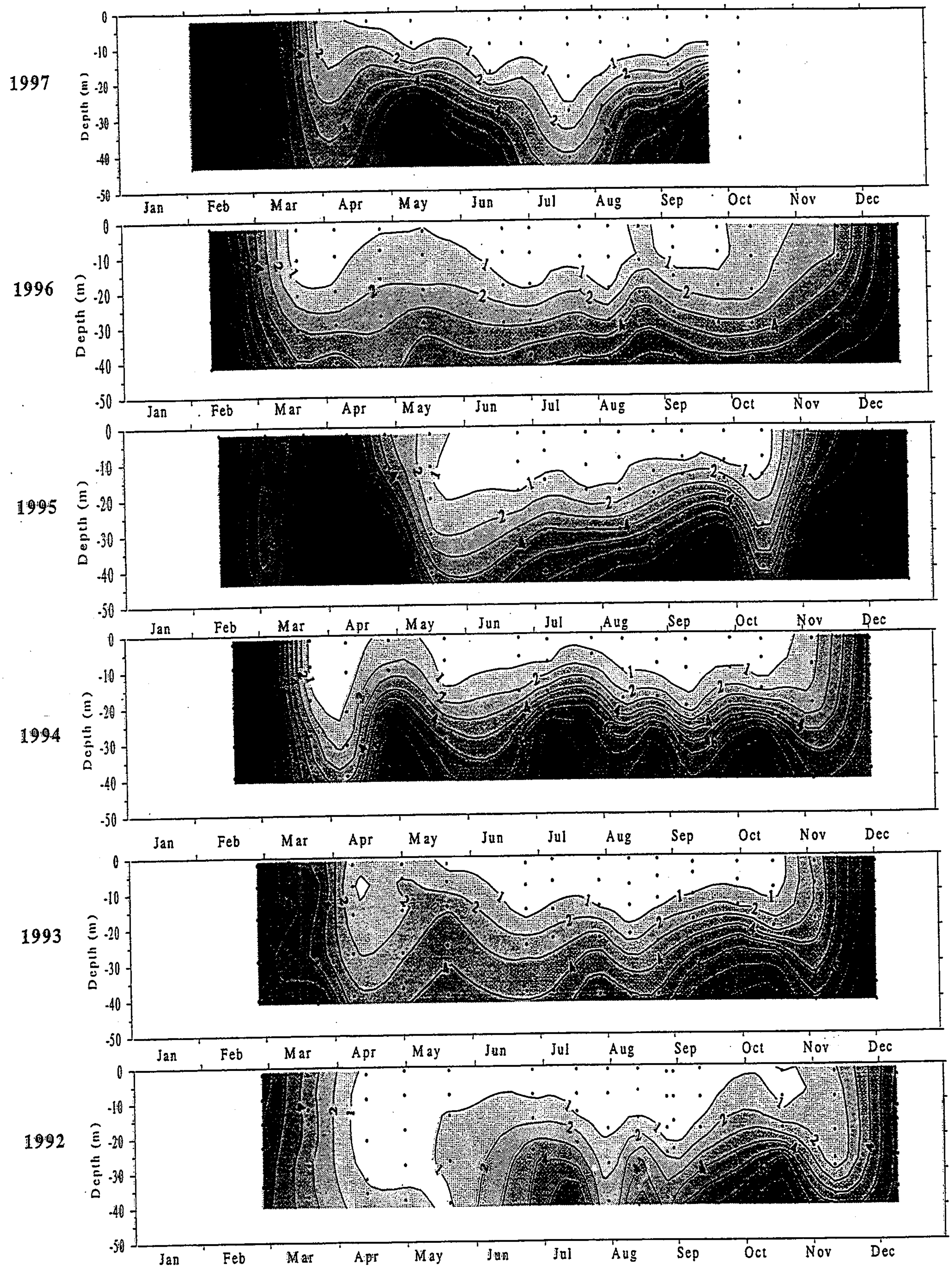
1997 Nearfield (N04, N07, N16, N20)



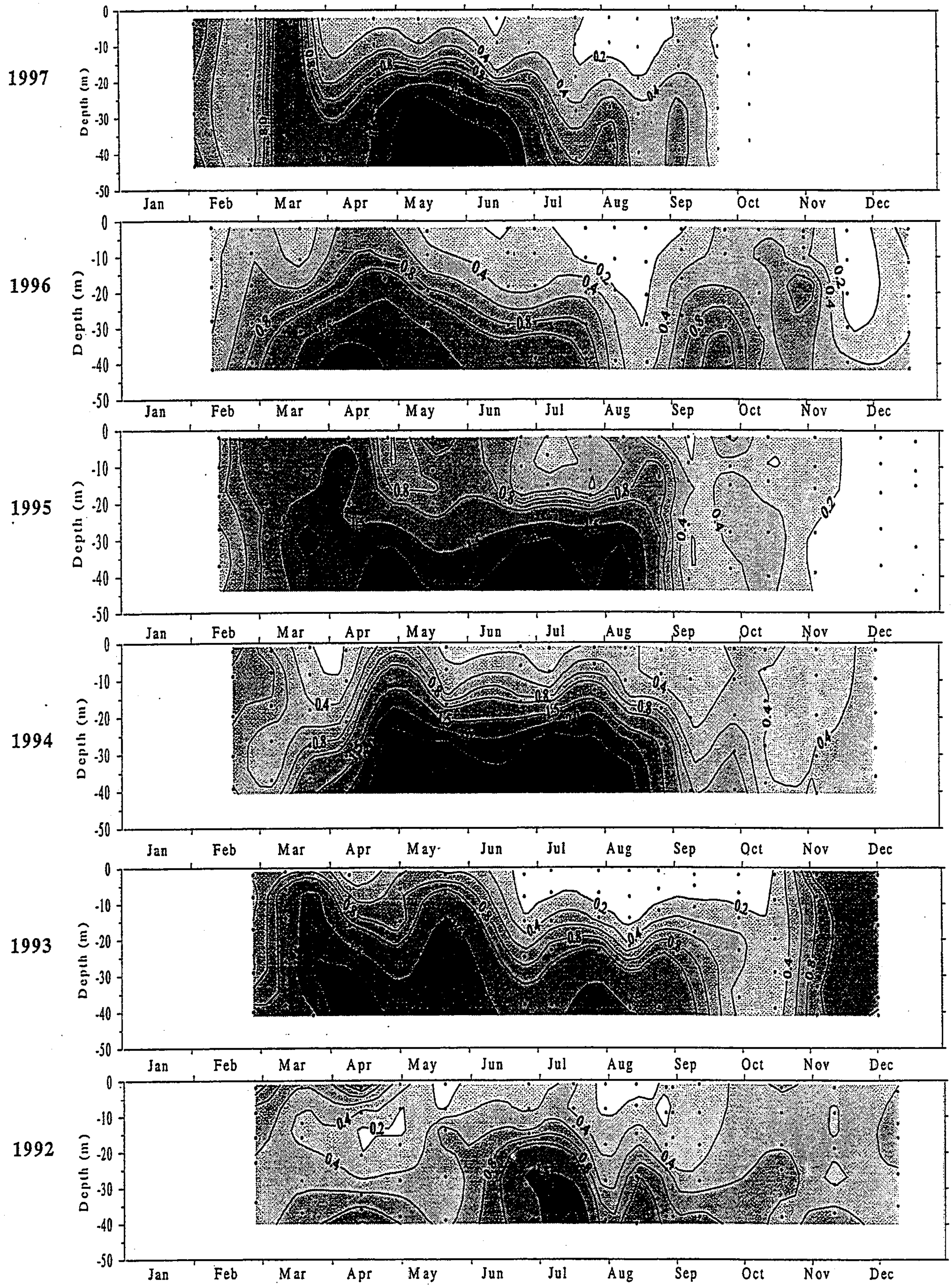
1997 Nearfield (N04, N07, N16, N20)



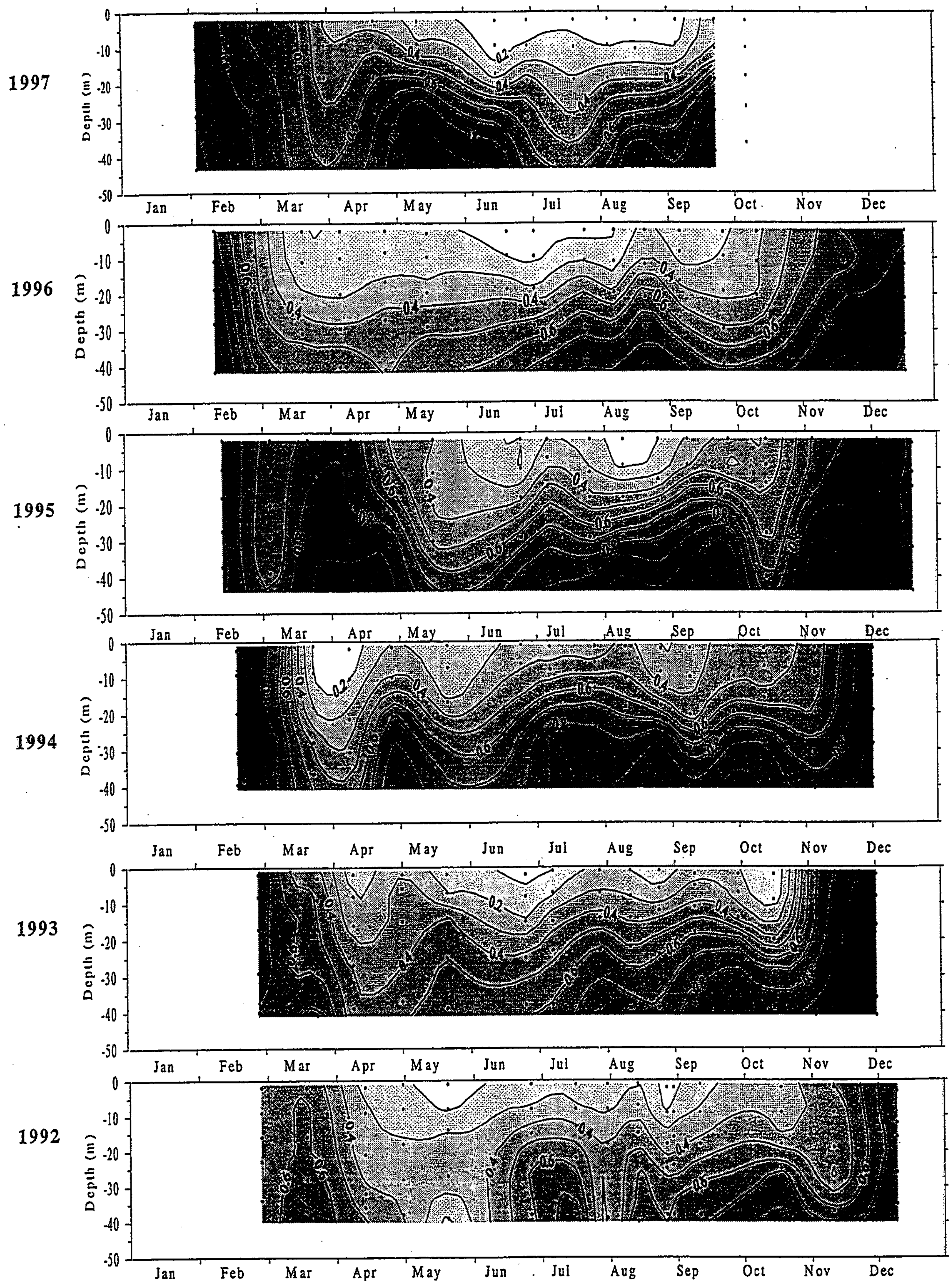
1992-1997 Nearfield (N04, N07, N16, N20)
DIN (Nitrate + Nitrite + Ammonium) (µM)



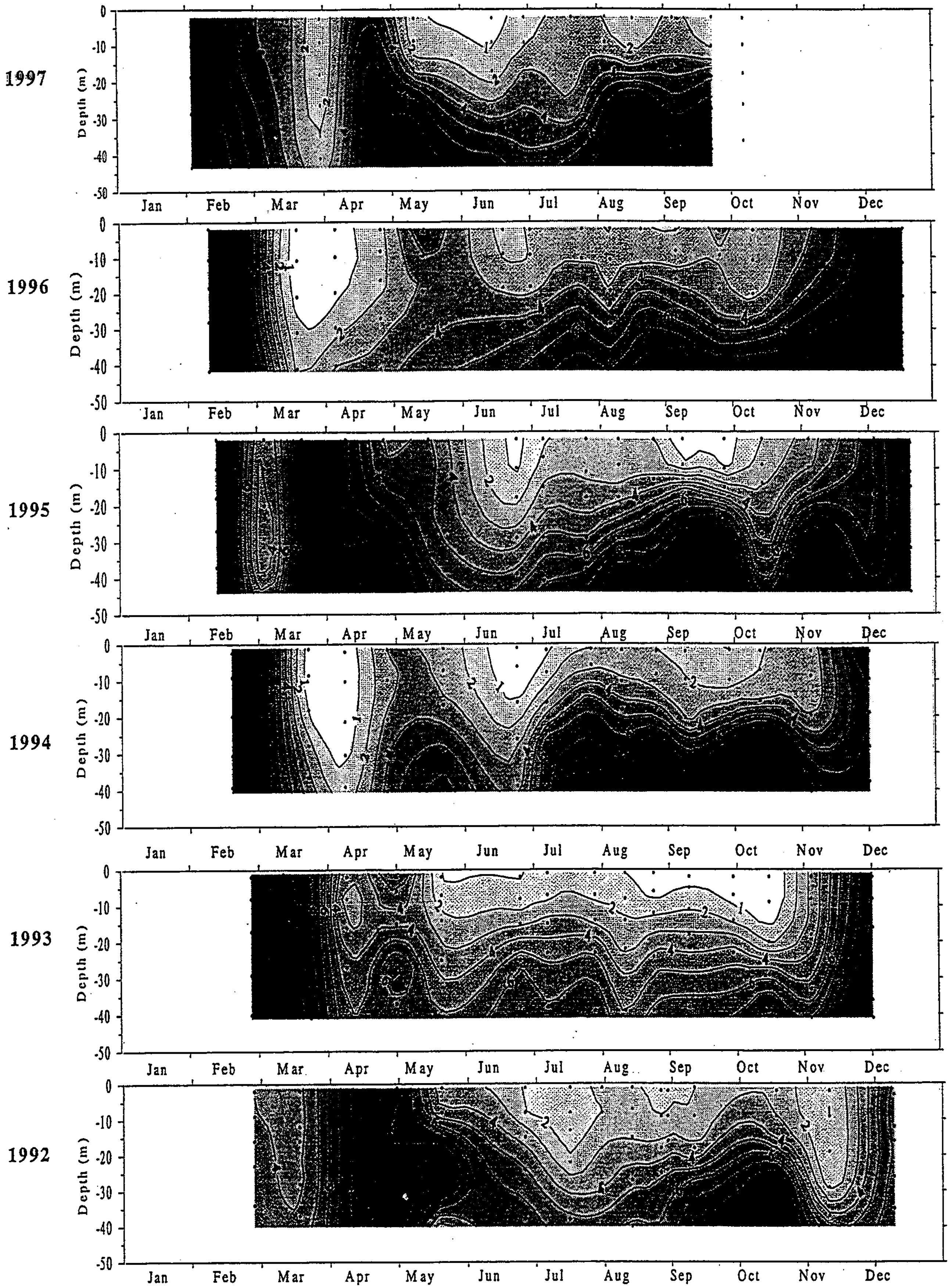
1992-1997 Nearfield (N04, N07, N16, N20) Ammonium (µM)



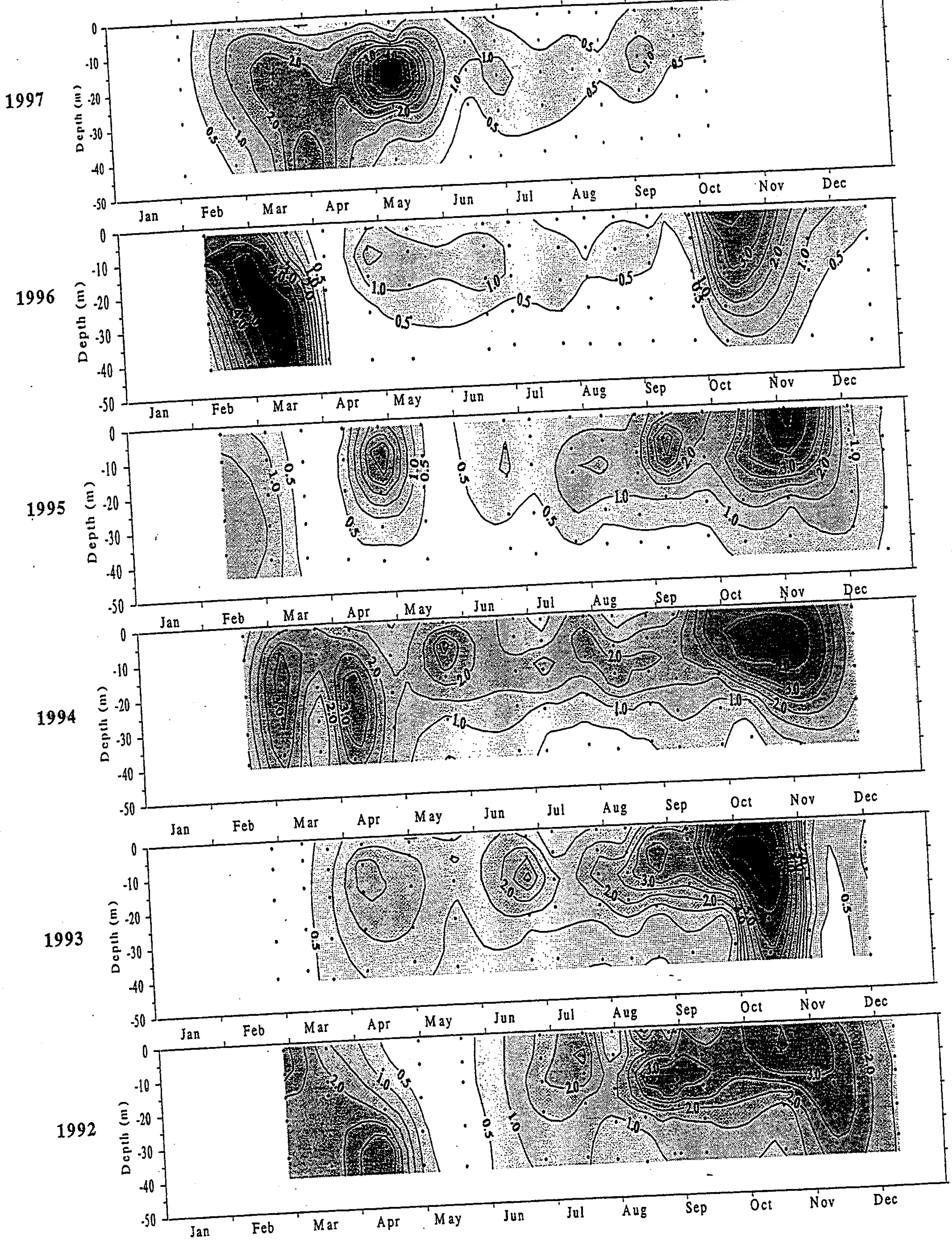
1992-1997 Nearfield (N04, N07, N16, N20)
Phosphate (μM)



1992-1997 Nearfield (N04, N07, N16, N20)
Silicate (µM)



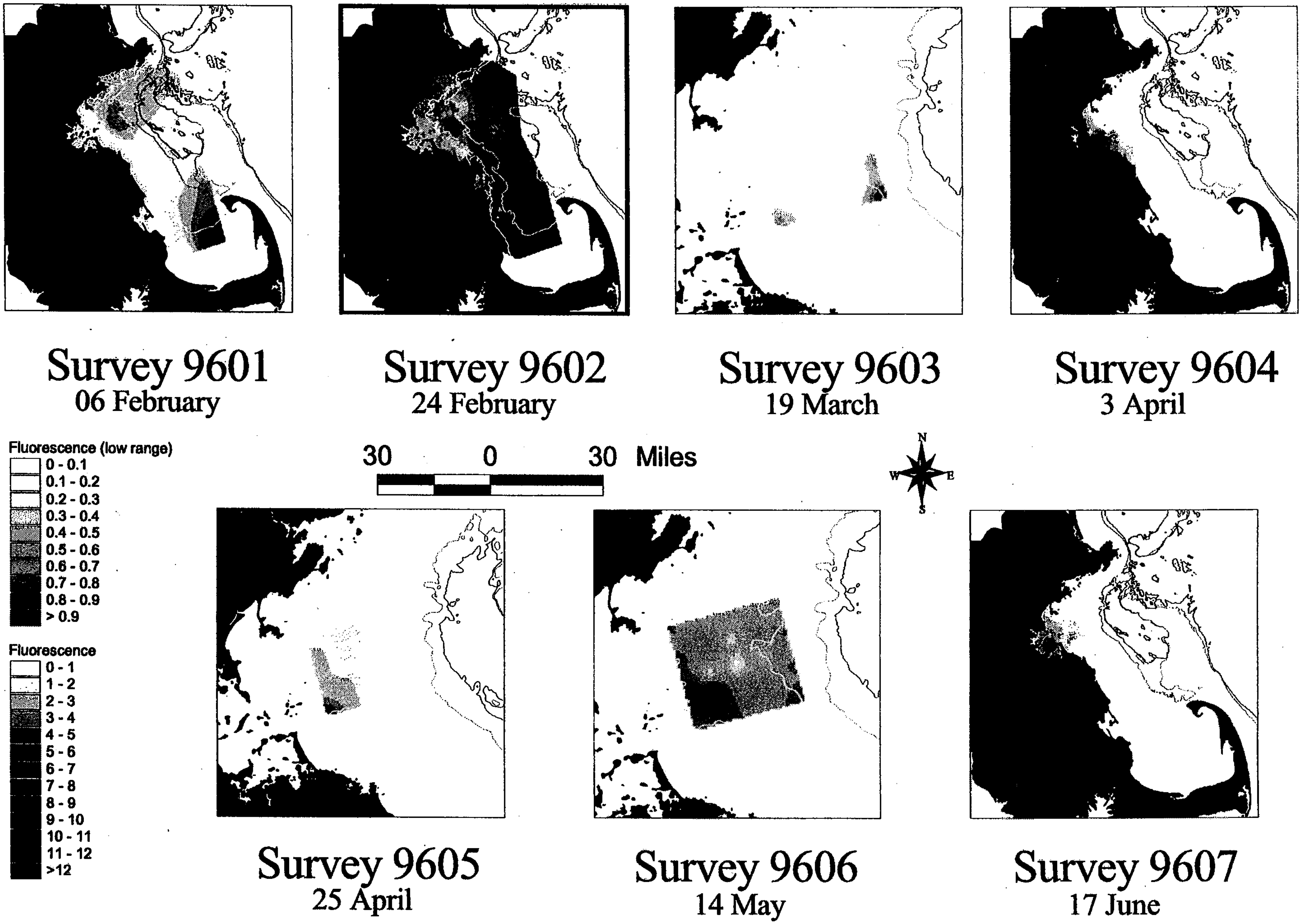
1992-1997 Nearfield (N04, N07, N16, N20)
Fluorescence (µg/l)



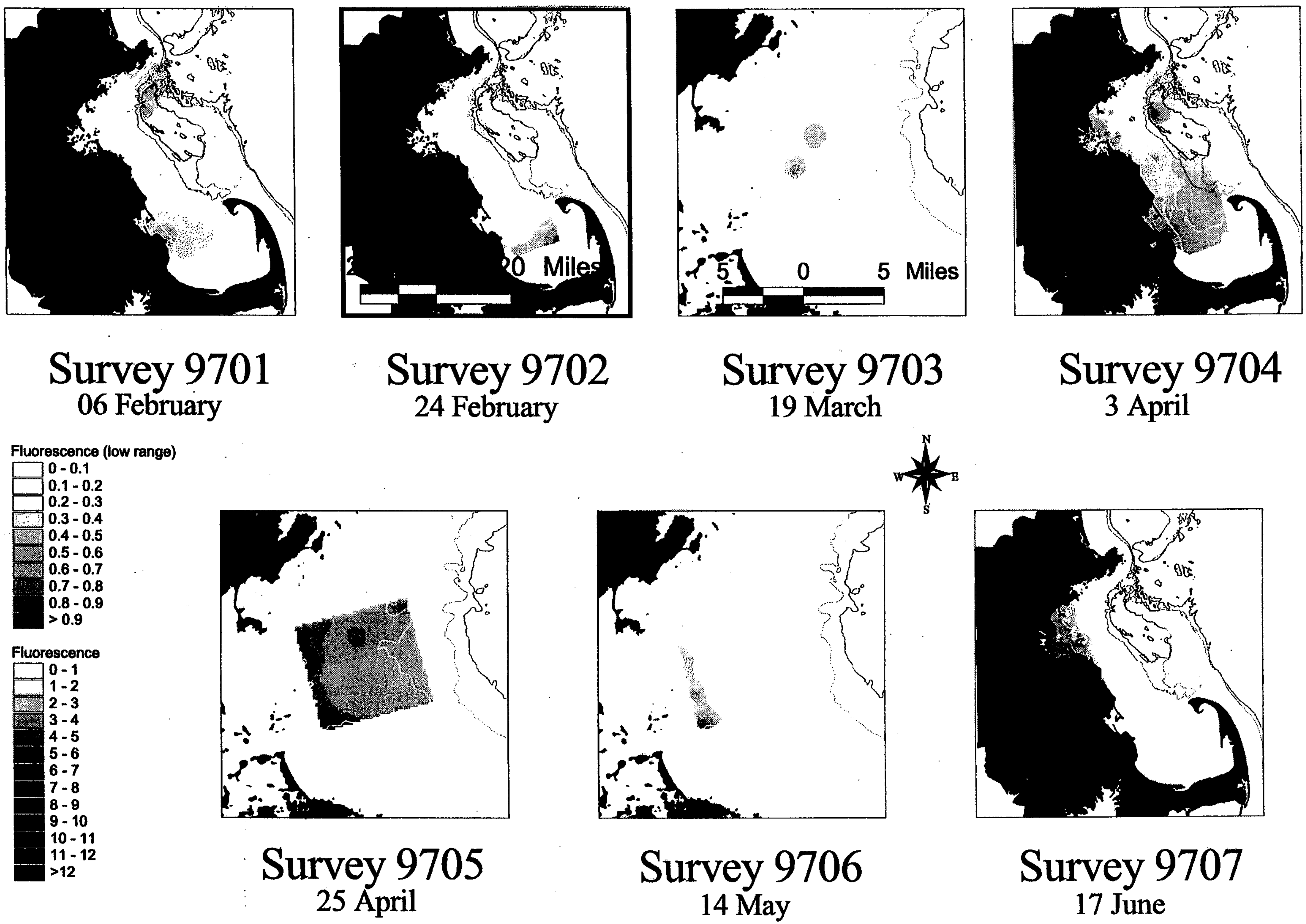
Variability (Cont'd) - Spring Bloom

- 1996 and 1997 = Excellent Contrast
  - 1996 "biggest" bloom of baseline period
  - Widespread centric diatom bloom (>2.5Mcells/L)
  - 1997 "pale" by comparison (centrics only 10% of '96 densities)
  - 1997 had ca. 50% more POC!? Why? *Phaeocystis pouchetii* bloom
- What's the Difference?

MWRA Baseline Monitoring Program
Progression of the Spring Bloom - 1996

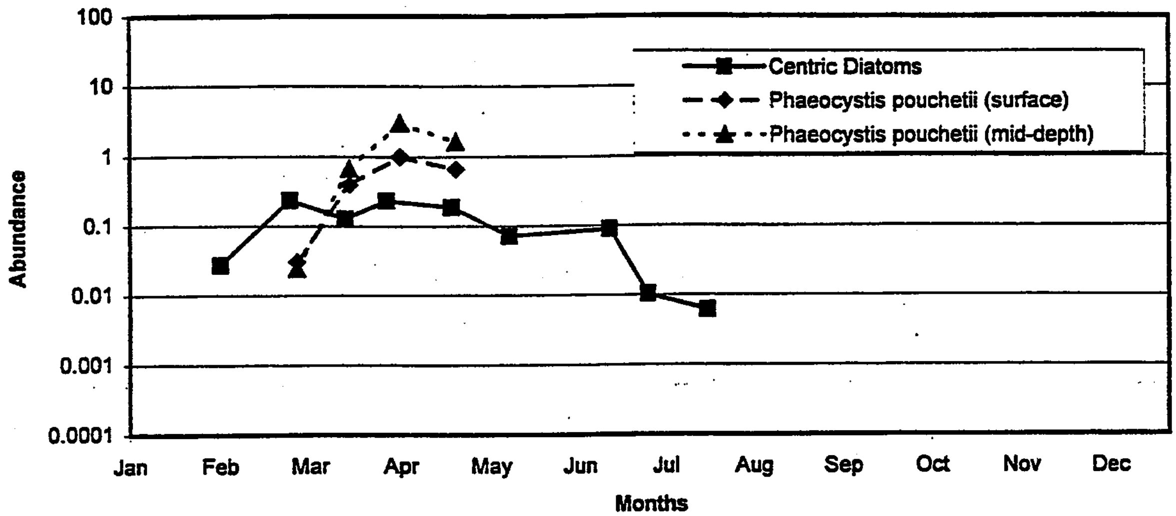


MWRA Baseline Monitoring Program
Progression of the Spring Bloom - 1997

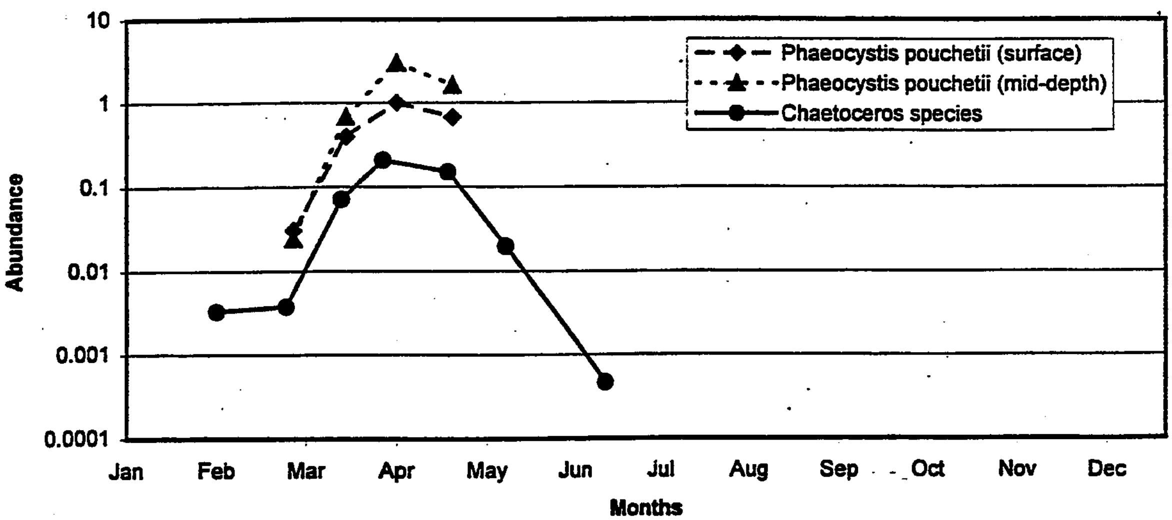


Variability (Cont'd) - *Phaeocystis* vs. Diatoms

- **Both Resource- and Predator-Based Controls**
  - Nutrient concentrations (N [primarily NO_3], P and S) and ratios
  - Light (both from buoyancy and relative photoefficiency)
  - Differential grazing pressure (relative size distributions of *Phaeocystis*, presence of overwintering meso- and meta-zooplankton)
  - Co-occurrence with certain diatom species?
- **Implications on carbon cycling and fate**
  - Water column recycling vs. sedimentation



Centric Diatoms and *Phaeocystis pouchetii* succession observed in Massachusetts Bay (Station N04) during 1992, 1996 and 1997



***Chaetoceros* species and *Phaeocystis pouchetii* succession observed in Massachusetts Bay (Station N04) during 1992, 1996 and 1997**

Variability (Cont'd) - Dissolved Oxygen

- "Unpredictable" Bottom Water DO
- 1994 and 1995 "worst" DO years
- 1992, 1996, and 1997 had "bad starts"
- 1997 was an interesting experience..........

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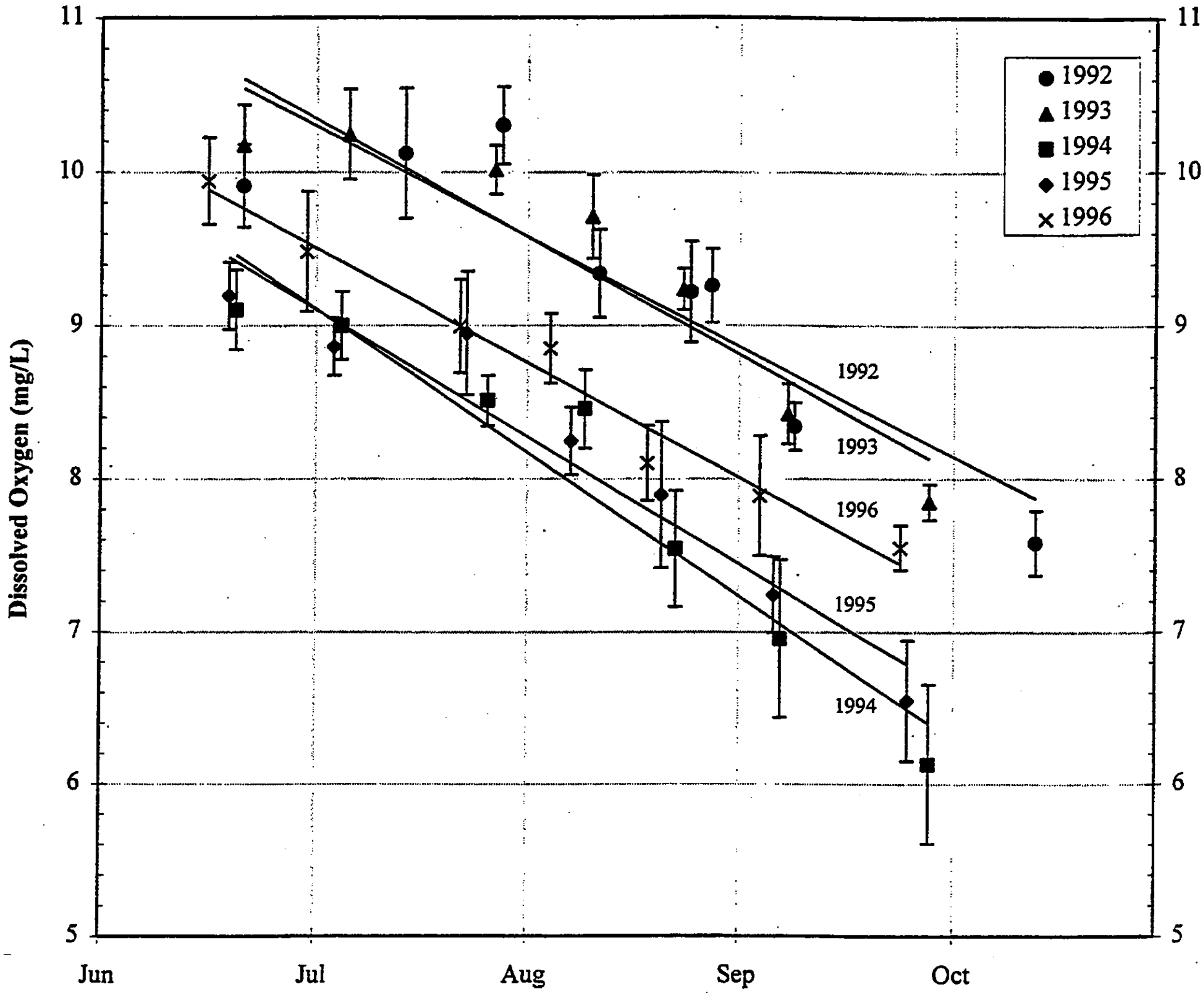
Variability (Cont'd) - 1997 Dissolved Oxygen

- Lots of carbon from Phaeocystis bloom
- High respiration
- Relatively warm bottom water
- Decided to predict annual minima for NF and SB
- Moral is: system still has a few surprises left

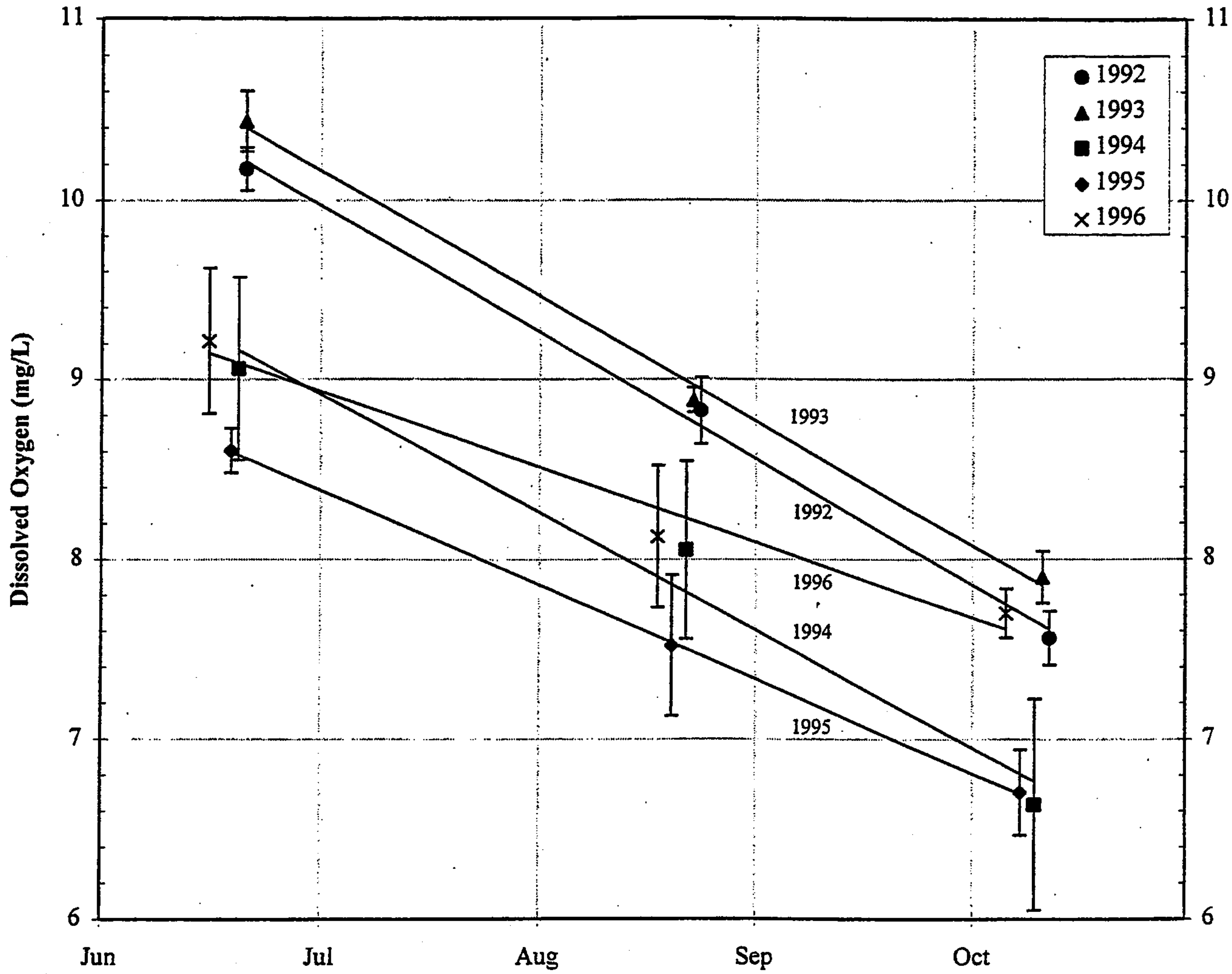


Year	Slope (mg/L/day)	Intercept* (mg/L)	R^2
1992	-0.024	11.0	0.808
1993	-0.025	11.1	0.885
1994	-0.031	10.1	0.929
1995	-0.027	9.9	0.932
1996	-0.025	10.3	0.978
* Predicted DO on June 1st based on: DO = Slope * Date + Intercept			

FIGURE 6-3

Nearfield Dissolved Oxygen Concentrations in Bottom Waters

Symbols indicate the mean of 17 nearfield stations; error bars represent +/- one standard deviation.

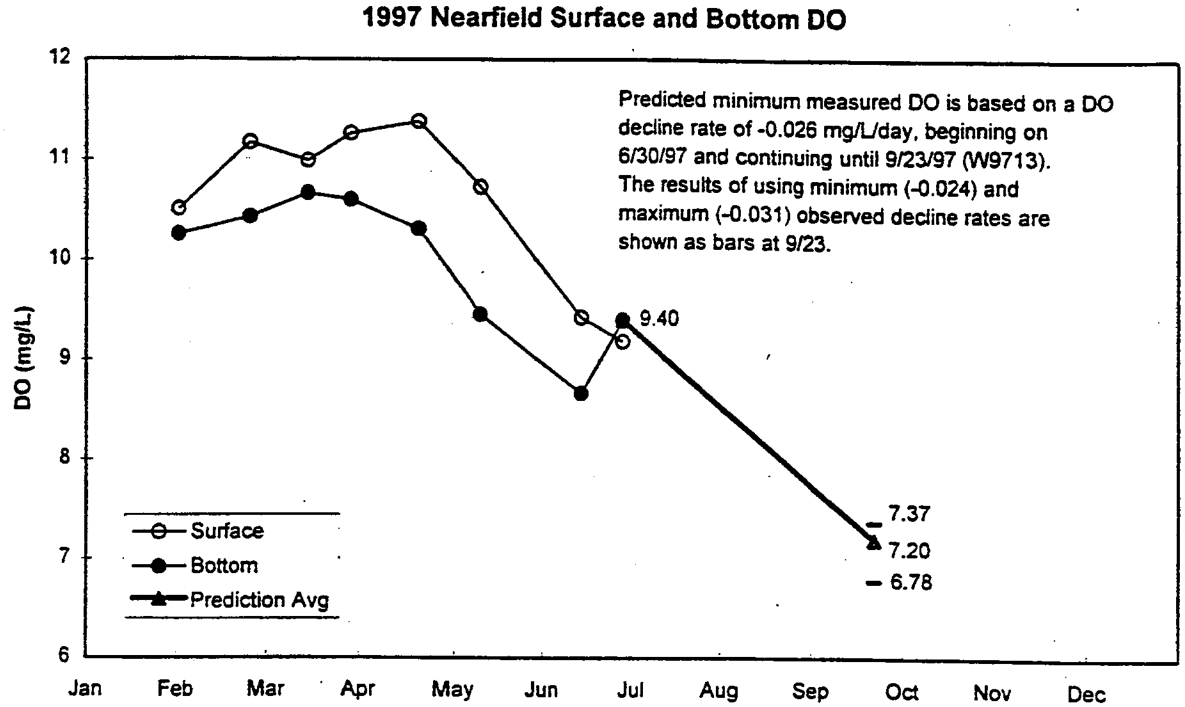


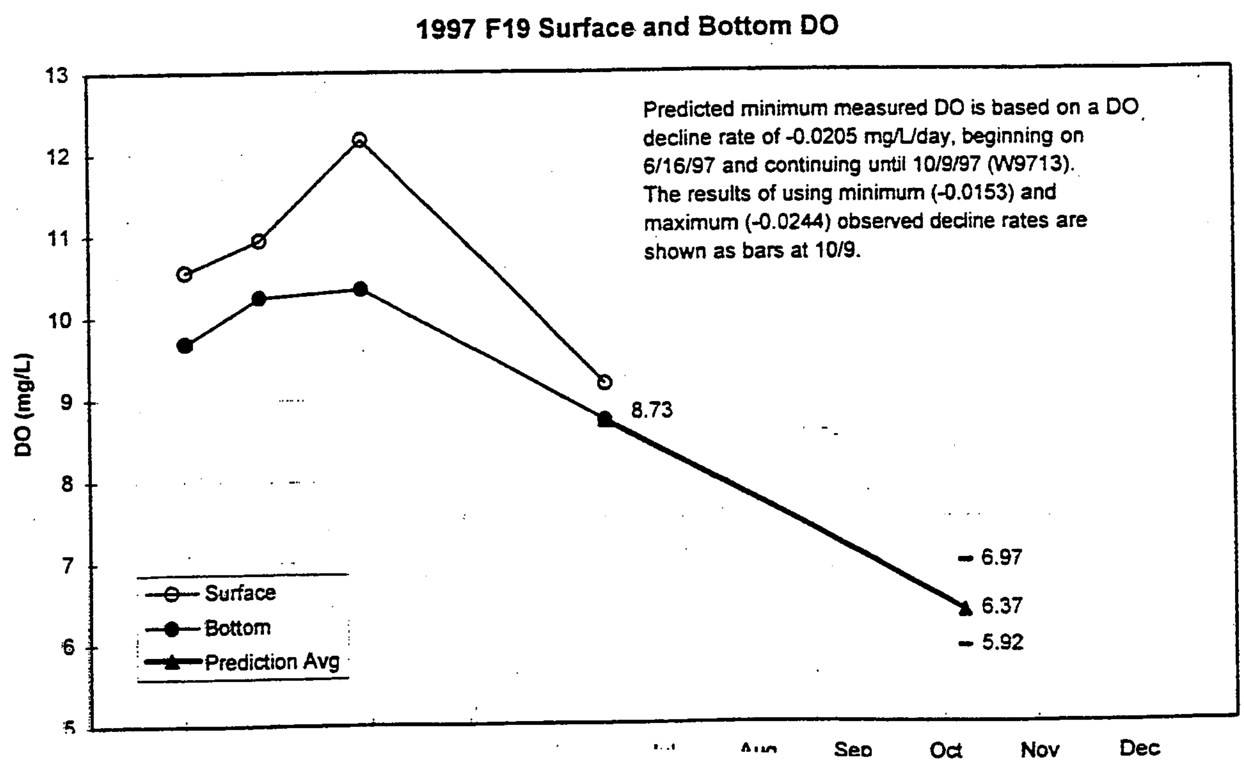
Year	Slope (mg/L/day)	Intercept* (mg/L)
1992	-0.023	10.7
1993	-0.023	10.9
1994	-0.021	9.6
1995	-0.017	8.9
1996	-0.014	9.4
* Predicted DO on June 1st based on: DO = Slope * Date + Intercept		

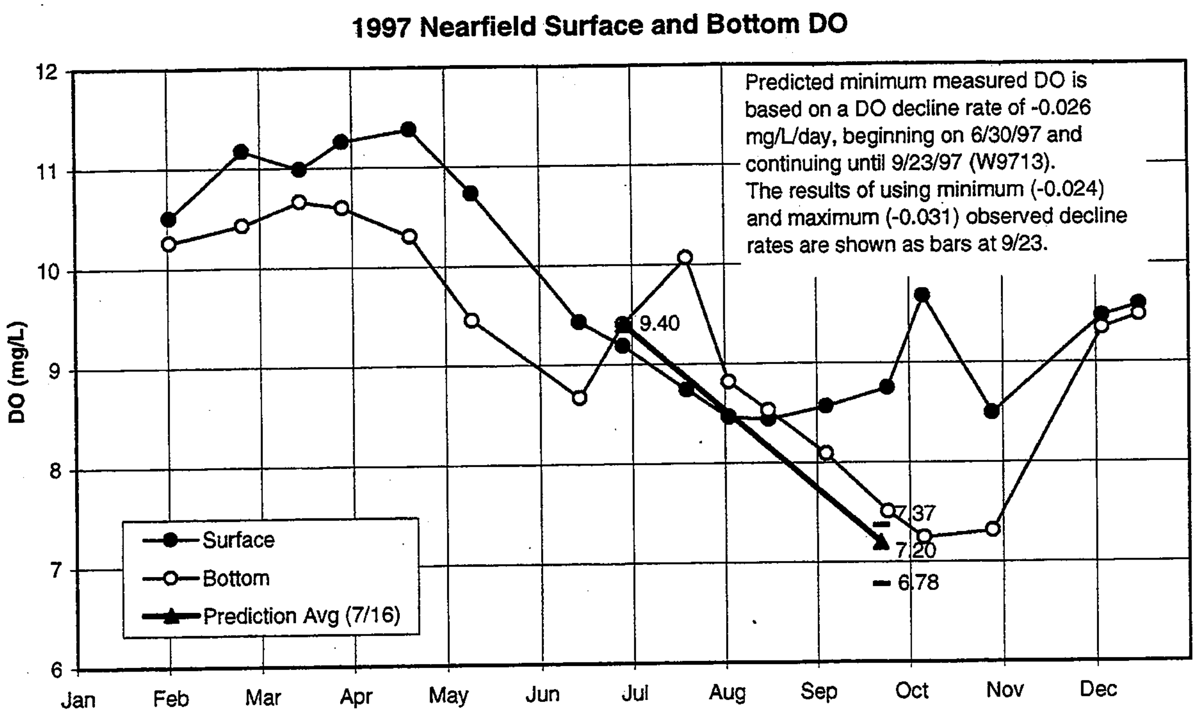
FIGURE 6-8

Stellwagen Basin Dissolved Oxygen Concentrations in Bottom Waters

Symbols indicate the mean of 4 Stellwagen stations; error bars represent +/- one standard deviation.


1997 Nearfield Surface and Bottom DO
Predicted minimum measured DO is based on a DO decline rate of -0.026 mg/L/day, beginning on 6/30/97 and continuing until 9/23/97 (W9713). The results of using minimum (-0.024) and maximum (-0.031) observed decline rates are shown as bars at 9/23.
DO (mg/L)
9.40
7.37
7.20
6.78
Surface
Bottom
Prediction Avg
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


1997 F19 Surface and Bottom DO
Predicted minimum measured DO is based on a DO decline rate of -0.0205 mg/L/day, beginning on 6/16/97 and continuing until 10/9/97 (W9713). The results of using minimum (-0.0153) and maximum (-0.0244) observed decline rates are shown as bars at 10/9.
DO (mg/L)
8.73
6.97
6.37
5.92
Surface
Bottom
Prediction Avg
Sep
Oct
Nov
Dec



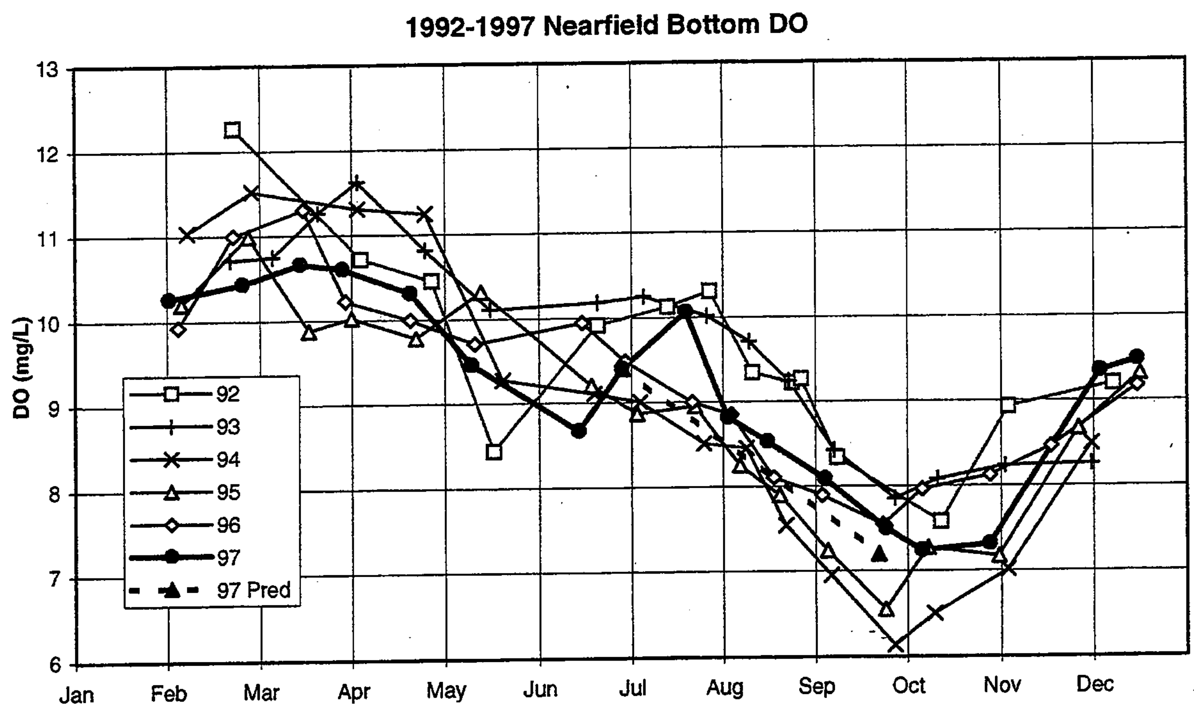
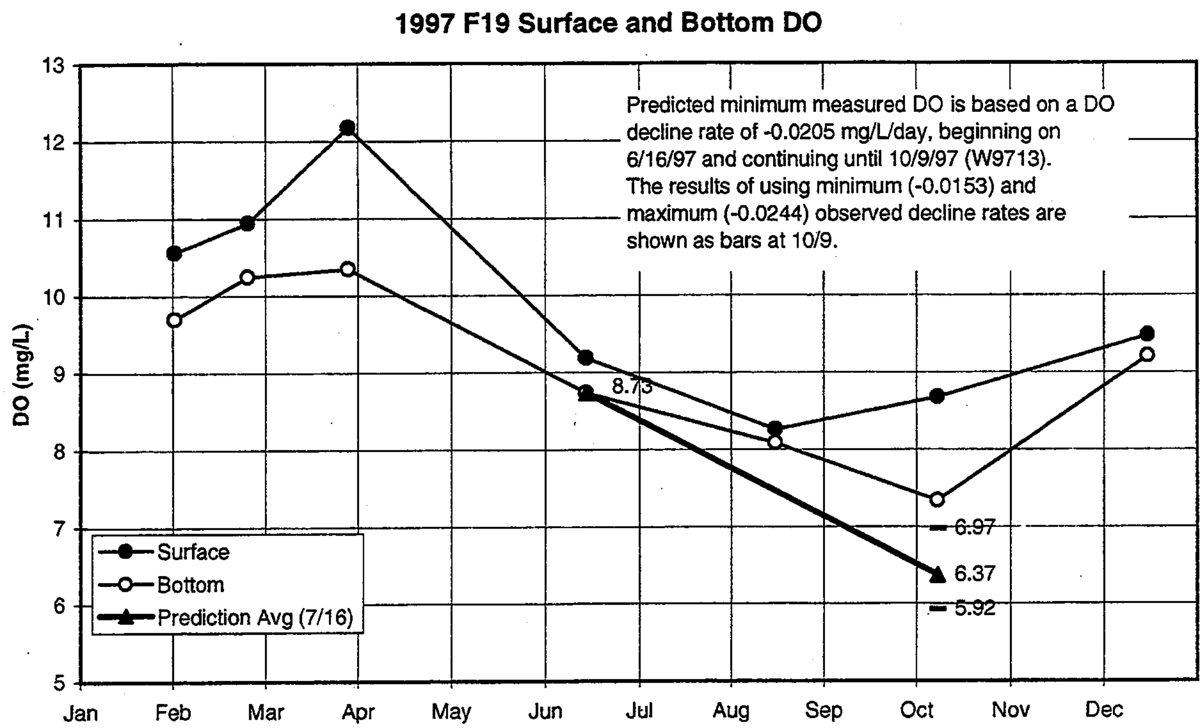


FIGURE 2a

Do97pred
2/16/98



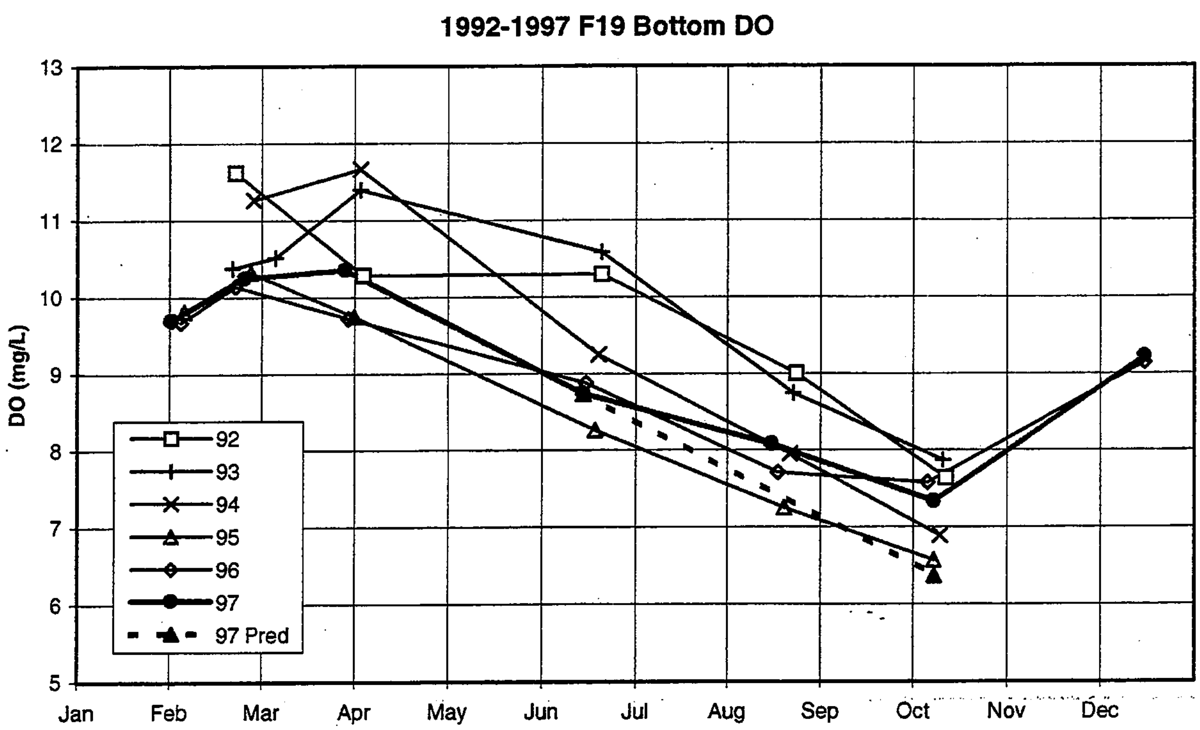
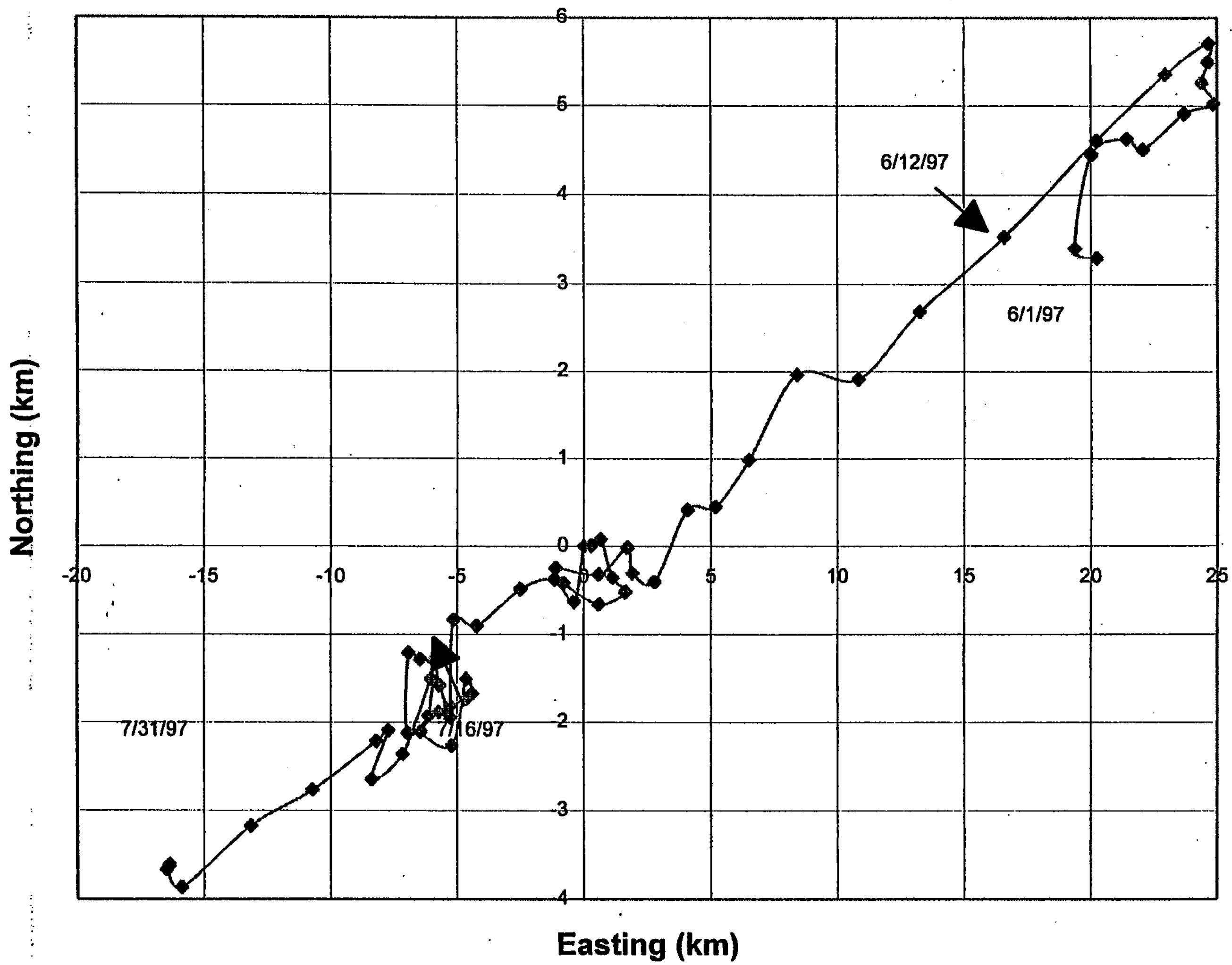


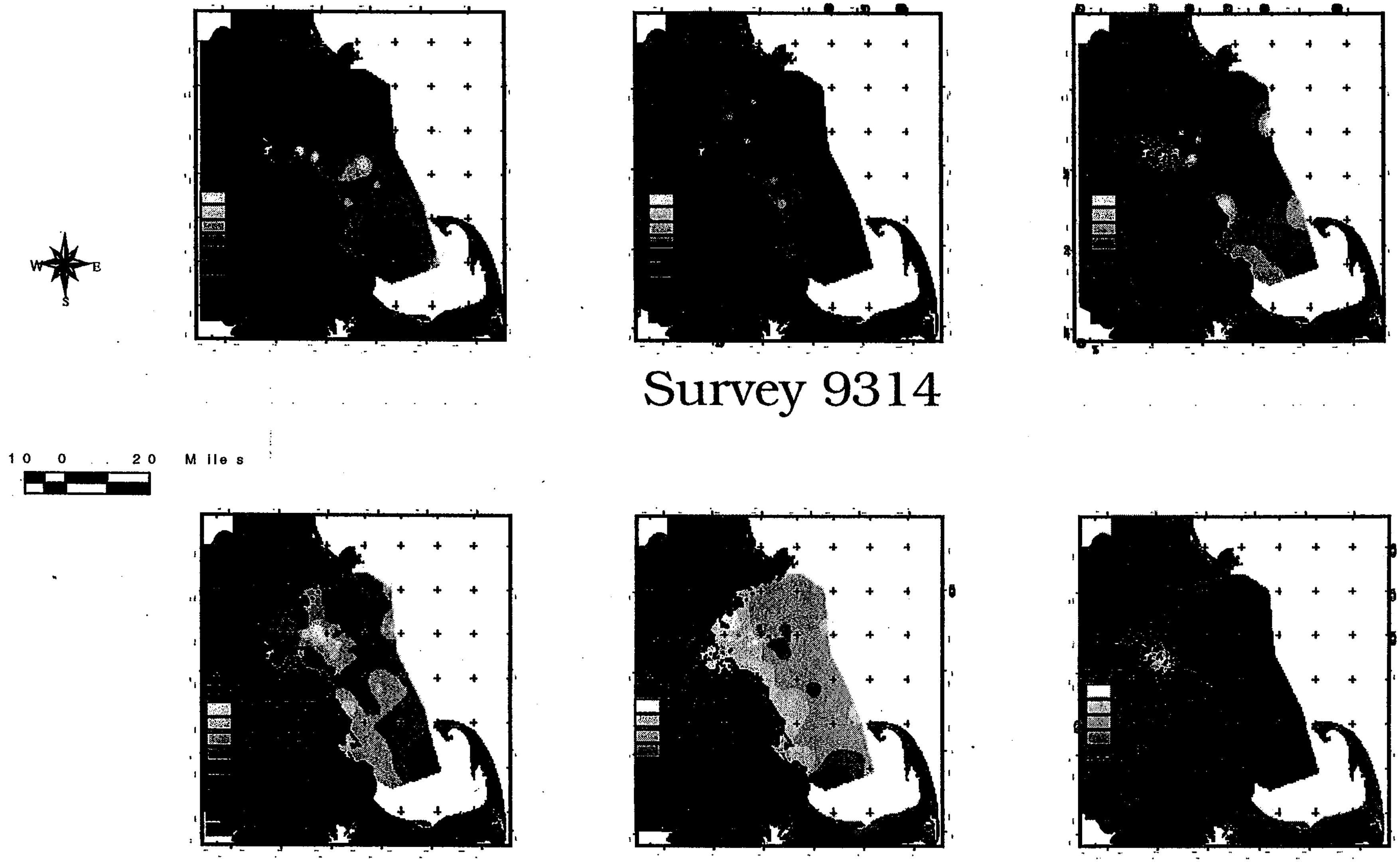
FIGURE 2b

F19pred
2/17/98

Progressive Vector Plot: June-July 1997
Depth = 29.2 meters (Bottom)



MWRA Baseline Monitoring Program
Bottom Water Dissolved Oxygen 1992 - 1997
October Farfield Surveys



Water Column Monitoring Thresholds

- Dissolved Oxygen
  - Concentration in NF and SB bottom water
  - Depletion rate in NF and SB
- Chlorophyll a
  - Annual NF concentration
  - Seasonal NF concentrations
- Nuisance Algae and PSP
- Zooplankton Community Assemblage

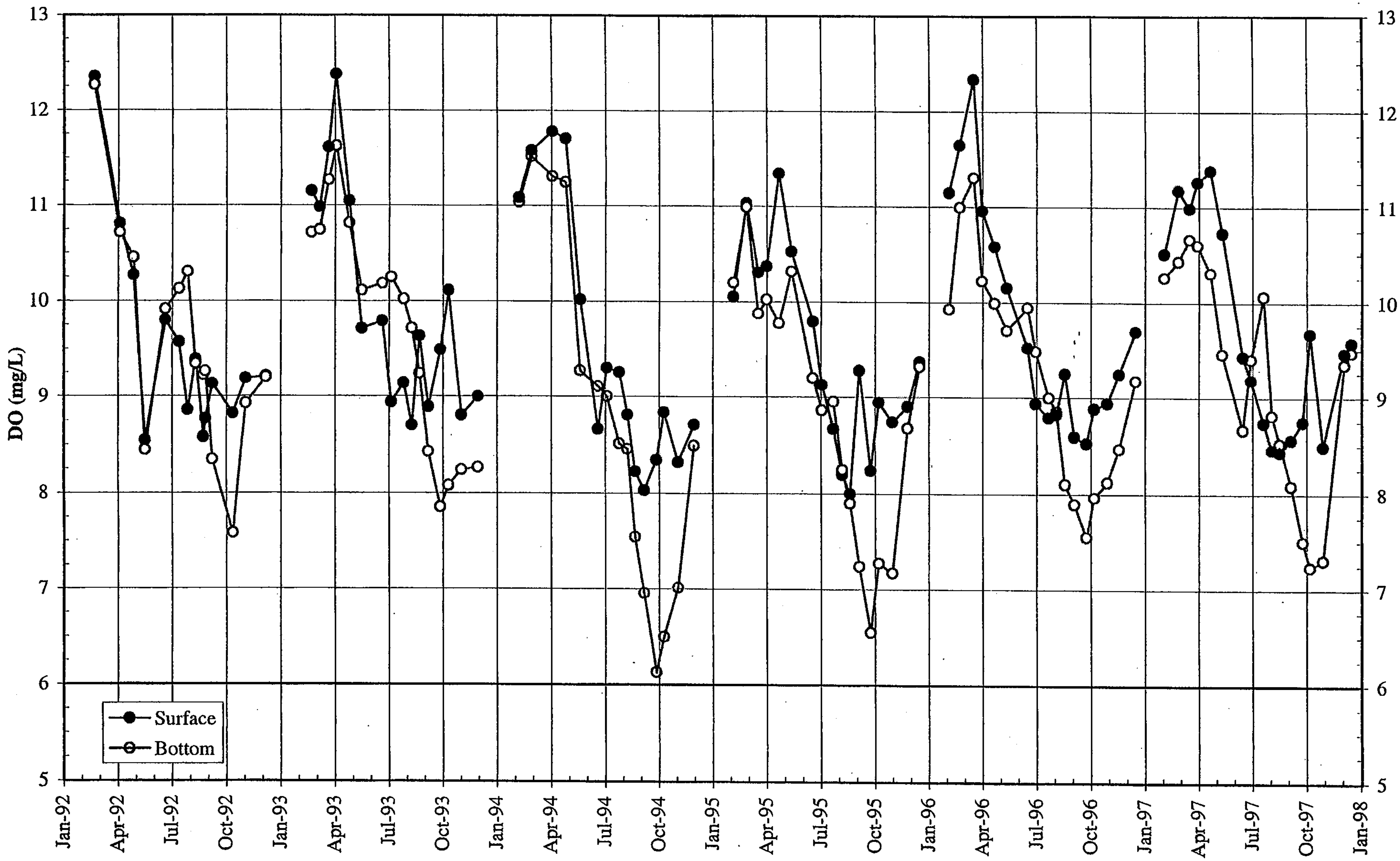


FIGURE 1a

Interannual Nearfield Dissolved Oxygen Cycle in Surface and Bottom Waters

Symbols indicate the mean of 17 nearfield stations; error bars represent +/- one standard deviation.

Do97pred.xls
3/24/98

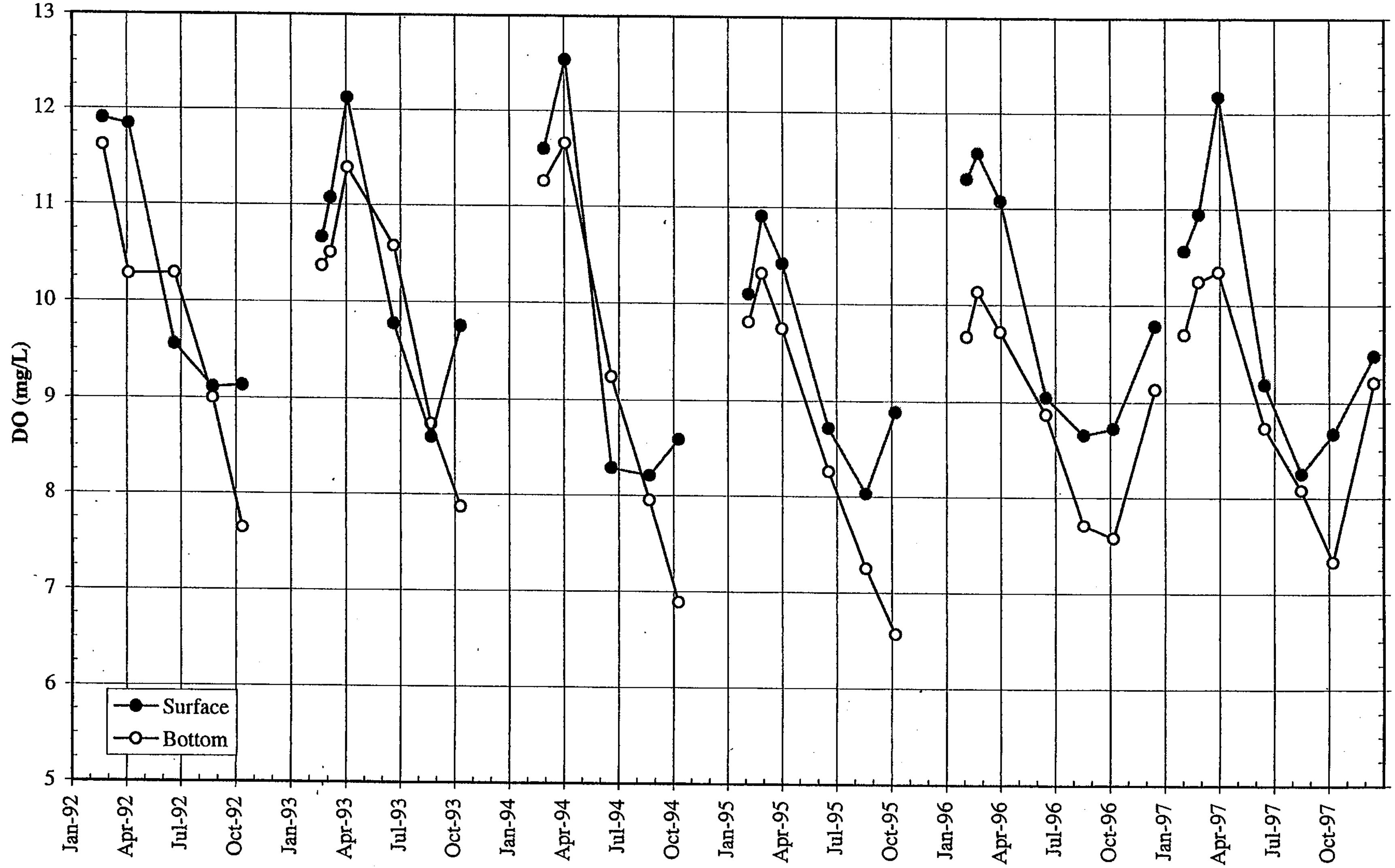
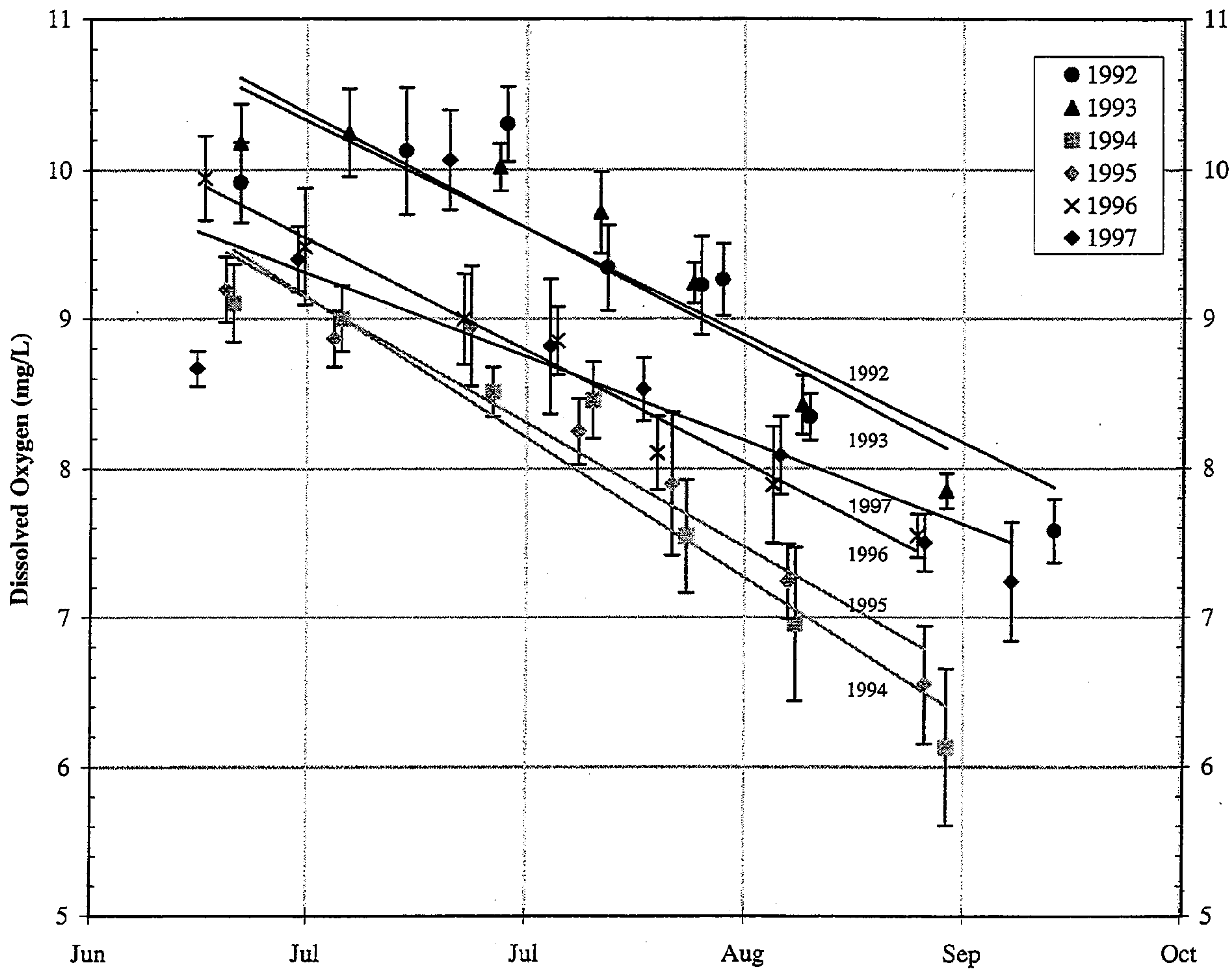


FIGURE 1b
Interannual F19 Dissolved Oxygen Cycle in Surface and Bottom Waters

F19pred.xls
3/24/98



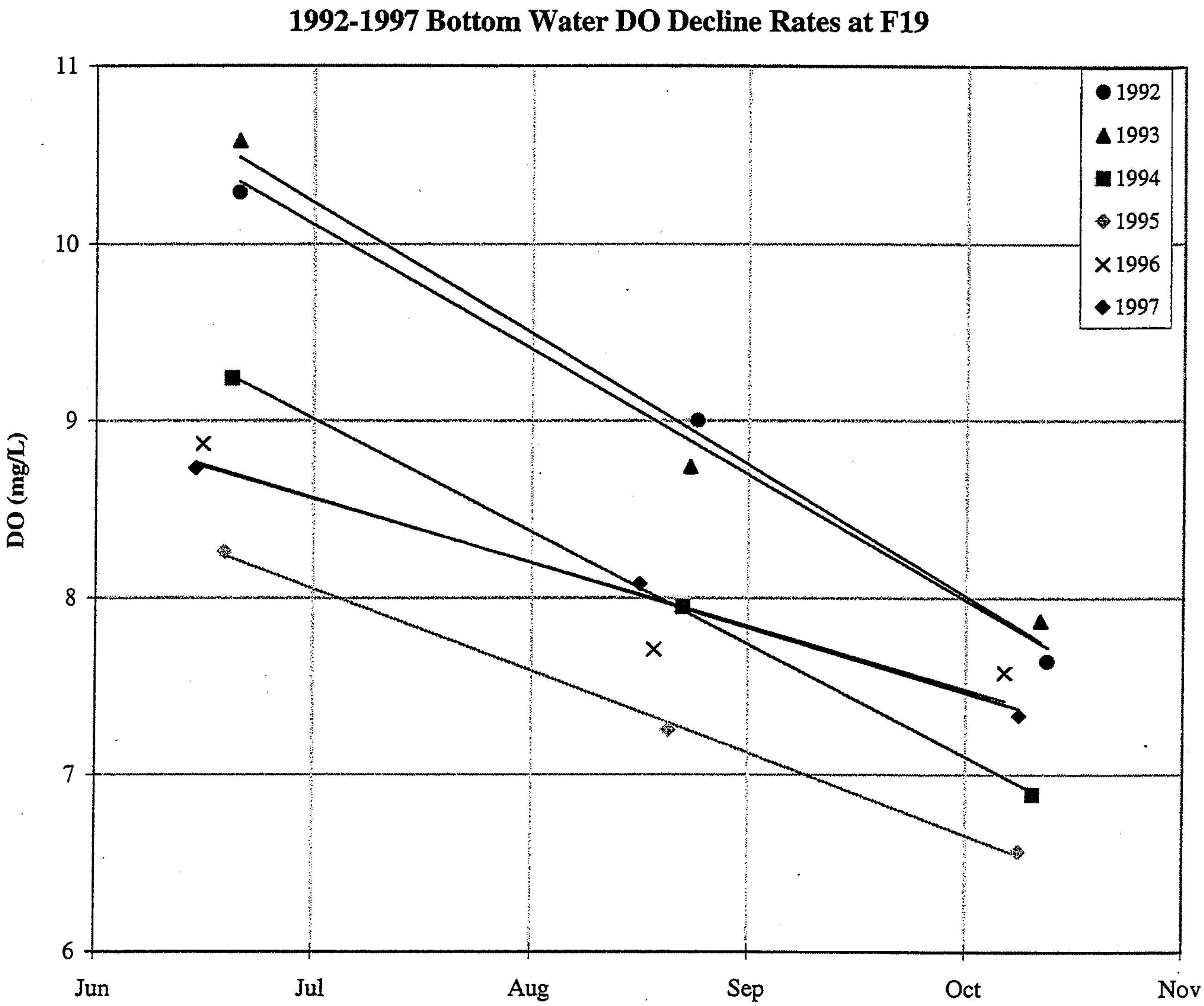
Year	Slope (mg/L/day)	Intercept* (mg/L)	R^2
1992	-0.024	11.0	0.808
1993	-0.025	11.1	0.885
1994	-0.031	10.1	0.929
1995	-0.027	9.9	0.932
1996	-0.025	10.3	0.978
1997	-0.020	9.8	0.632

FIGURE 6-3

Nearfield Dissolved Oxygen Concentrations in Bottom Waters

Symbols indicate the mean of 17 nearfield stations; error bars represent +/- one standard deviation.

Do97pred.xls



Year	Slope
1992	-0.0233
1993	-0.0244
1994	-0.0210
1995	-0.0153
1996	-0.0119
1997	-0.0121
Average	-0.018

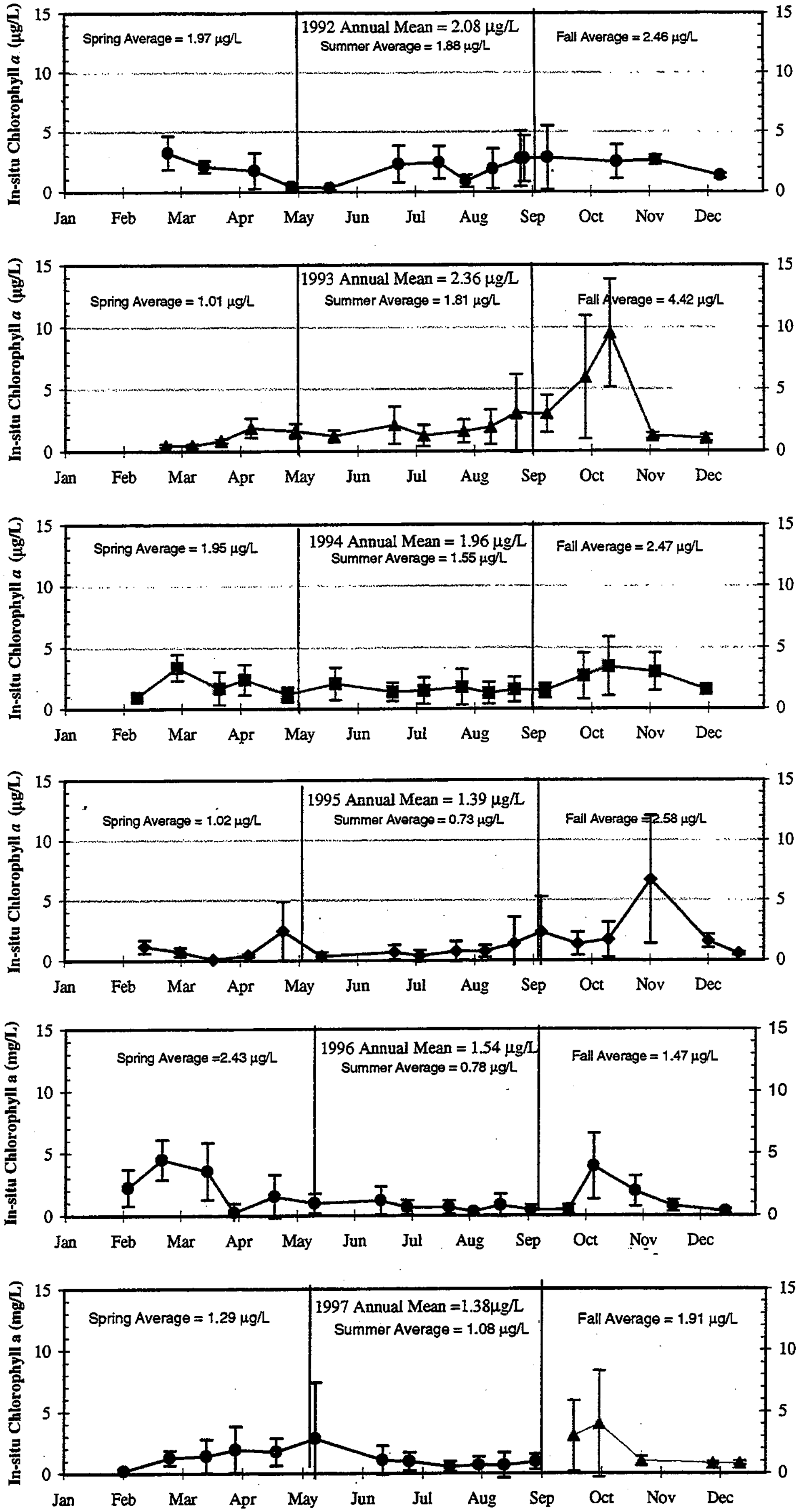
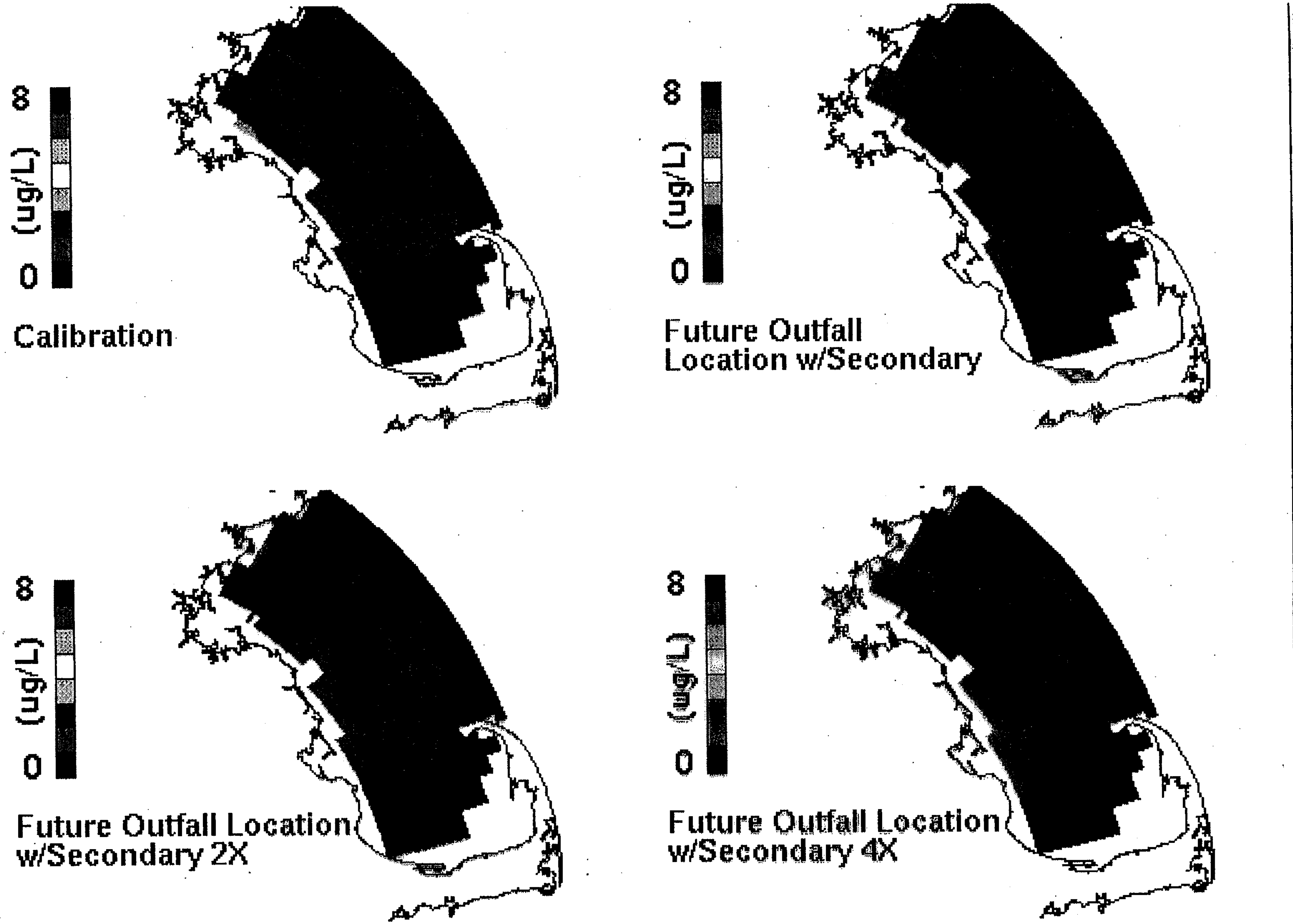


FIGURE 5-10
Interannual Nearfield Survey In-situ Chlorophyll a Averages
All depths at all nearfield stations included.
Error bars represent +/- one standard deviation.

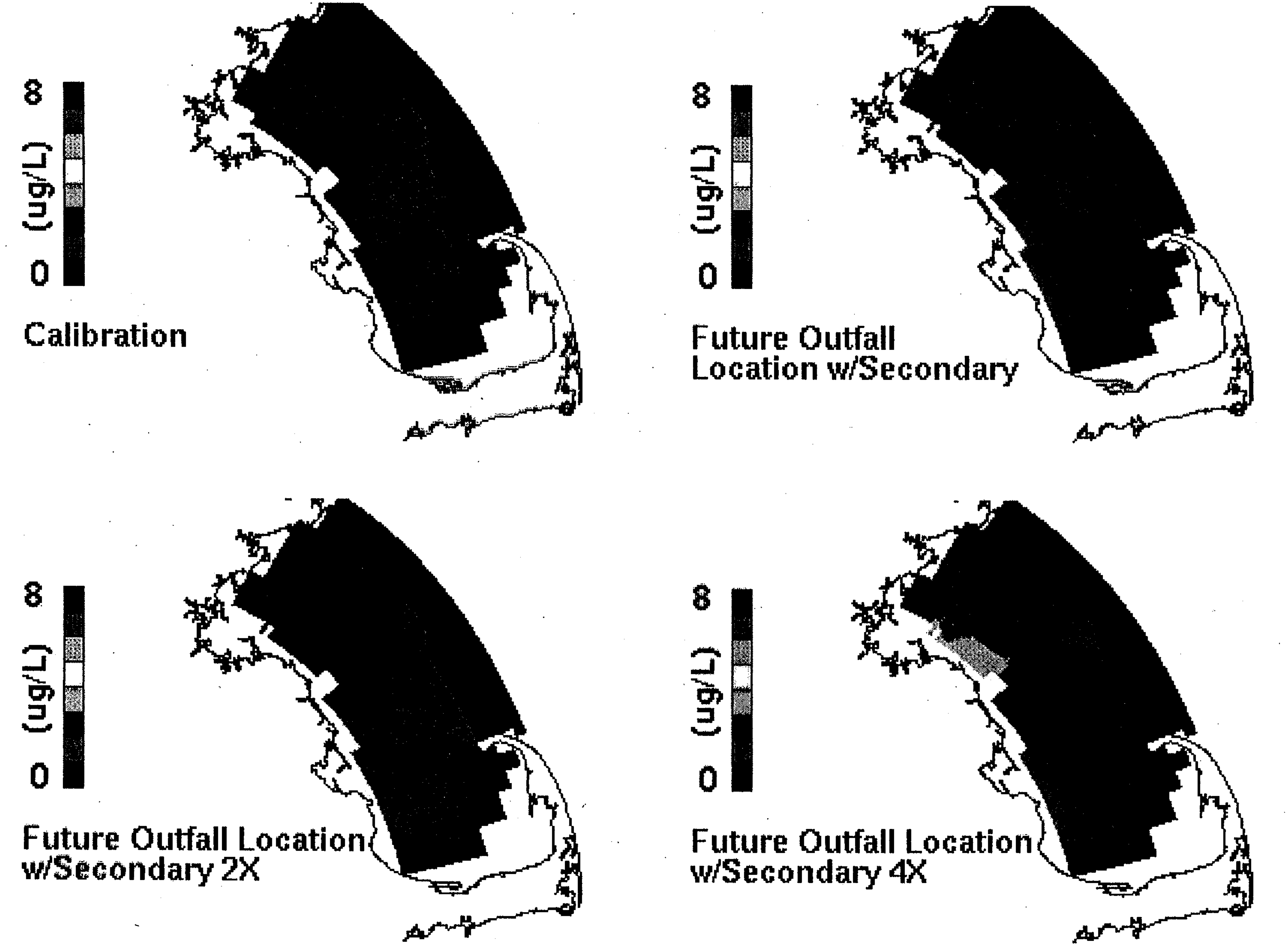
MWRA HOM Water Column Thresholds

Parameter	Caution Level	Warning Level
Dissolved oxygen concentration in Nearfield region bottom waters	Monthly mean DO is less than 6.5 ppm or 80% of saturation levels for any one month during stratification (June-Oct.)	Monthly mean DO is less than 6 ppm or 75% of saturation levels for any one month during stratification (June-Oct.)
Dissolved oxygen concentration in Stellwagen Basin bottom waters	Monthly mean DO is less than 6.5 ppm or 80% of saturation levels for any one month during stratification (June-Oct.)	Monthly mean DO is less than 6 ppm or 75% of saturation levels for any one month during stratification (June-Oct.)
Dissolved oxygen depletion rate in Nearfield region bottom waters	DO depletion rate is greater than 1.5 times the baseline rate during stratification (June-Oct.) 1992-1997 Caution Level: **-0.038 mg/L/day**	DO depletion rate is greater than 2 times the baseline rate during stratification (June-Oct) 1992-1997 Warning Level: **-0.051 mg/L/day**
Chlorophyll in Nearfield region	Annual mean concentration greater than 1.5 times the baseline annual mean 1992-1997 Caution Level: **2.68 μg/L**	Annual mean concentration greater than 2 times the baseline annual mean 1992-1997 Warning Level: **3.57 μg/L**
Chlorophyll in Nearfield region	Season mean concentration exceeds 95th percentile of the 1992-1997 baseline seasonal distribution: Spring: **2.58 μg/L** Summer: **2.14 μg/L** Fall: **4.21 μg/L**	None.
Nuisance algae in Nearfield region	Season mean population densities exceed 95th percentile of the baseline seasonal mean.	None.
PSP extent in Farfield region	New occurrence. PSP has never been observed at 3 of the 18 monitoring stations.	None.
Zooplankton assemblage in Nearfield region	Nearfield assemblage shifts form a transitional community towards an inshore community. Inshore: *Acartia, Eurytemora, Centropages hamatus.* Offshore: *Calanus, Pseudocalanus, Centropages typicus, Oithona*	None.

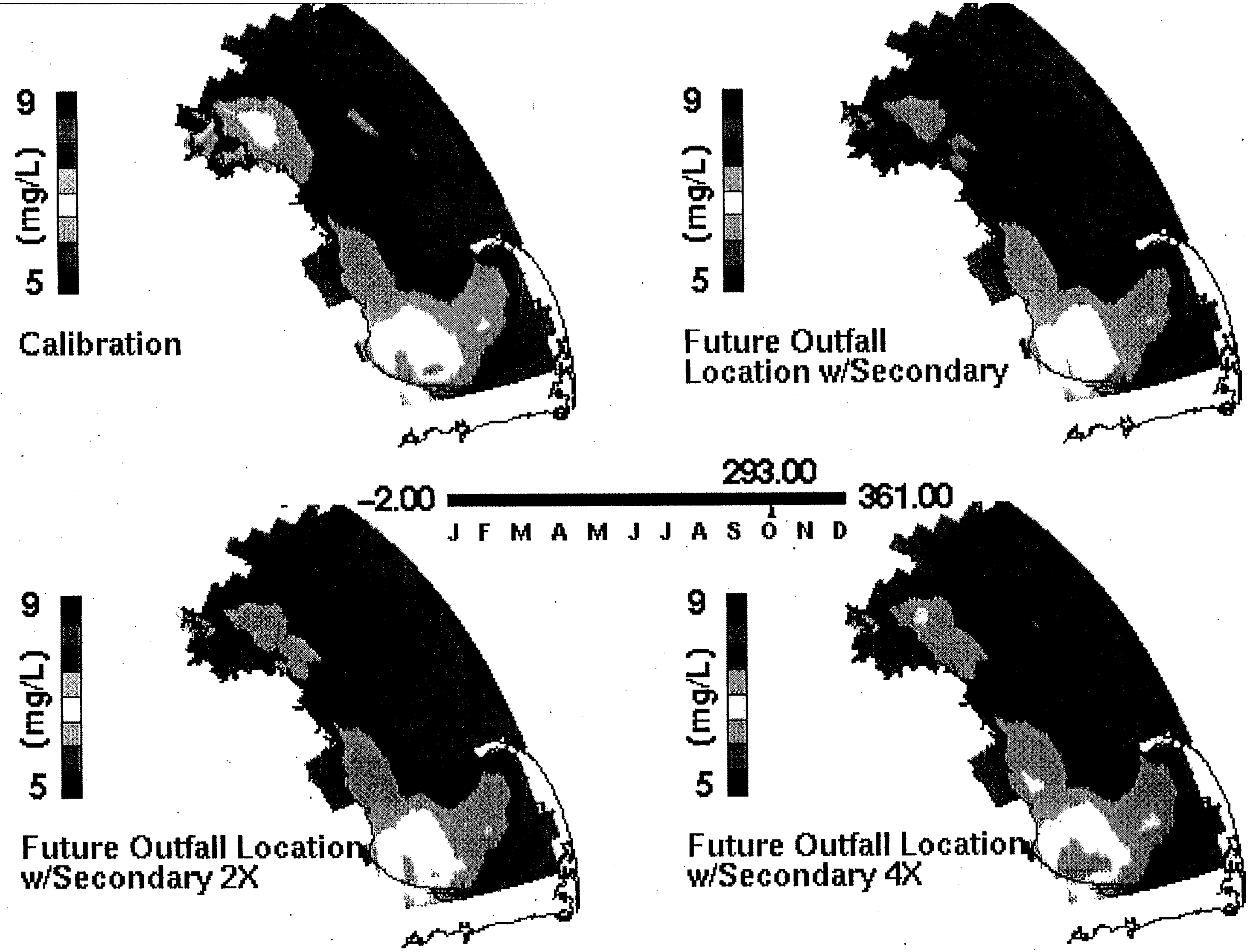
APPENDIX B-2
Bay Eutrophication Model: Jim Fitzpatrick



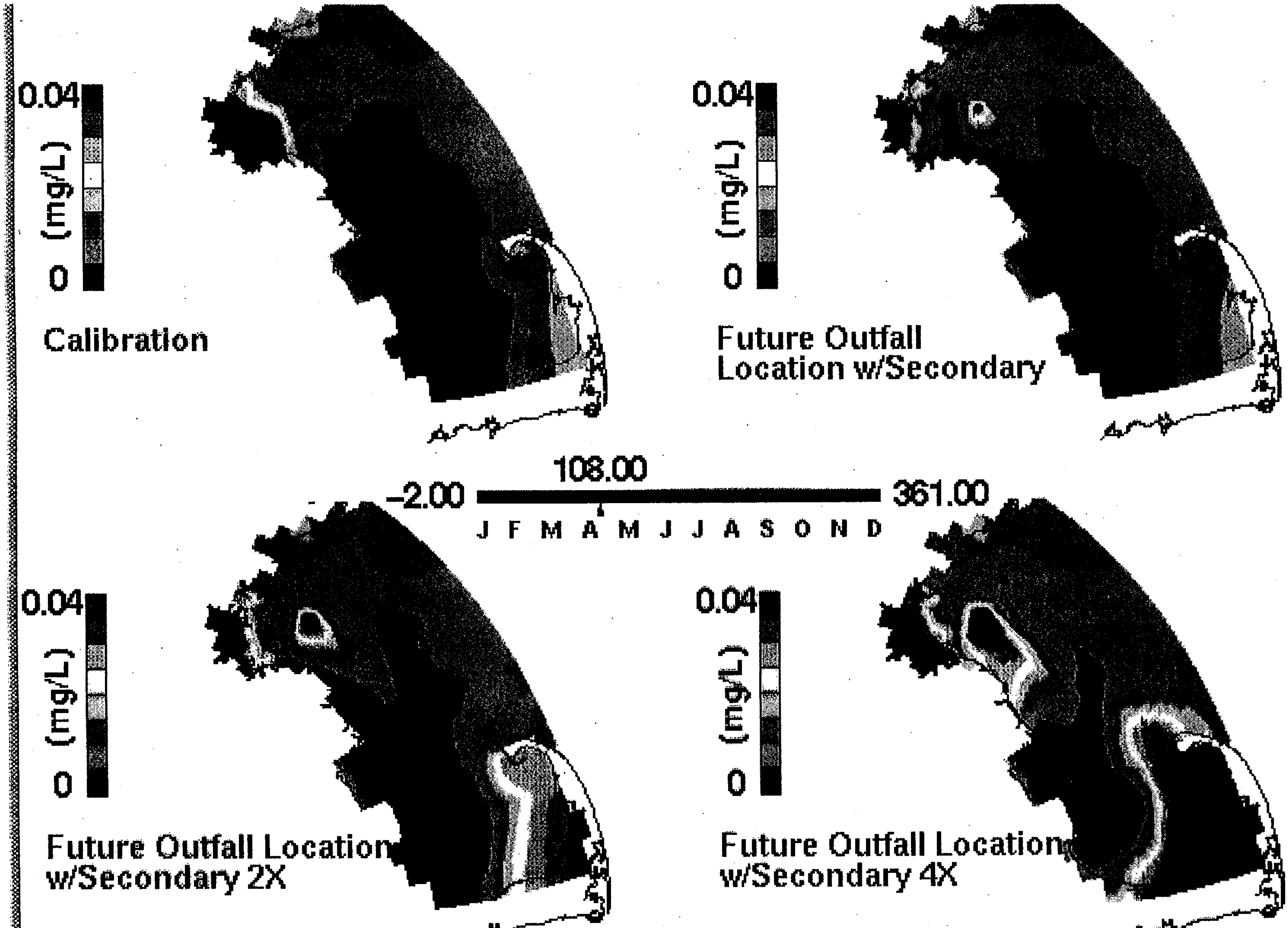
Calibration/Projection Comparison of Avg. Chl–a at 17.5m (Aug)



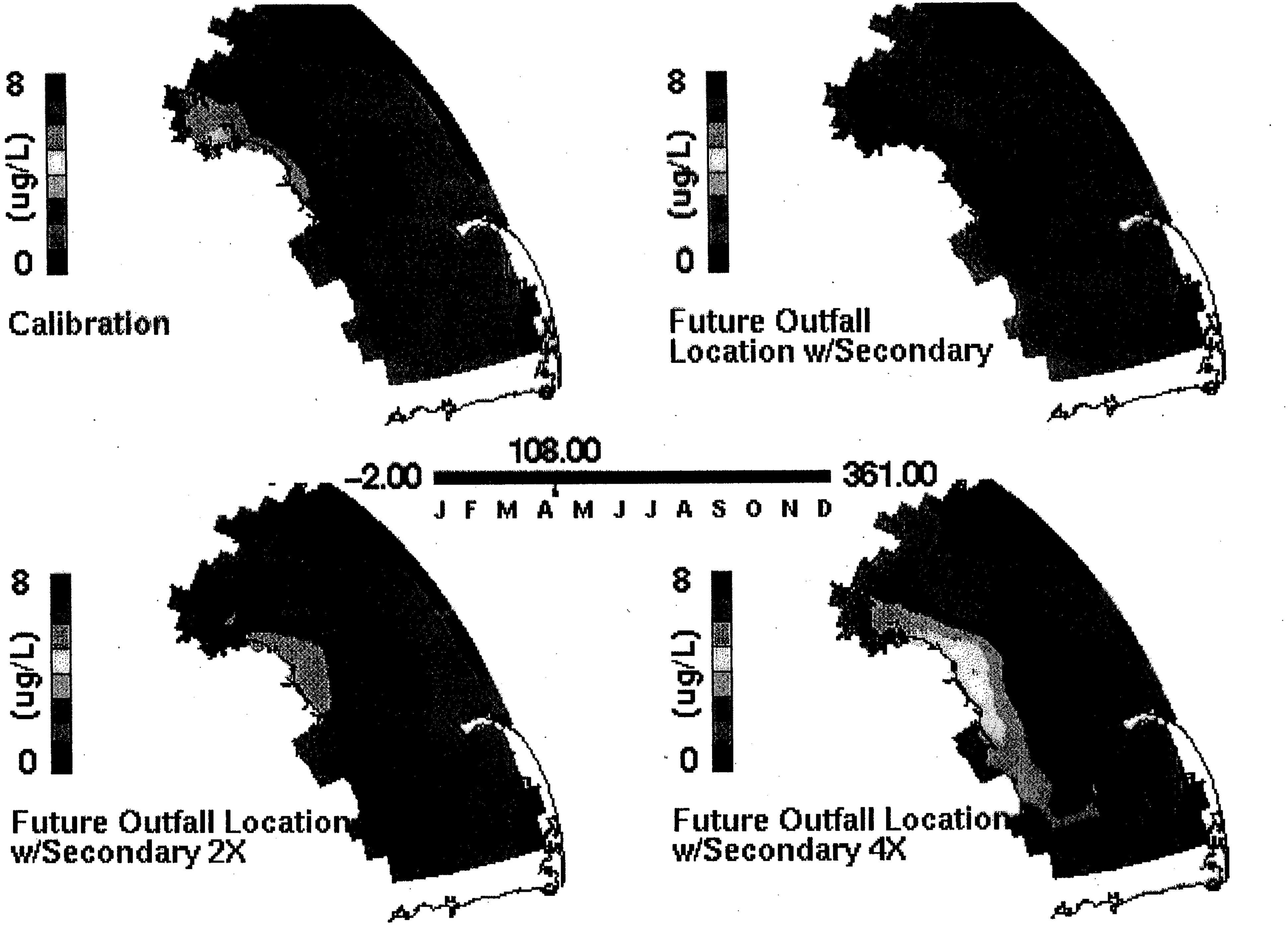
Calibration/Projection Comparison of Avg. Chl–a at 17.5m (Sep)



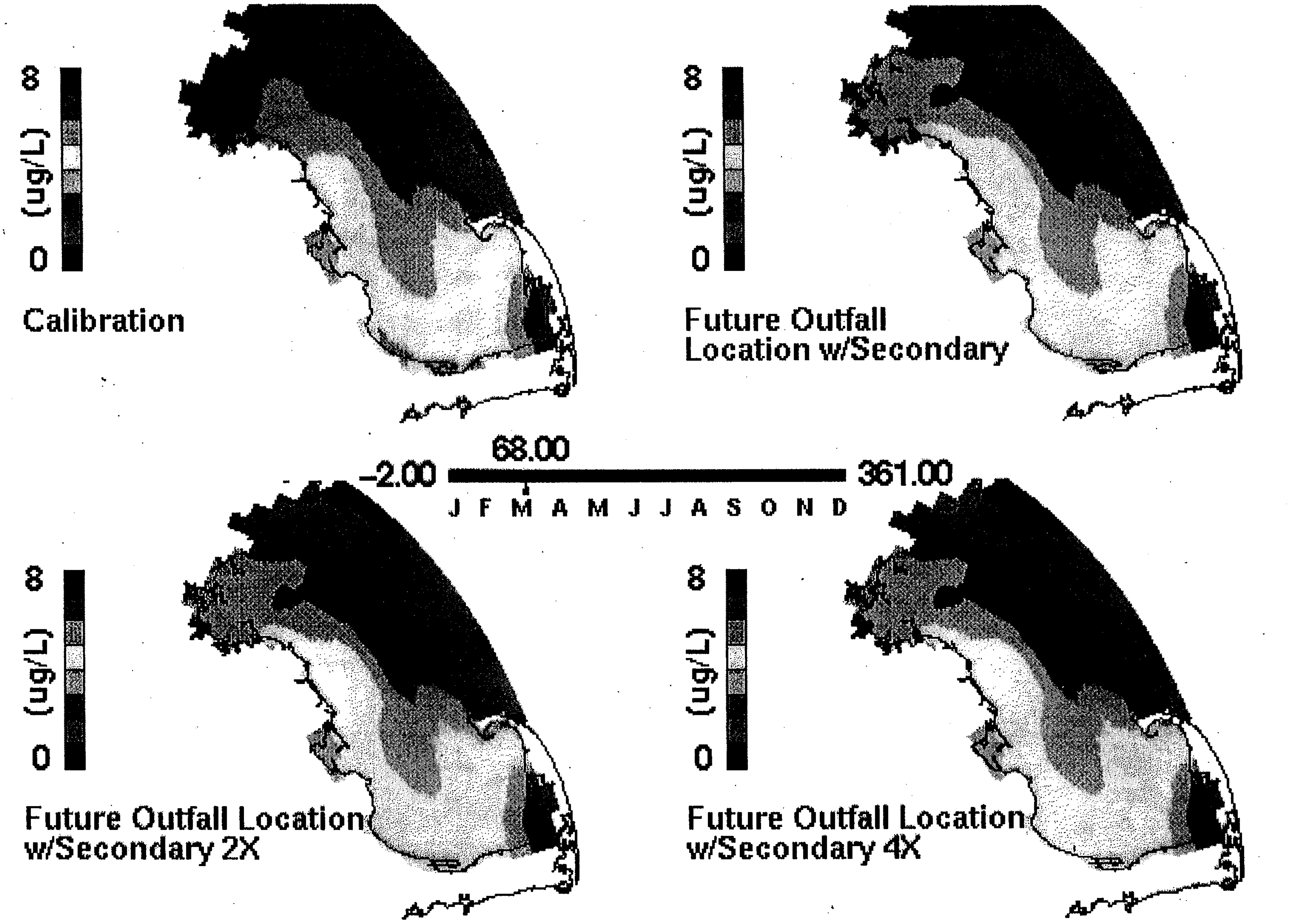
Calibration/Projection Comparison of Bottom DO



Calibration/Projection Comparison of Surface DIN



Calibration/Projection Comparison of Surface Chl-a



Calibration/Projection Comparison of Surface Chl–a

Summary of

MWRA
Water Quality Workshop

of
February 18, 1998

Prepared by
Stephen J. Cibik
Jessica E. Morton

ENSR
35 Nagog Park
Acton, MA 01720

ms-52

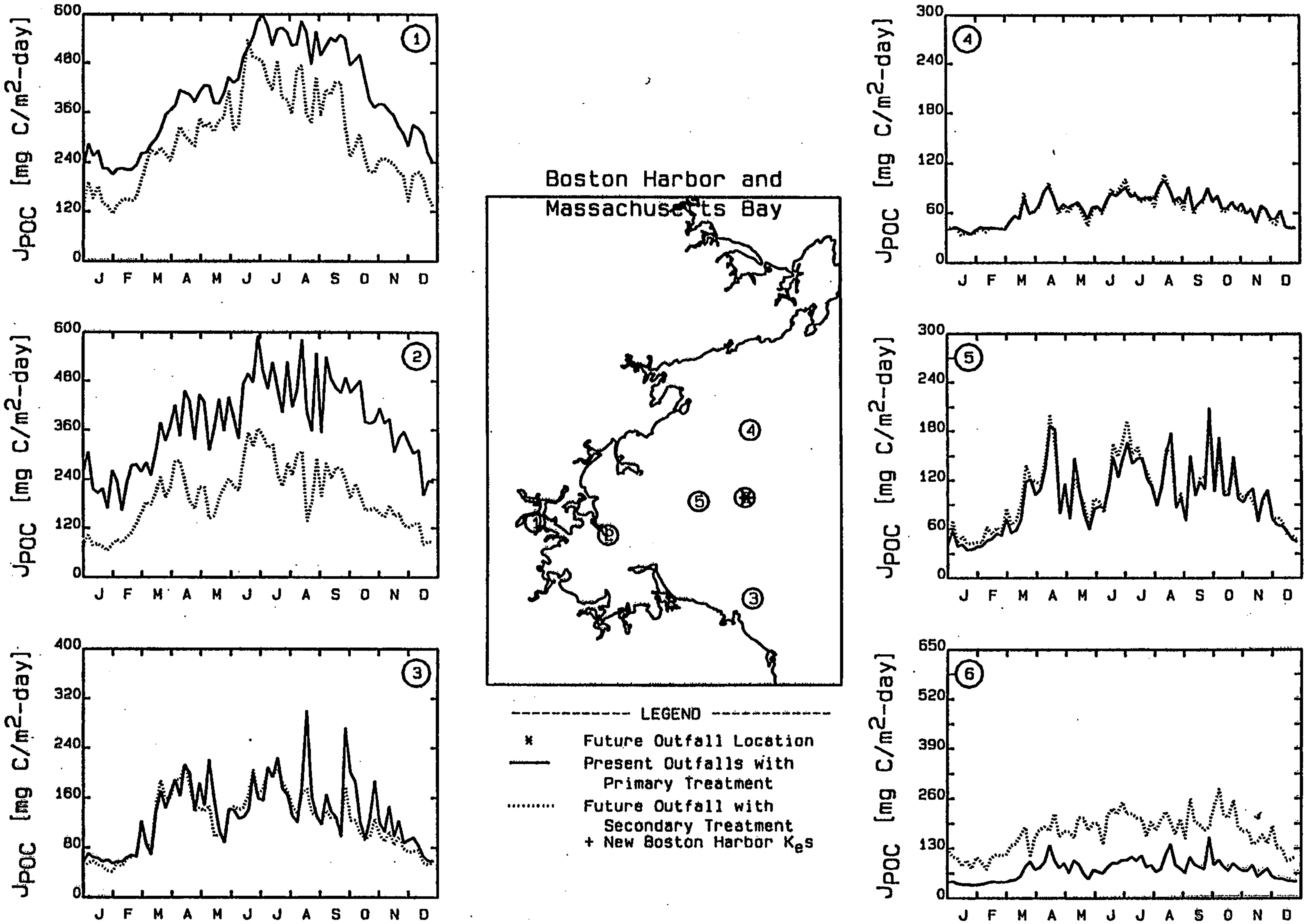


FIGURE 7-27. COMPARISONS OF NEARFIELD TEMPORAL CALIBRATION AND REDUCED K_e PROJECTION RESULTS FOR POC FLUX

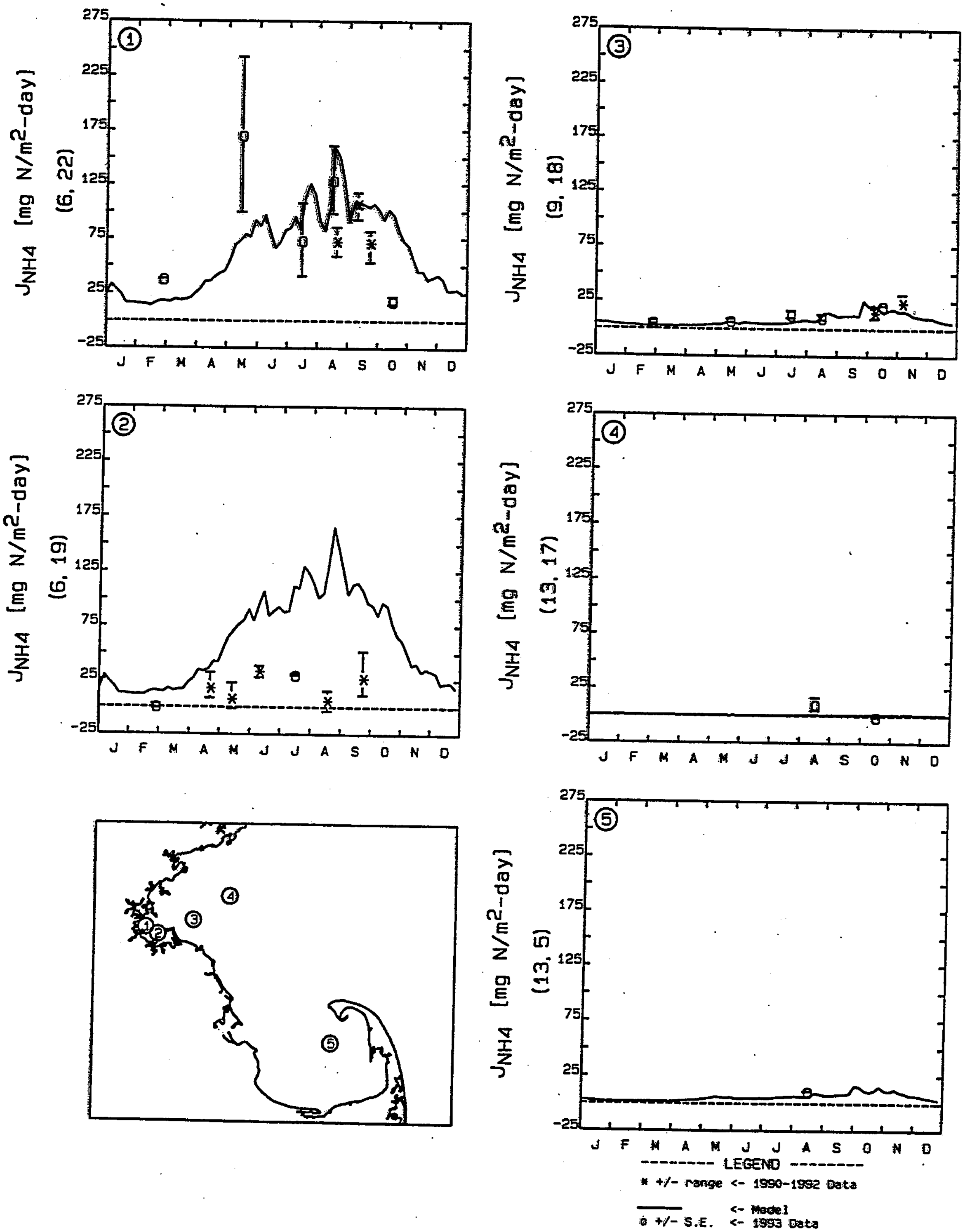
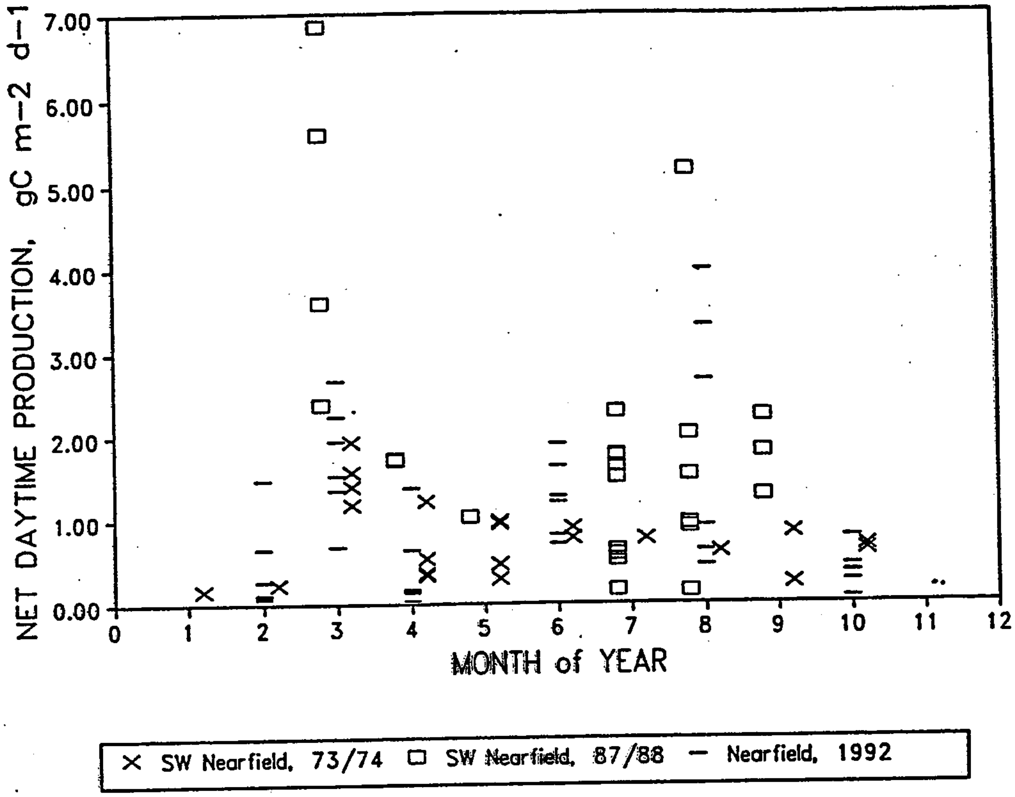


FIGURE 5-32. 1992 SEDIMENT FLUX SUBMODEL CALIBRATION RESULTS FOR J_{NH4}



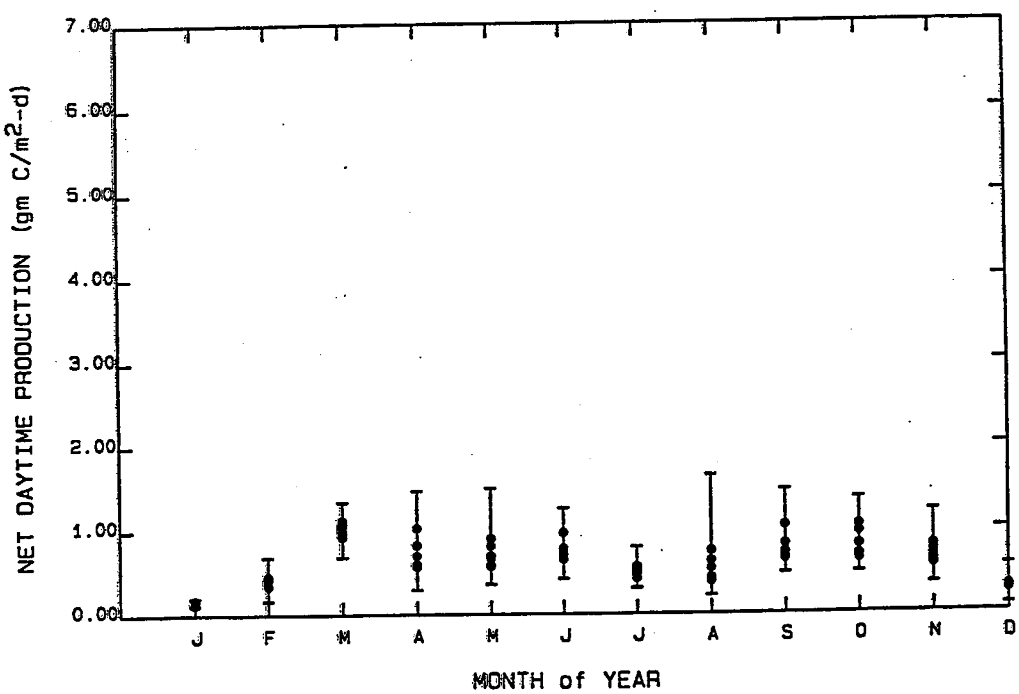


FIGURE 5-24. COMPARISONS OF OBSERVED AND MODEL COMPUTED NEARFIELD PRIMARY PRODUCTIVITY

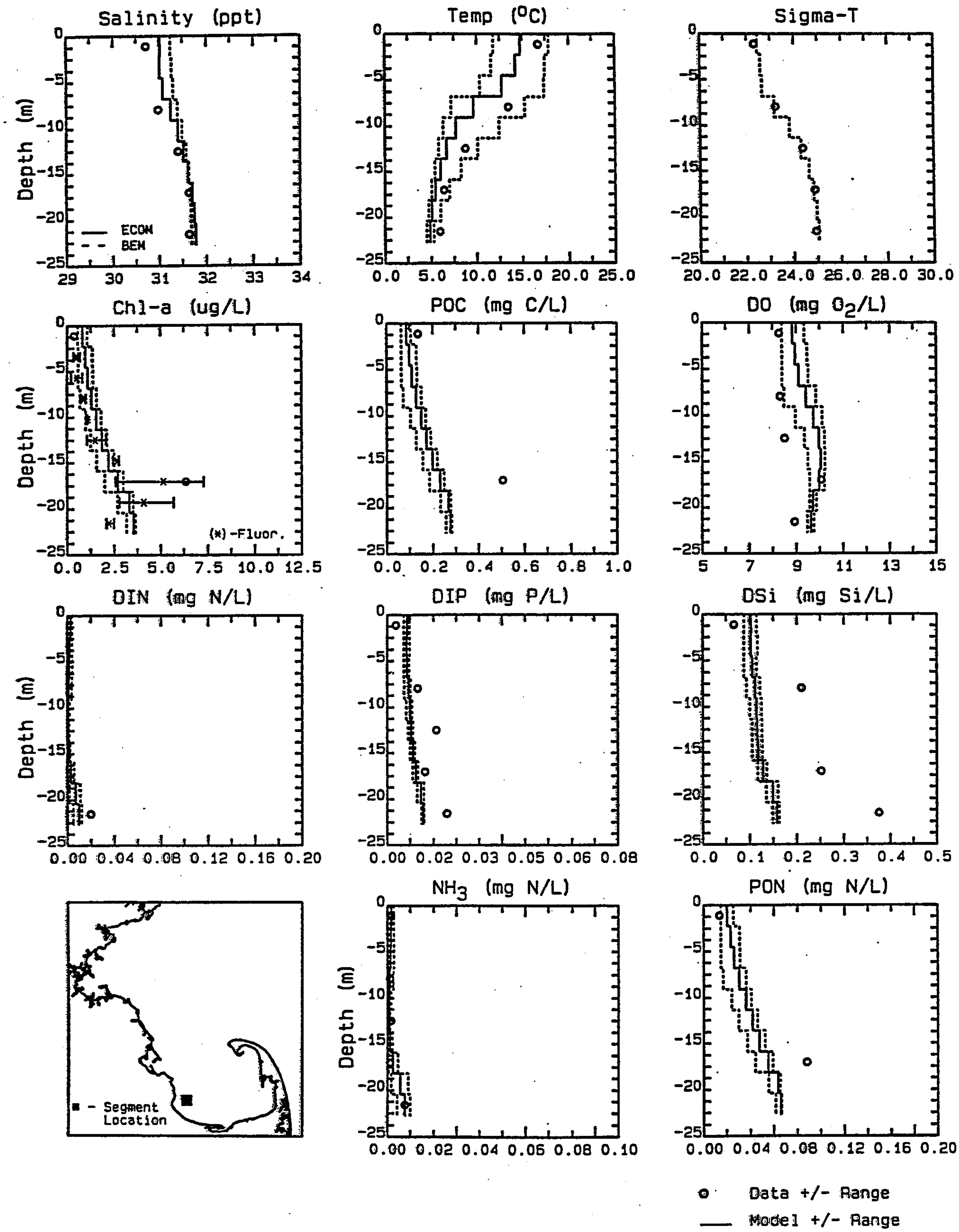


FIGURE 5-22. CALIBRATION RESULTS FOR GRID CELL (6,4) VERSUS DATA STATION F01P FOR JUNE 22, 1992

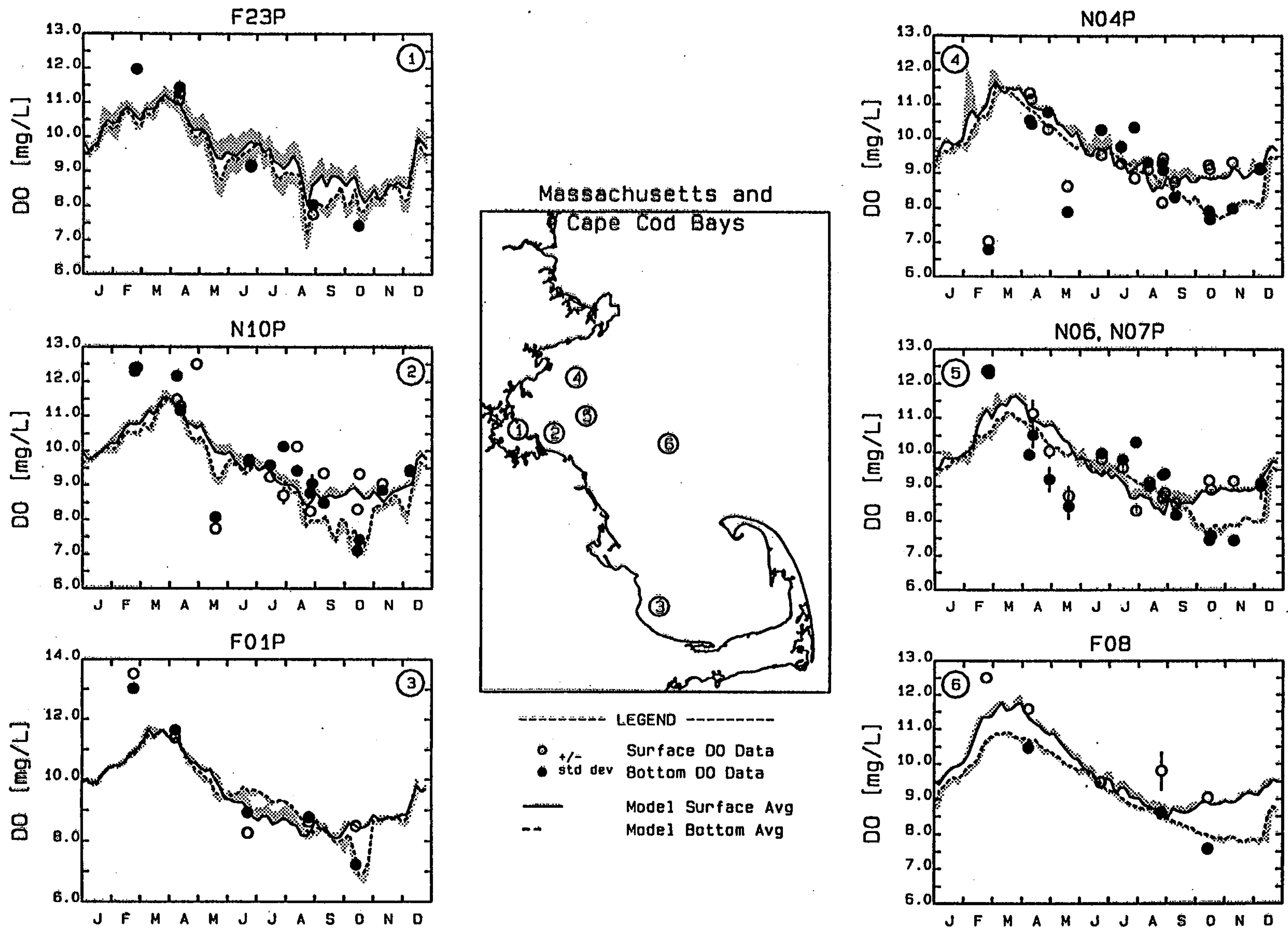


FIGURE 5-19. 1992 DO CALIBRATION FOR SELECTED STATIONS

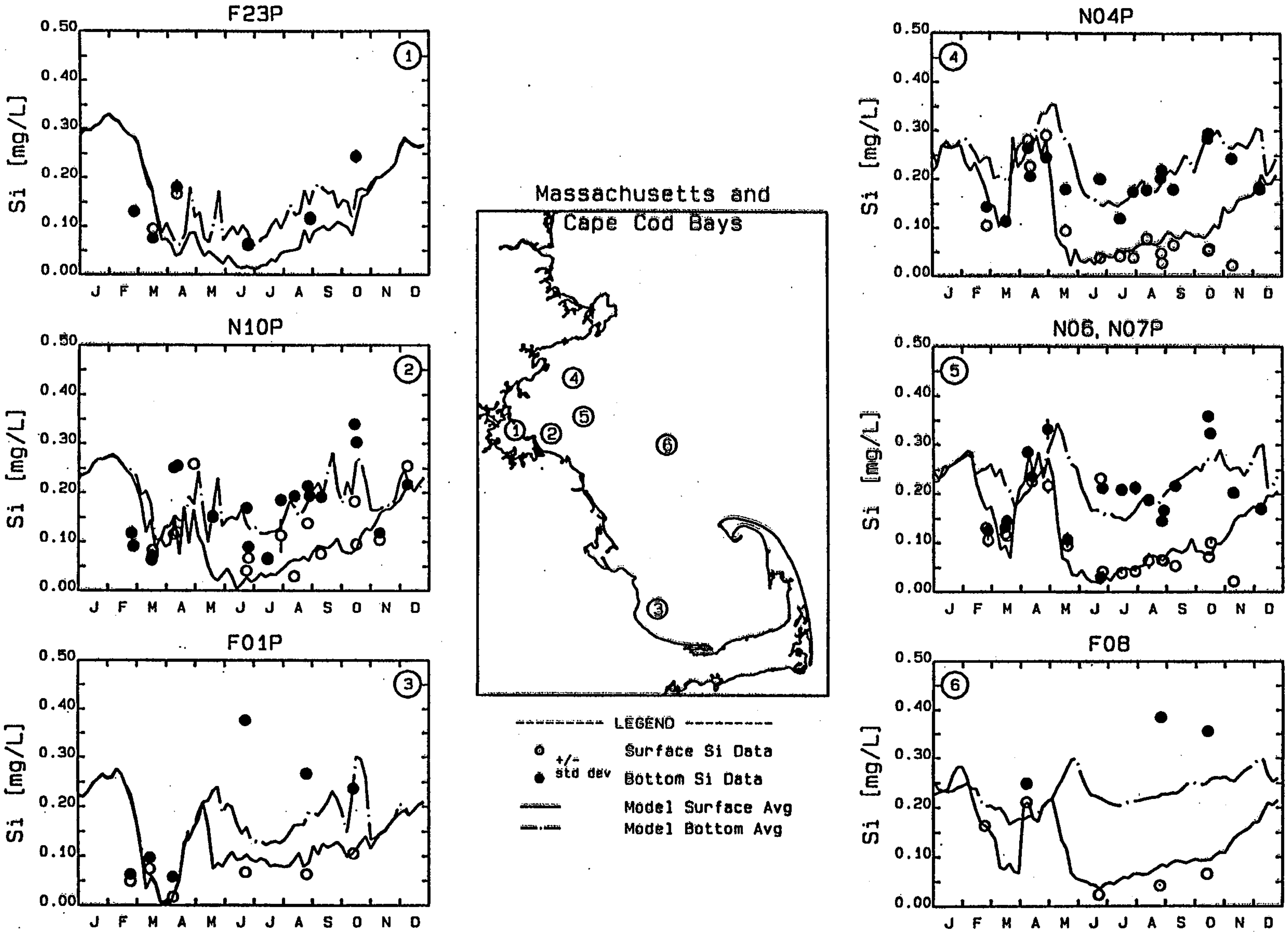


FIGURE 5-17. 1992 DSi CALIBRATION FOR SELECTED STATIONS

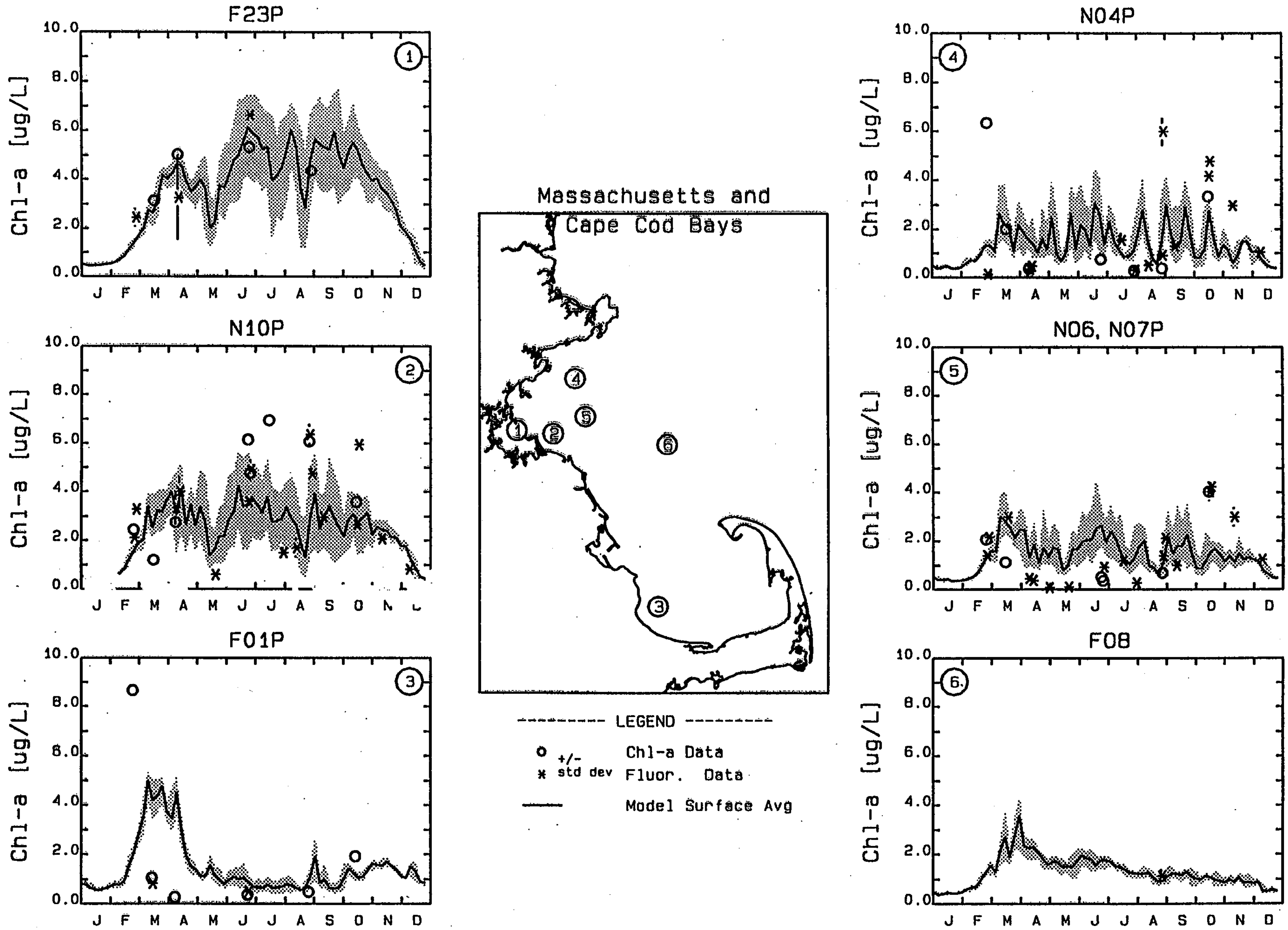


FIGURE 5-16. 1992 CHLOROPHYLL-a CALIBRATION FOR SELECTED STATIONS

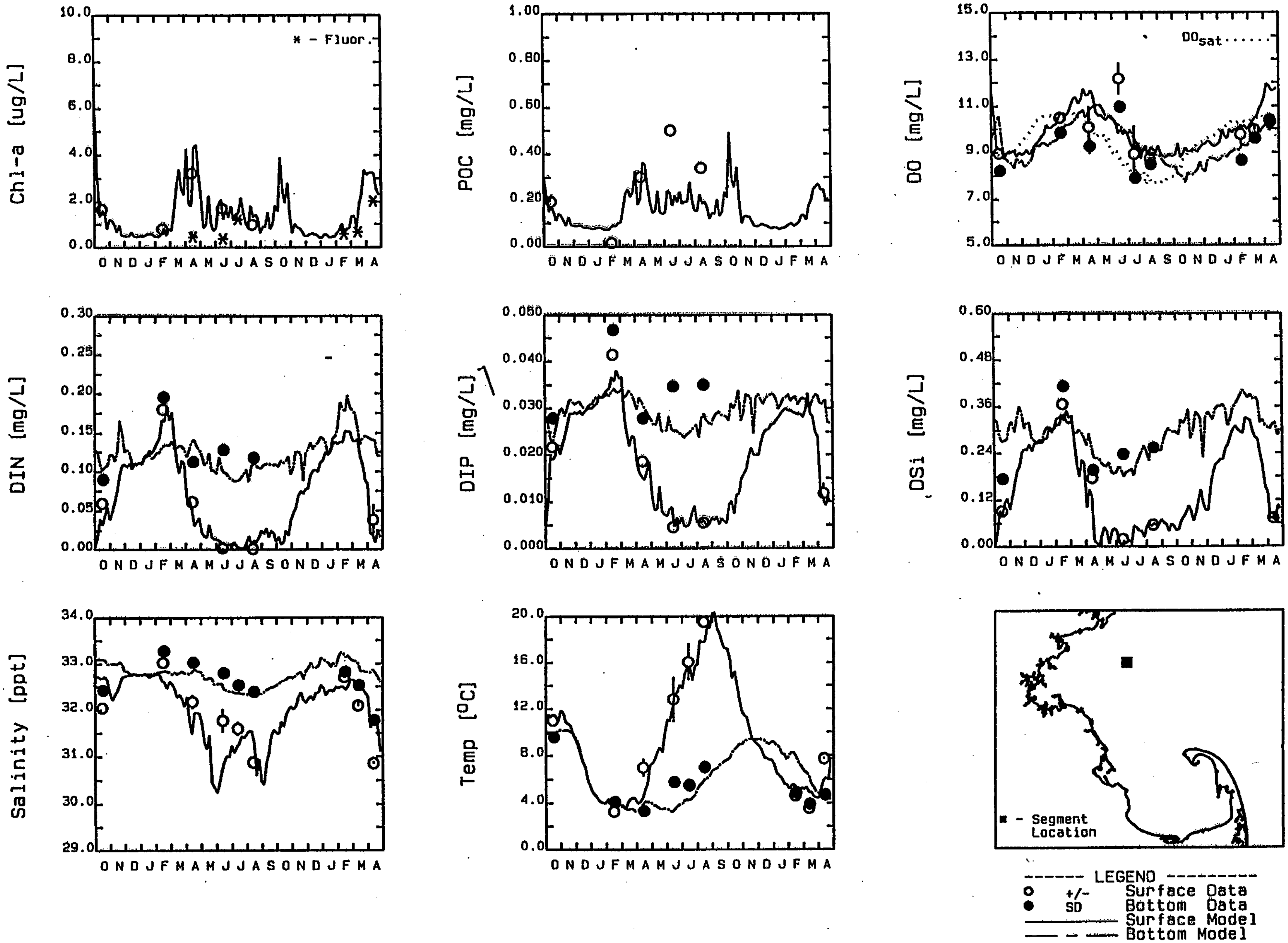


FIGURE 5-11. 1989 THROUGH 1991 TEMPORAL CALIBRATION RESULTS FOR GRID CELL (15,16) VERSUS DATA STATIONS BIGELOW 10, WHOI/UMB/UNH SA4 AND SA5

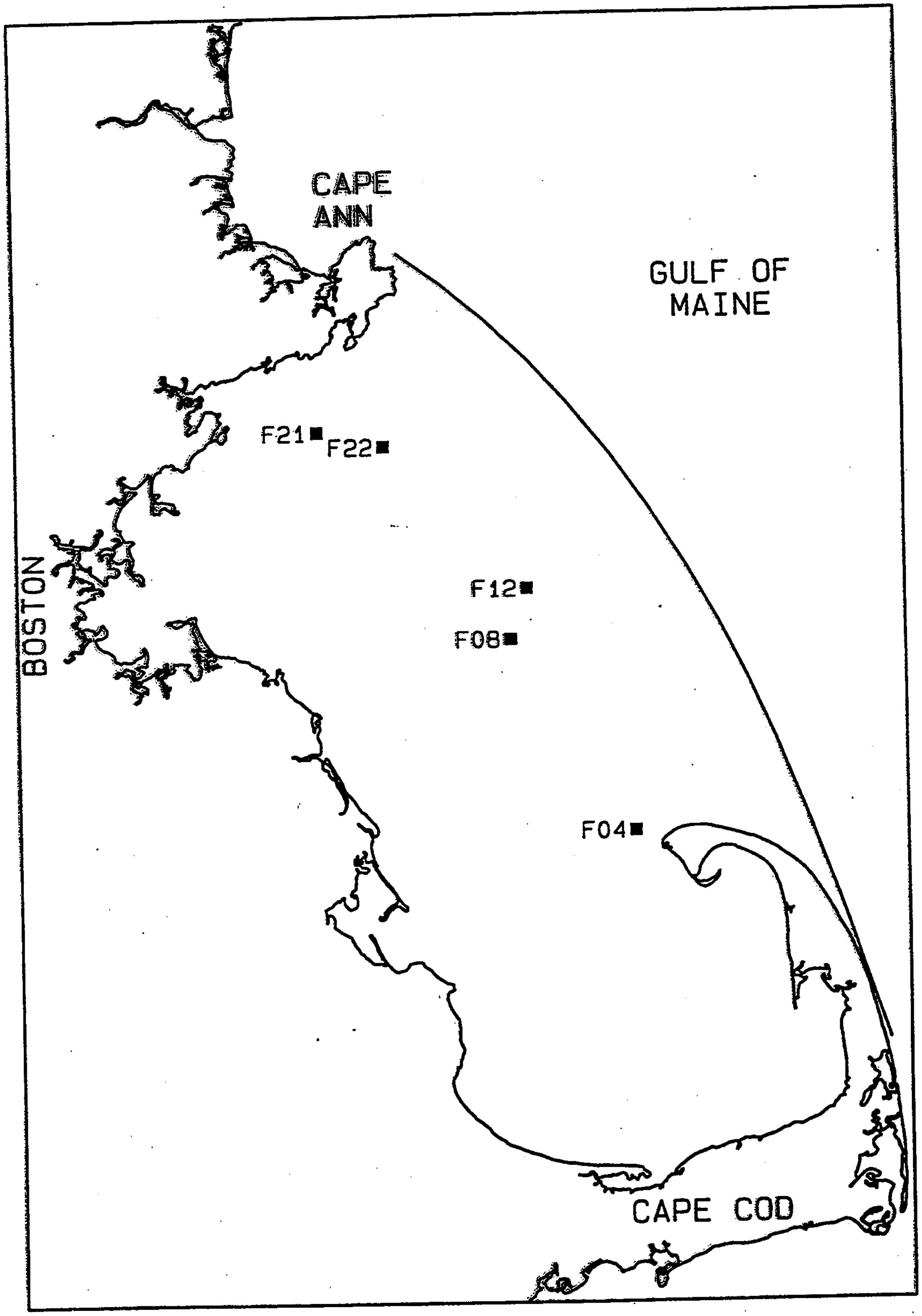


FIGURE 3-48. 1992 SAMPLING STATIONS USED FOR BOUNDARY CONDITIONS

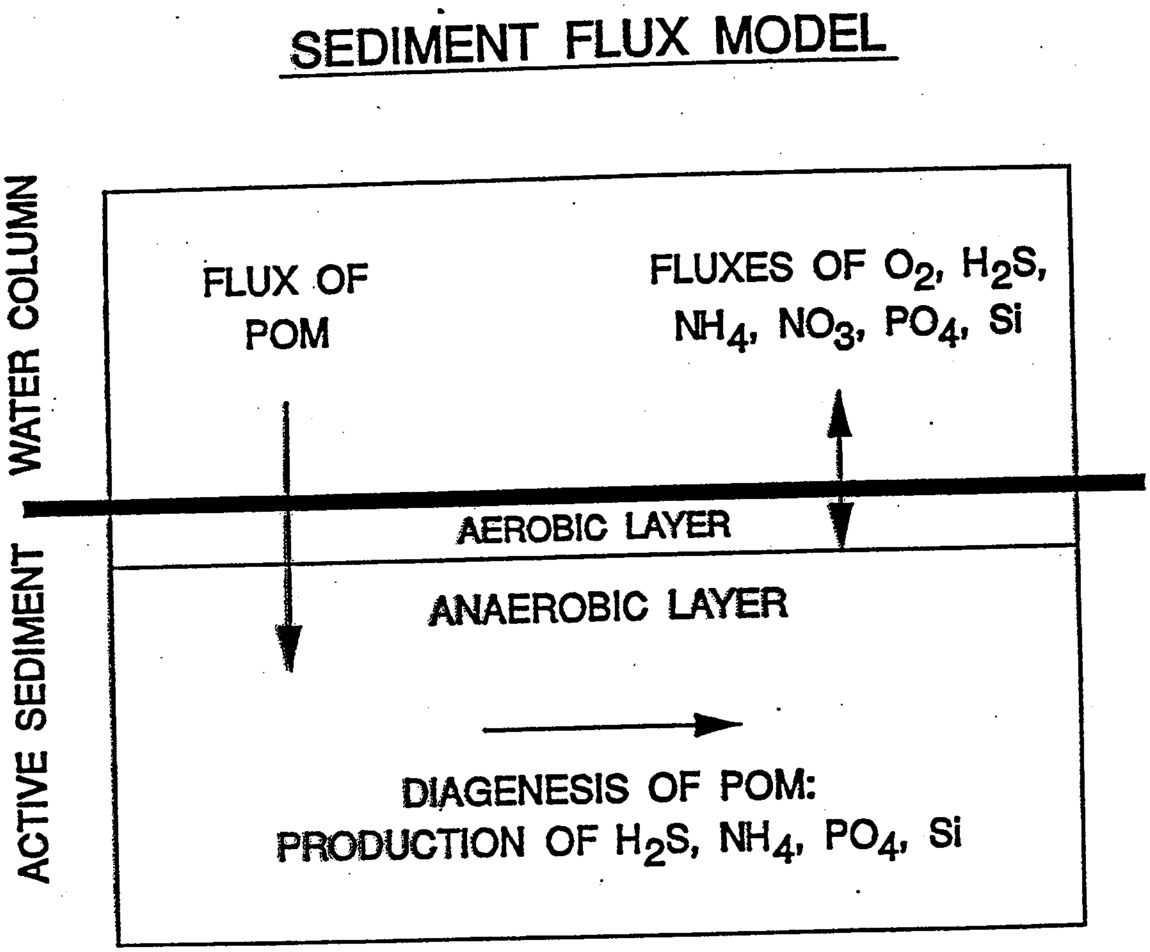
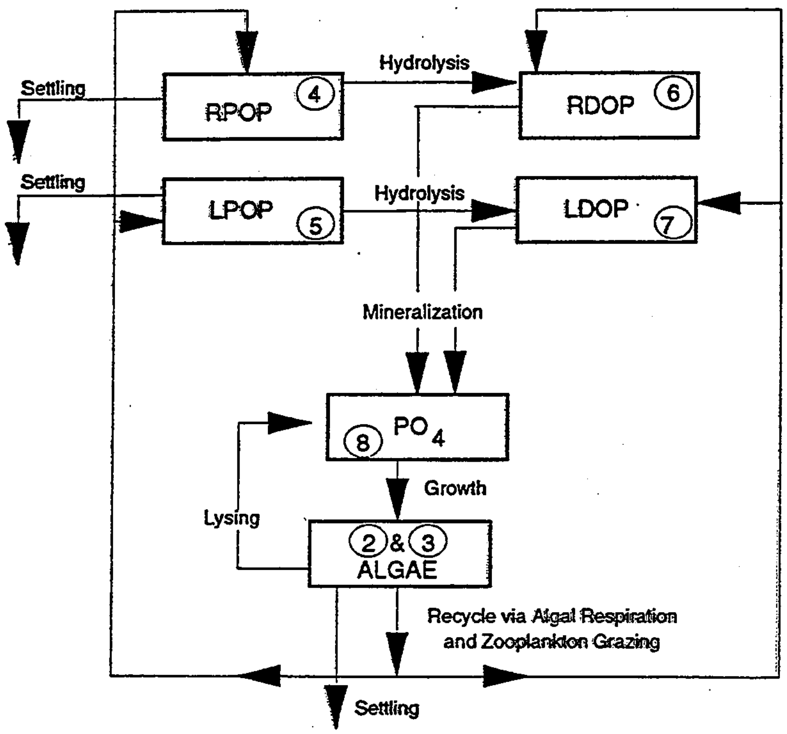


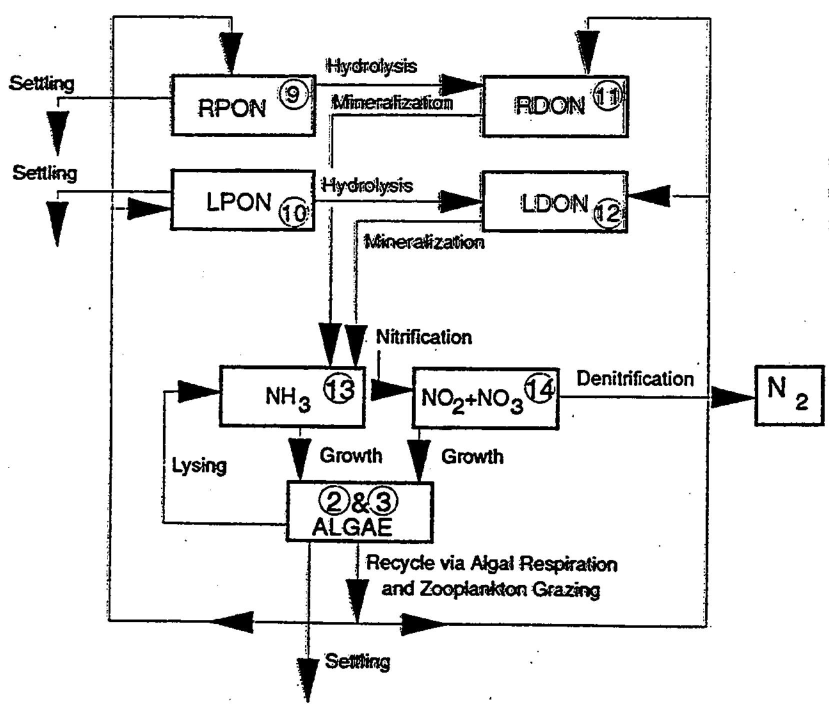
FIGURE 4-4. SEDIMENT FLUX MODEL



PHOSPHORUS KINETICS

(4) = System Number

RPOP = Refractory Particulate Organic Phosphorus
LPOP = Labile Particulate Organic Phosphorus
RDOP = Refractory Dissolved Organic Phosphorus
LDOP = Labile Dissolved Organic Phosphorus
PO_4 = Inorganic Phosphorus (Orthophosphate)



NITROGEN KINETICS

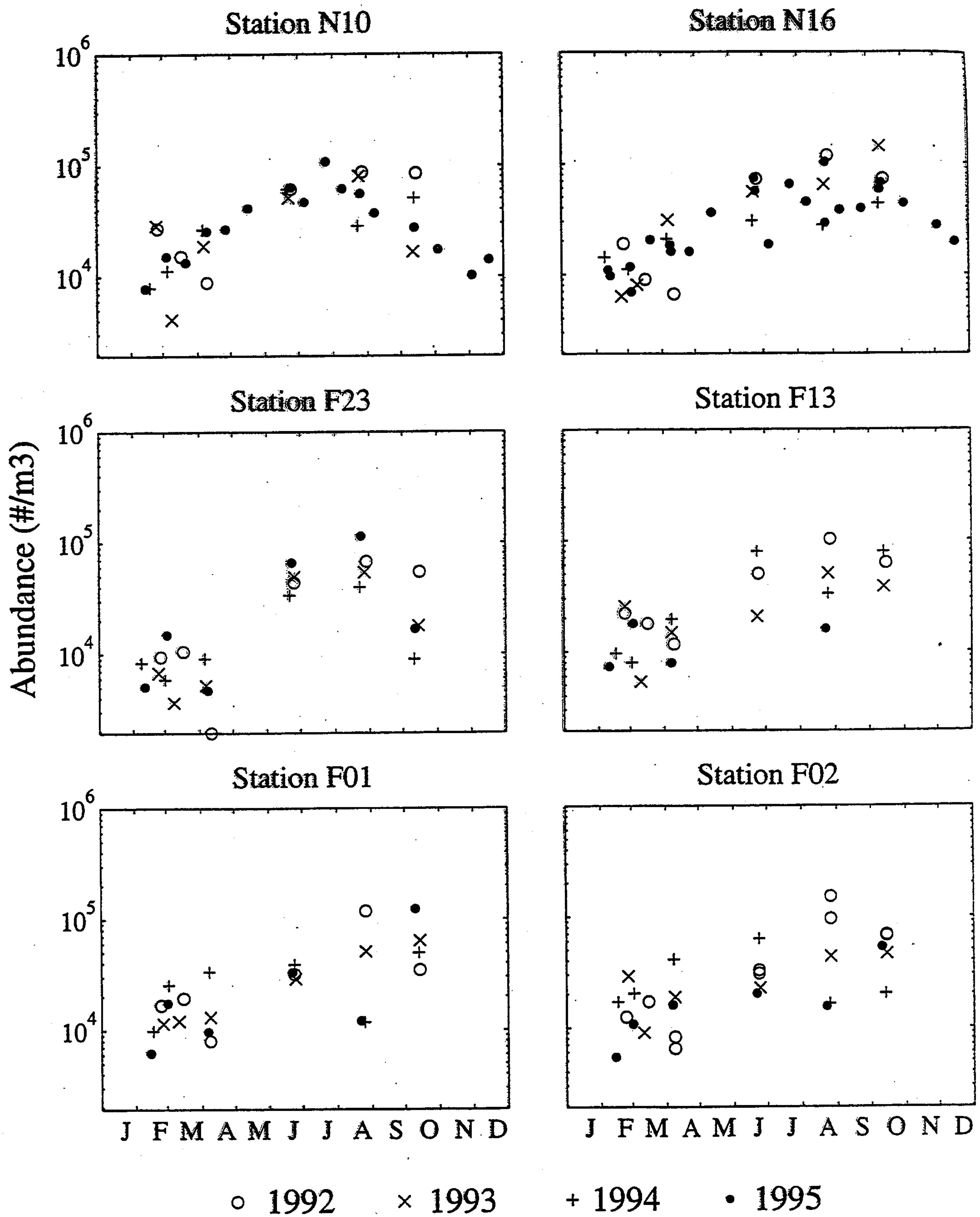
(9) = System Number

RPON = Refractory Particulate Organic Nitrogen
LPON = Labile Particulate Organic Nitrogen
RDON = Refractory Dissolved Organic Nitrogen
LDON = Labile Dissolved Organic Nitrogen
NH_3 = Ammonia Nitrogen
NO_2+NO_3 = Nitrite + Nitrate Nitrogen

FIGURE 4-1. PRINCIPAL KINETIC INTERACTIONS FOR PHOSPHORUS AND NITROGEN

FIGURE 4-32

Total Zooplankton



Net Algal Growth:

$$G = [R_N R_L \mu_{sx} (T) (1 - r_g) - r_b(T) - G_{rz} (T) - \frac{V_{sb}}{H} - \frac{V_{sn}}{H} (1 - R_n)] P_c$$

Carbon to Nitrogen Ratio (weight)

$$\frac{C}{N} = 5.67 + \alpha (1 - R_N)$$

Chlorophyll to Carbon Ratio

$$\frac{Chl-a}{c} = \beta_1 + \beta_2 R_N (1 - R_L)$$

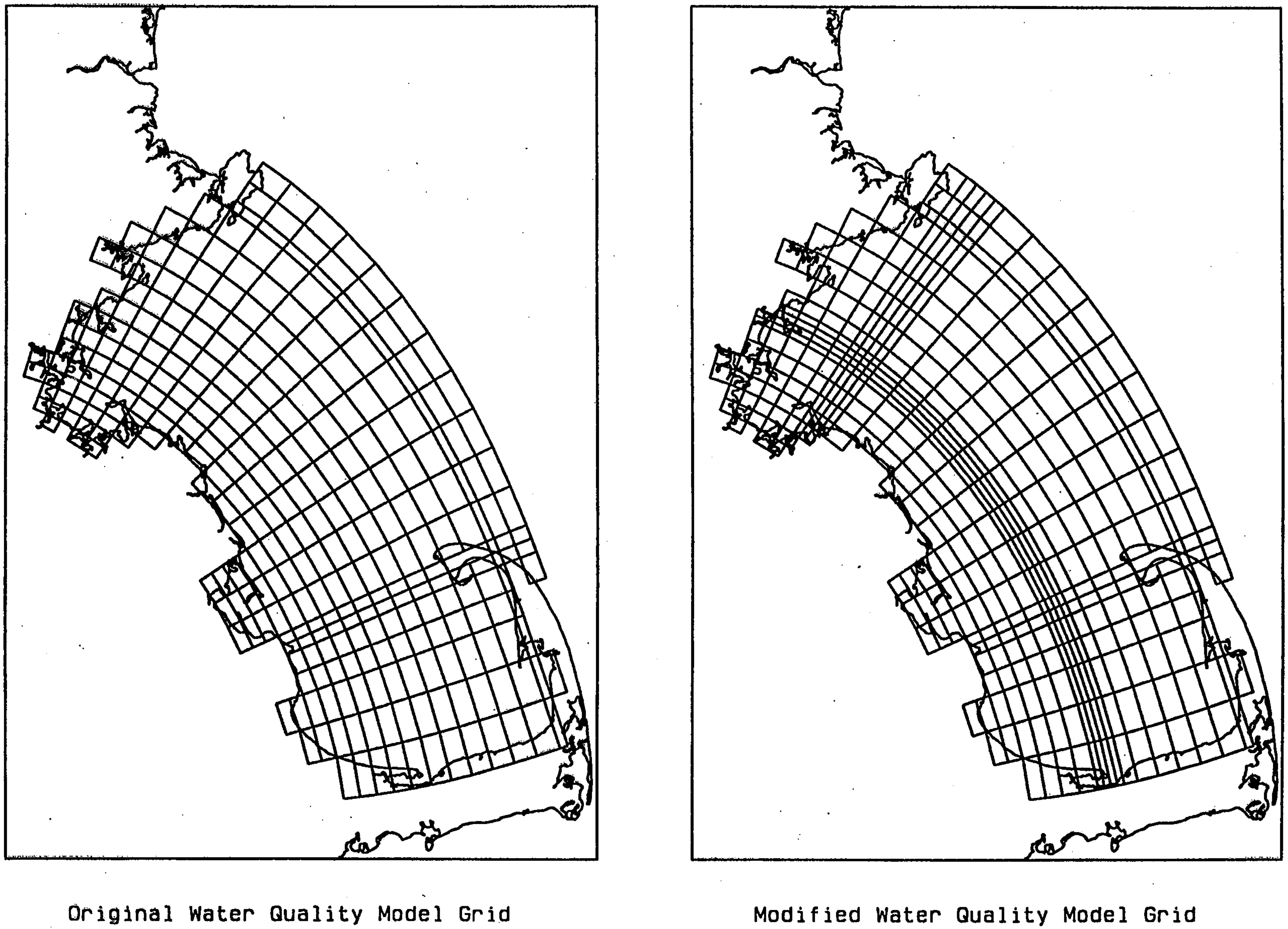


FIGURE 7-1. ORIGINAL AND MODIFIED WATER QUALITY MODEL GRIDS

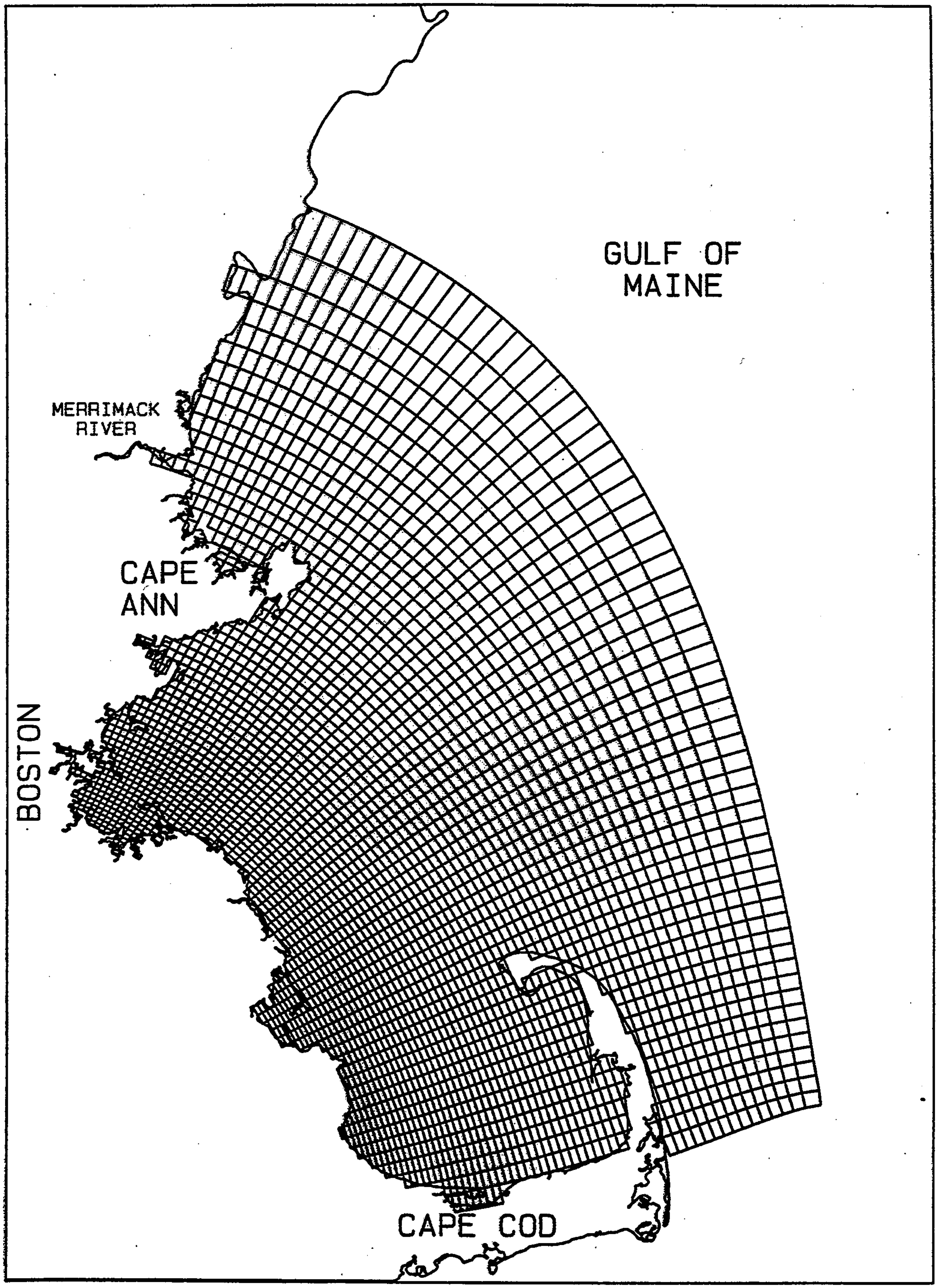
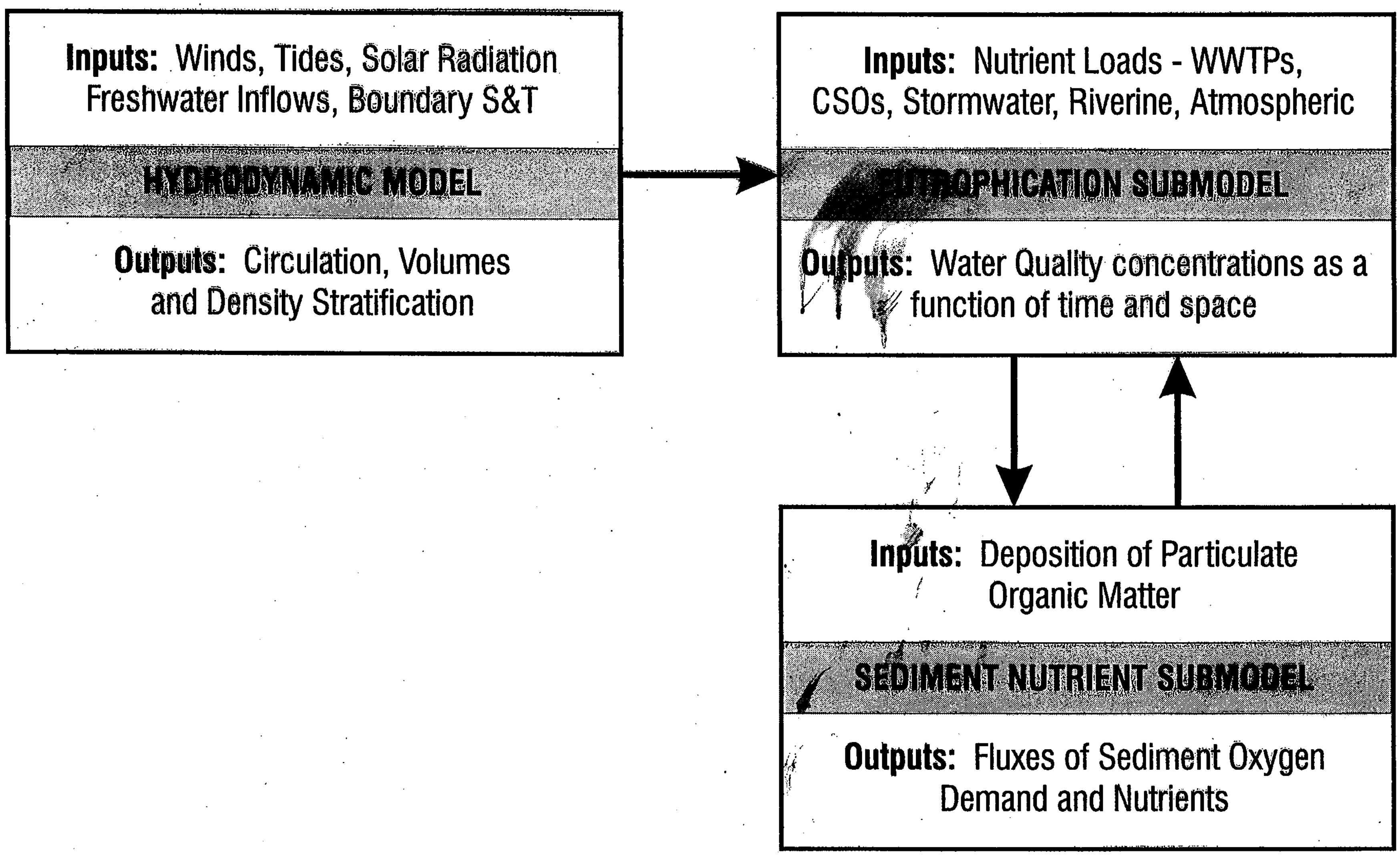


FIGURE 5-1. HYDRODYNAMIC MODEL GRID

MASSACHUSETTS BAY EUTROPHICATION MODEL



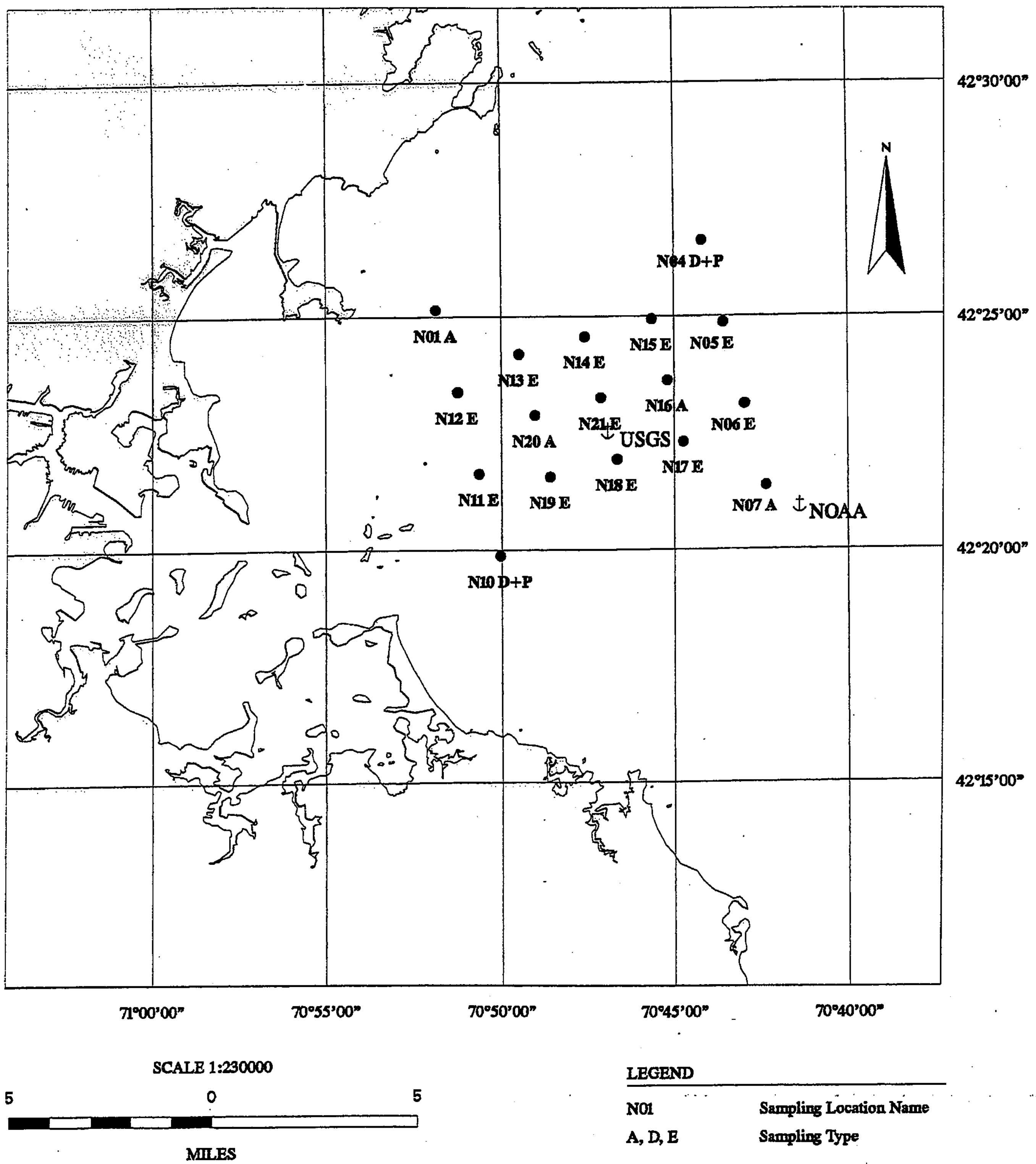
APPENDIX B-3
Nearfield Carbon/Oxygen Balance: Mark Gerath

Nearfield Carbon/Oxygen Balance

Mark Gerath

The Mass Balance

- Changes in C and O Mass within a Defined Volume of the Nearfield
- Changes Based on Data Set
  - Change from one survey to the next
    - Accounting for concentration changes and variation in layer dimension
  - Independent estimate of processes
    - Advection, “dispersion”, production, destruction



42°30'00"
42°25'00"
42°20'00"
42°15'00"
71°00'00"
70°55'00"
70°50'00"
70°45'00"
70°40'00"
N
N04 D+P
N01 A
N15 E
N05 E
N14 E
N13 E
N16 A
N12 E
N06 E
N21 E
USGS
N20 A
N17 E
N18 E
N11 E
N19 E
N07 A
NOAA
N10 D+P
SCALE 1:230000
5
0
5
MILES
LEGEND
N01 Sampling Location Name
A, D, E Sampling Type

Goals

- Evaluate Data for Trends in Carbon and Oxygen Dynamics
  - Relative magnitude of different fluxes, gradients
  - Fluxes relative to measured shifts in concentration
  - Apparent fluxes around DO minima, DO rebound, blooms
  - Quantify fluxes for potential evaluation of numerical model
- Develop a Semi-quantitative Predictive Tool
  - Evaluate additional carbon loading beneath the pycnocline

Processes Considered

- Survey-to-Survey Changes in Mass
- Advection into Nearfield - Daily Average Current Velocity and Distribution of Concentration
- "Dispersion" - Simple Approach to Advection on Short Length and Time Scales
  - Function of hydrodyamics and horizontal, vertical concentration gradients
- Production - Measured Photosynthesis, Respiration, Benthic Fluxes

$$\frac{\partial \langle C \rangle_z}{\partial t} = [u \frac{\partial \langle C \rangle_z}{\partial x} + v \frac{\partial \langle C \rangle_z}{\partial y}] + [\frac{\partial \langle u' C' \rangle_z}{\partial x} + \frac{\partial \langle V' C' \rangle_z}{\partial y}] +$$

Measured Change — Advection — Correlation Between Velocity and Concentrations

$$K_h \left(\frac{\partial^2 \langle C \rangle_z}{\partial x^2} + \frac{\partial^2 \langle C \rangle_z}{\partial y^2} \right) + \frac{K_z}{z_2 - z_1} \left[\frac{\partial \langle C \rangle_z}{\partial z} \right]_{z_1}^{z_2} + \langle R_c \rangle_z$$

x,y Dispersion — Interlayer Dispersion — Reactions

Data Used

- 1996 Survey Data
- Current Meter Mooring - 3 Depths
- Salinity
  - Used to evaluate approach, parameters
  - Definition of pycnocline
    - Up to three layers - upper, lower, bottom
- Dissolved Oxygen - 0.5 Meter Bins
- Organic Carbon - Lower Frequency Lab. Measurements

Challenge is Reconciling Data

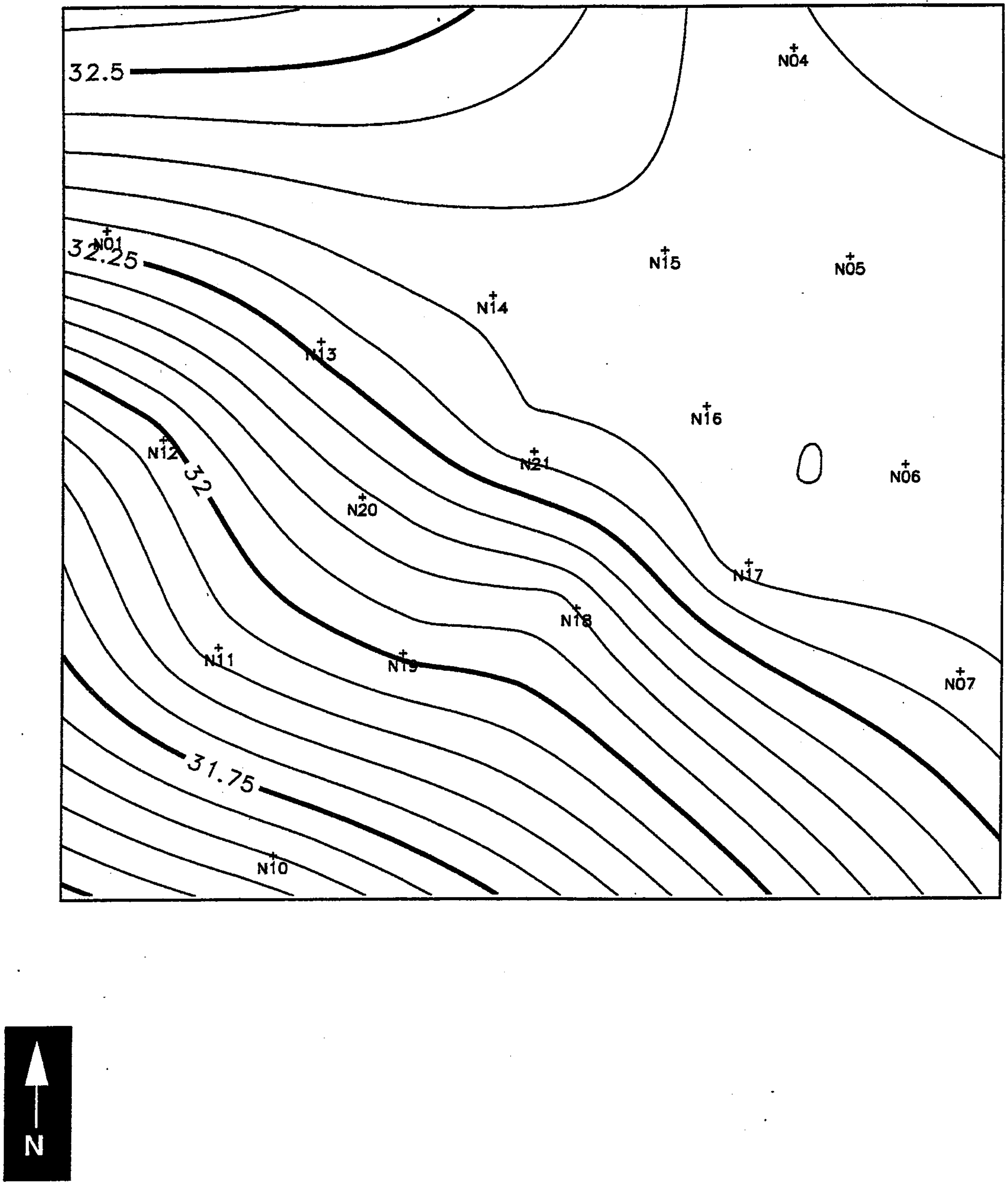
- Different Time and Space Scales
- Current Measurements
  - High time resolution
  - One point in x-, y-space
  - Three points in depth
- Water Quality
  - Good spatial resolution
  - Relatively poor resolution in time
  - Mooring provides some data

Process Outline - I

- Define Pycnocline Surface by Survey
  - Define layer depth, volume
  - Calculate depth-averaged concentration distribution within a layer
  - Calculate first and second derivative of concentration
- Calculate Velocity Series by Day - Smoothed Data
- Calculate Salinity Series by Day
  - Interprelation between surveys modified to account for mooring data
  - Day-by-day calculation of processes using daily velocities

Process Outline - II

- Evaluate Equation Performance for Salinity
  - No confounding influence of reactions
  - Potentially modify dispersion coefficients
  - Take a hard look at feasibility of approach
- Use Estimated K_h and K_z and Estimates of Reactions to Repeat Time Series for C and O
- Evaluate Relative Fluxes at Different Time Scales
  - Consider uncertainty in approach

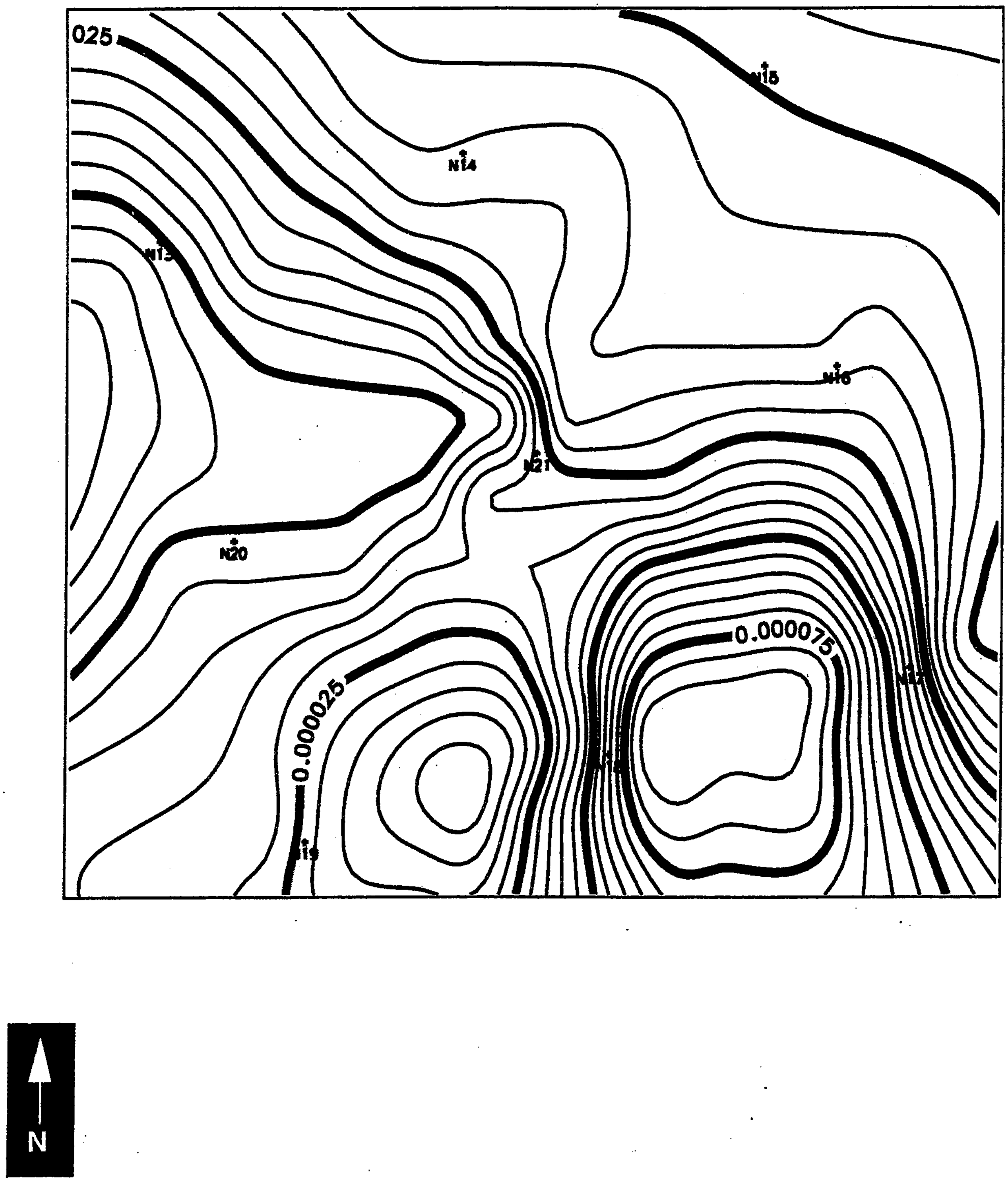


ENSR

Salinity – W9601 – Bottom Layer

Concentration (PPT)

4501-007-29G

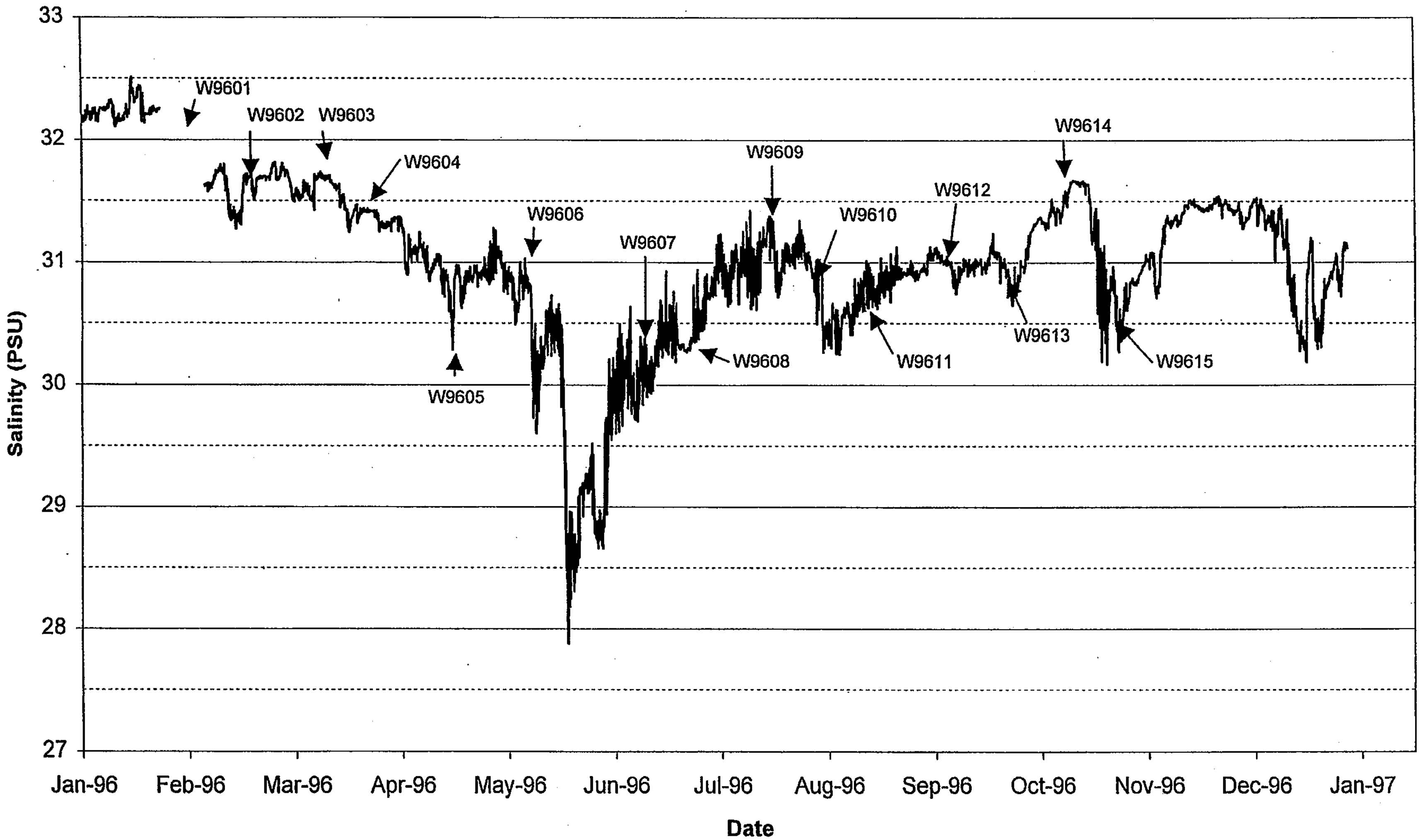


ENSR

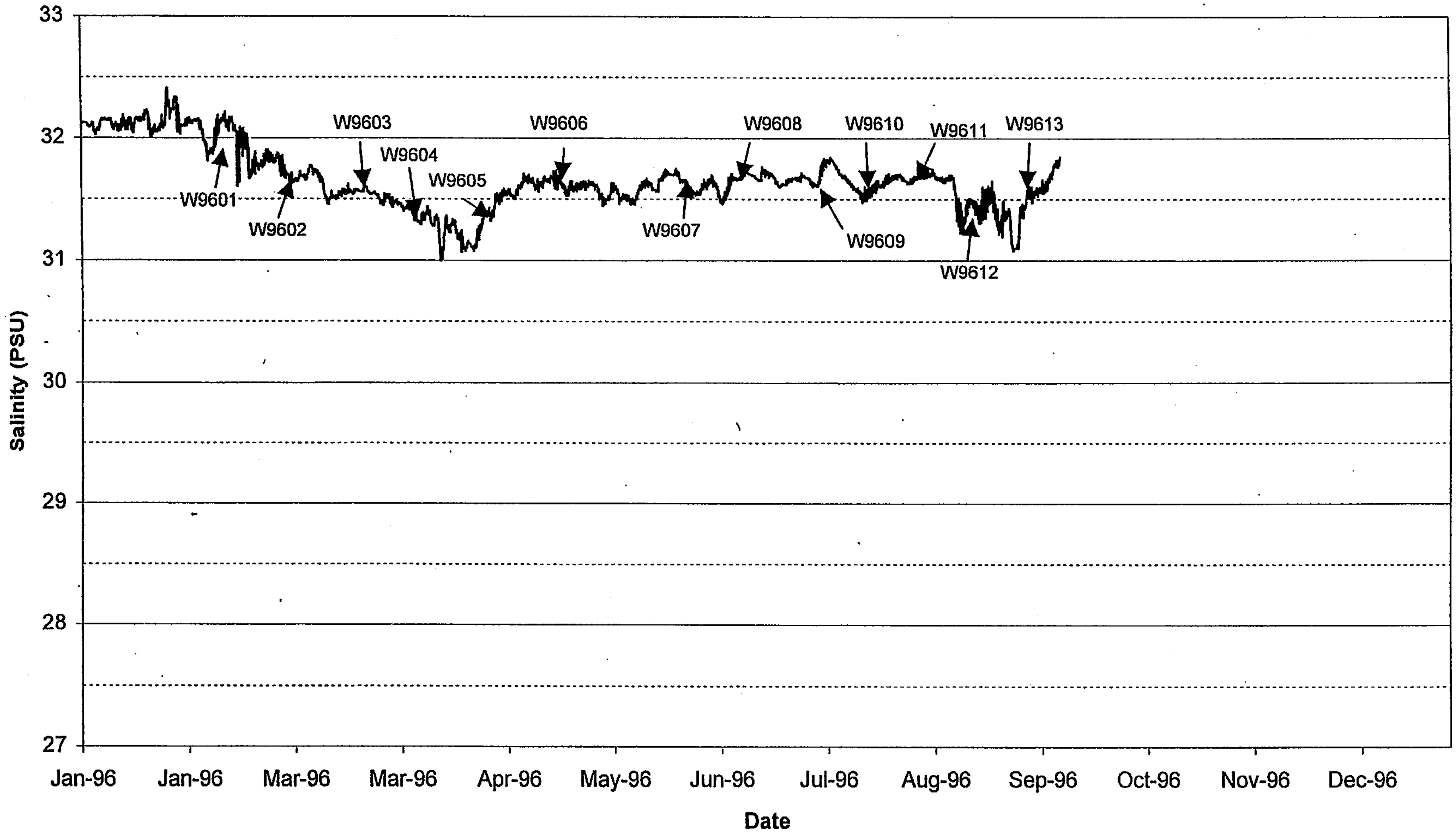
Salinity – W9601 – Bottom Layer
Ist Derivative Gradient (PPT/meter)

4501–007–29G

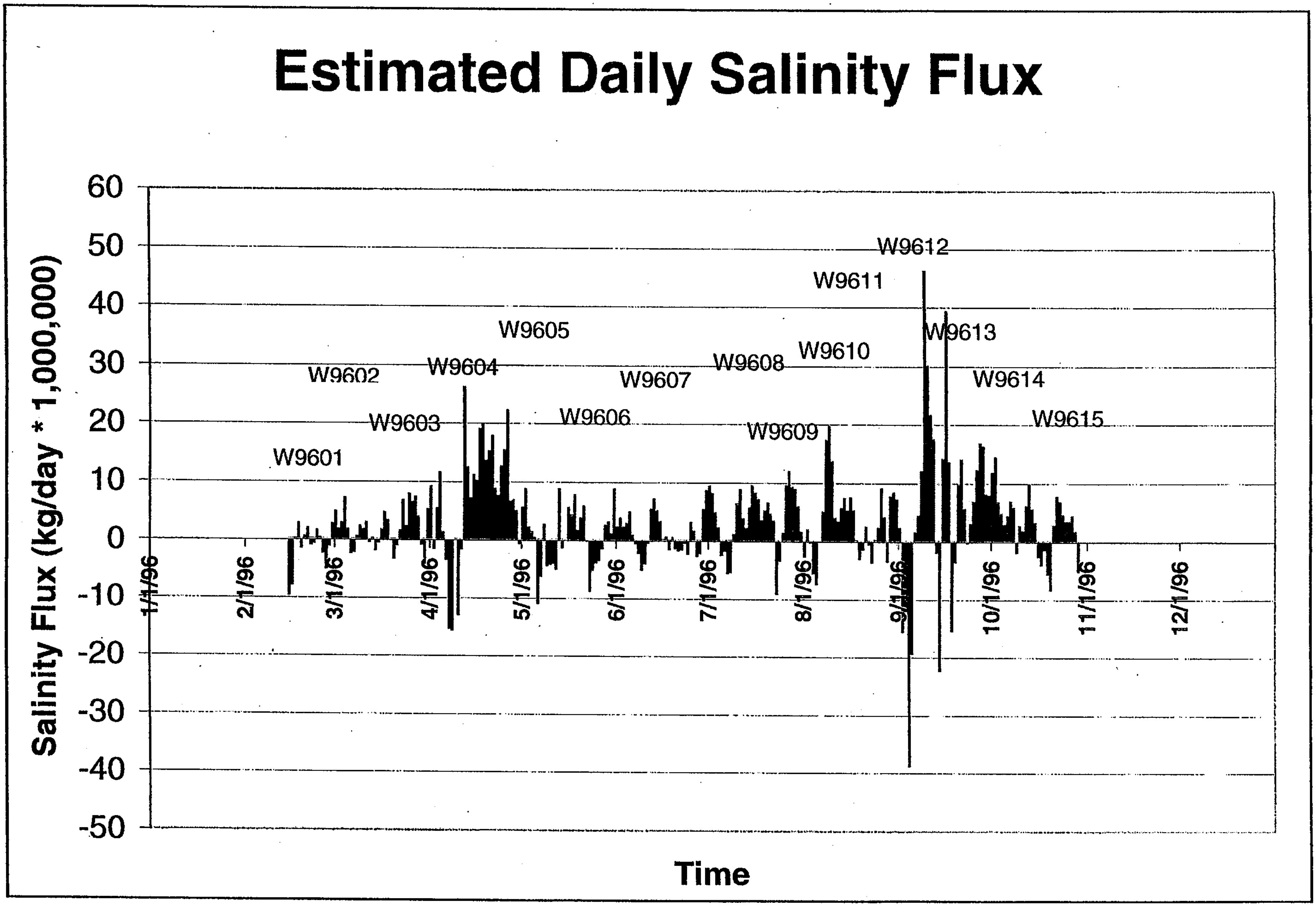
1996 Salinity Values at 5 Meters Depth
USGS Nearfield Buoy



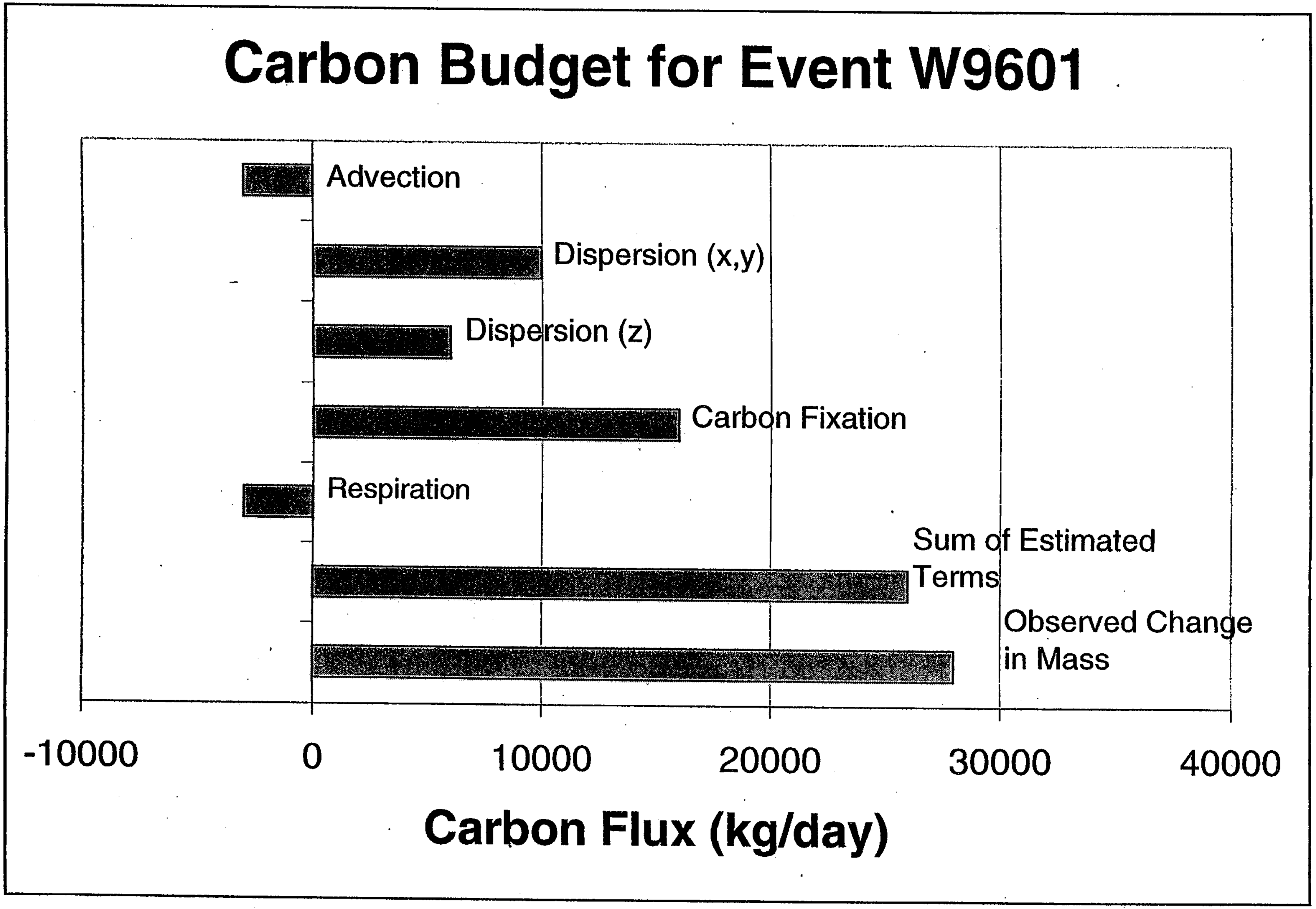
1996 Salinity Values at 29.5[1] Meters Depth
USGS Nearfield Buoy



[1]Depth of buoy from January February 1996 to is 27.5 meters, from February to June 1996 it is 31.3 meters, and from June to October it is 29.6 meters.



Estimated Daily Salinity Flux
Salinity Flux (kg/day * 1,000,000)
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
1/1/96
2/1/96
3/1/96
4/1/96
5/1/96
6/1/96
7/1/96
8/1/96
9/1/96
10/1/96
11/1/96
12/1/96
Time
W9601
W9602
W9603
W9604
W9605
W9606
W9607
W9608
W9609
W9610
W9611
W9612
W9613
W9614
W9615

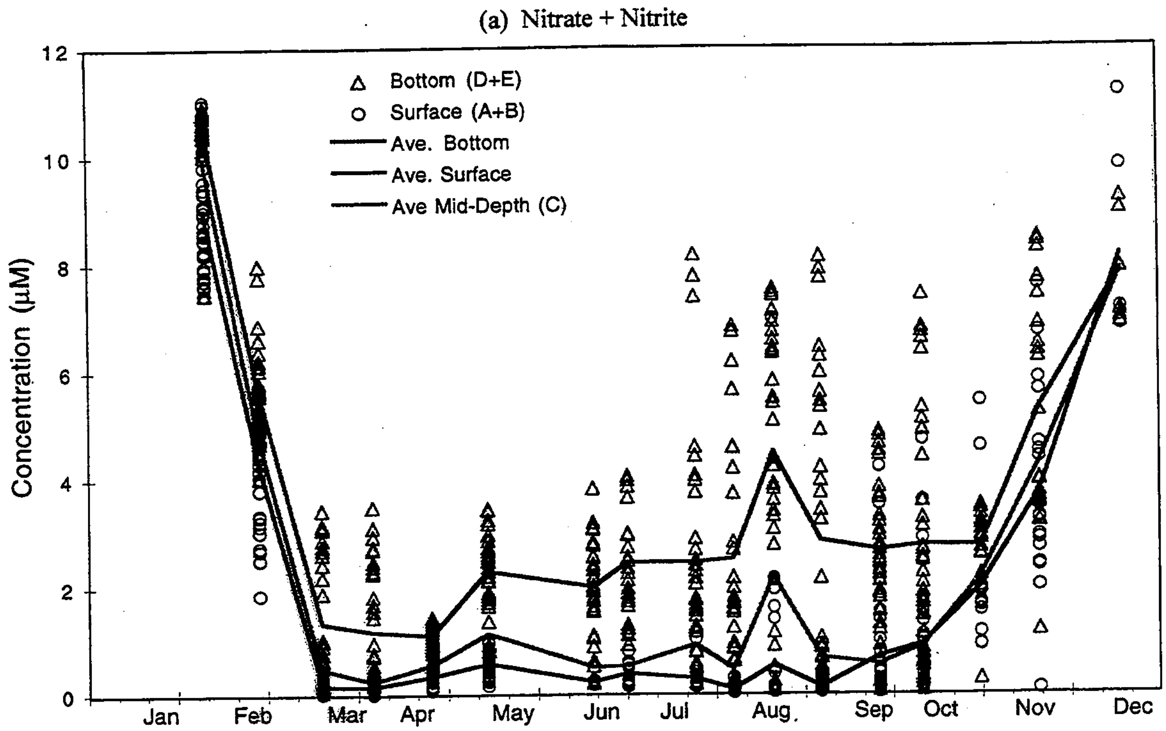

Carbon Budget for Event W9601
Advection
Dispersion (x,y)
Dispersion (z)
Carbon Fixation
Respiration
Sum of Estimated Terms
Observed Change in Mass
-10000
0
10000
20000
30000
40000
Carbon Flux (kg/day)

APPENDIX B-4

Not Available:

Stratification, Advection and Upwelling: Bernie Gardner

APPENDIX B-5
Potential Implications of Altered Nutrient Field: Ted Loder



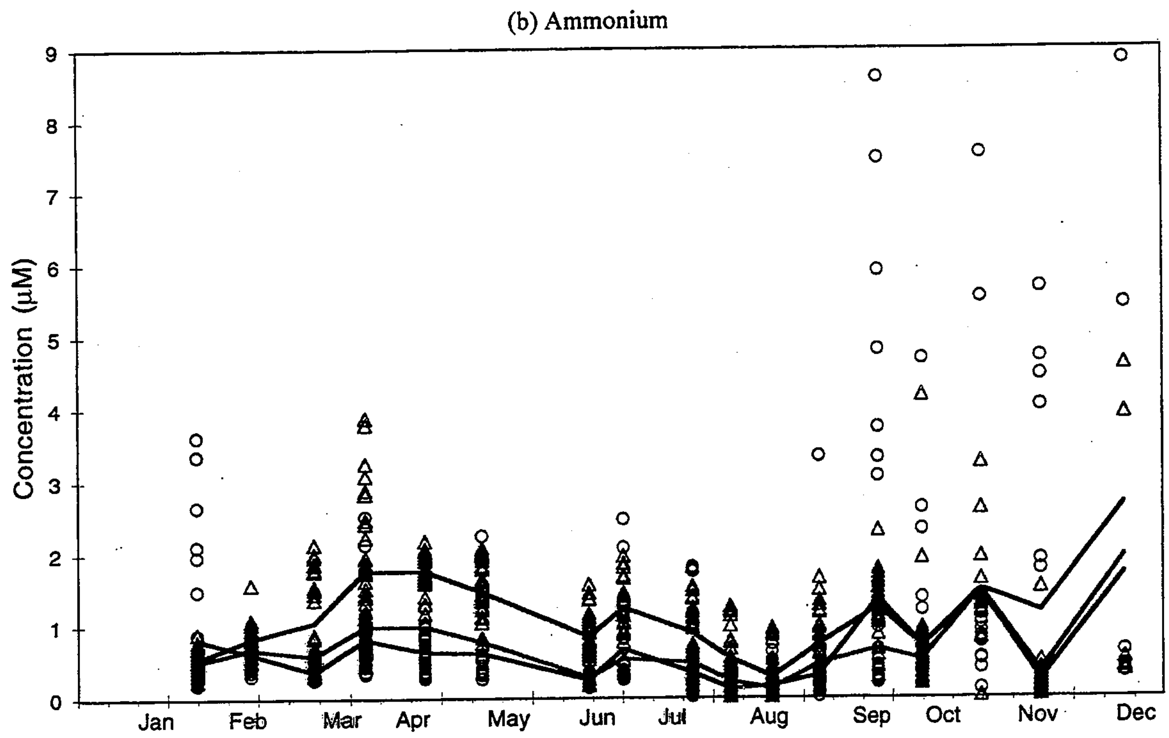


FIGURE 4-261
1996 Nearfield Nutrient Cycles
Surface, Bottom, Surface Averages, Mid-Depth Averages, and Bottom Averages

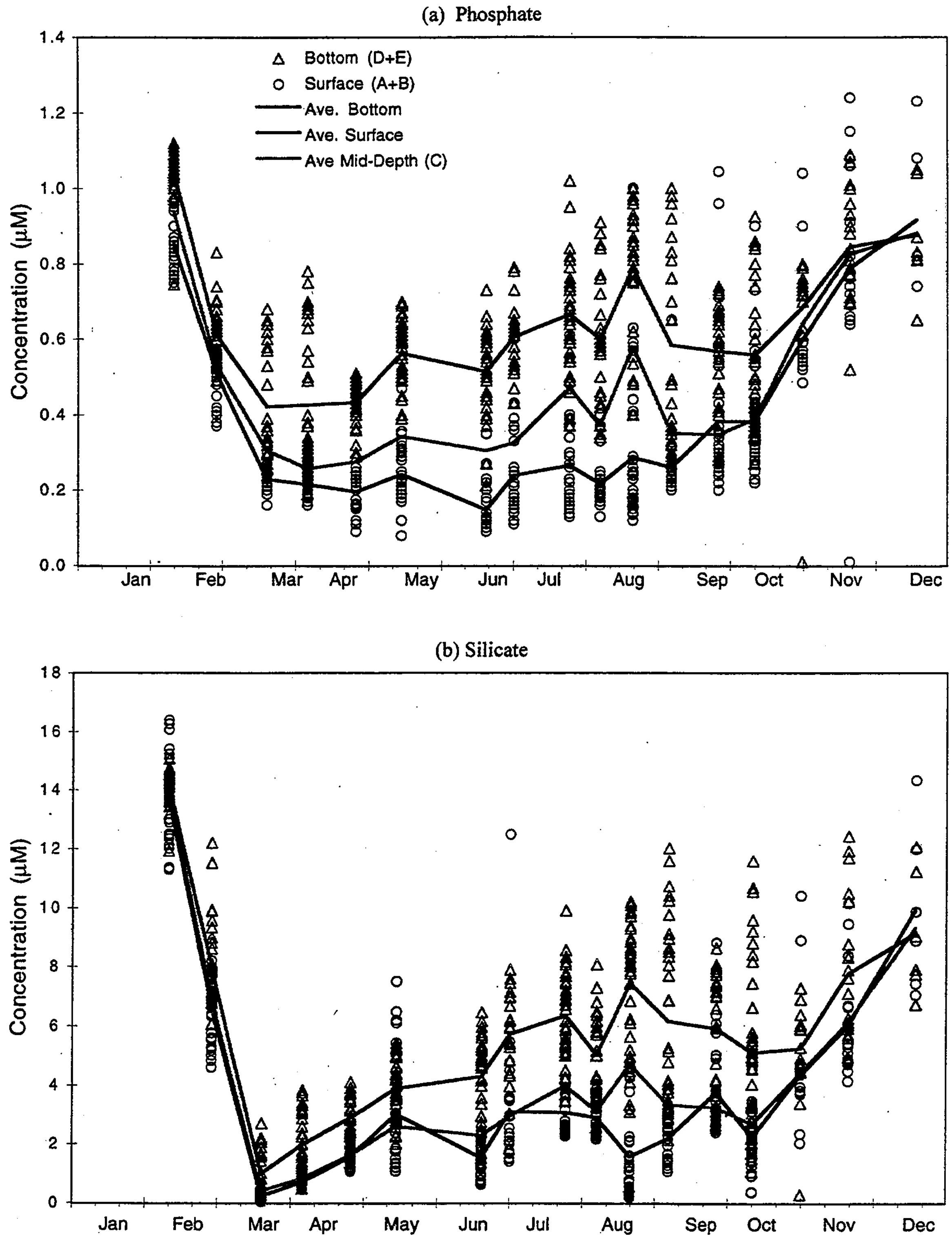
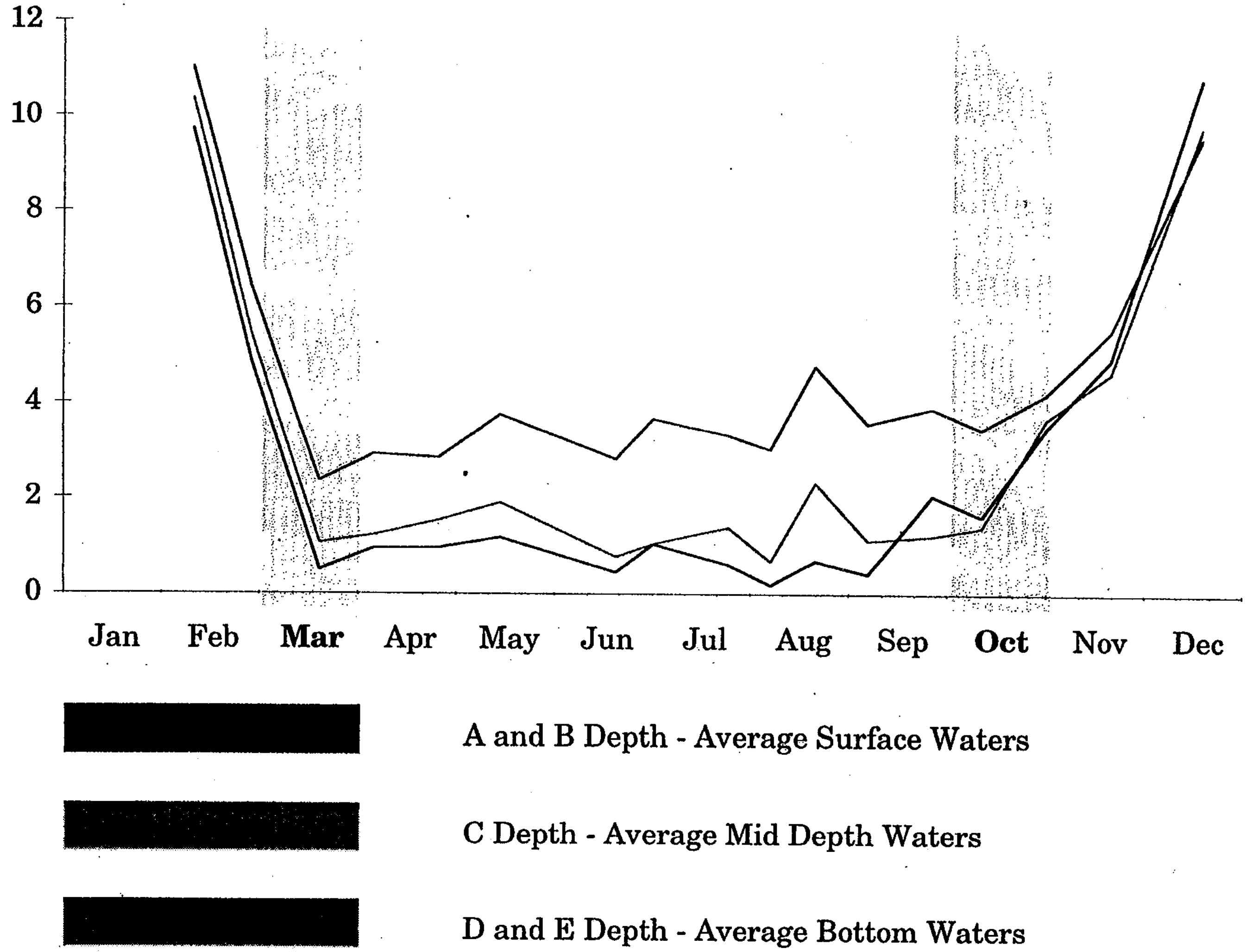
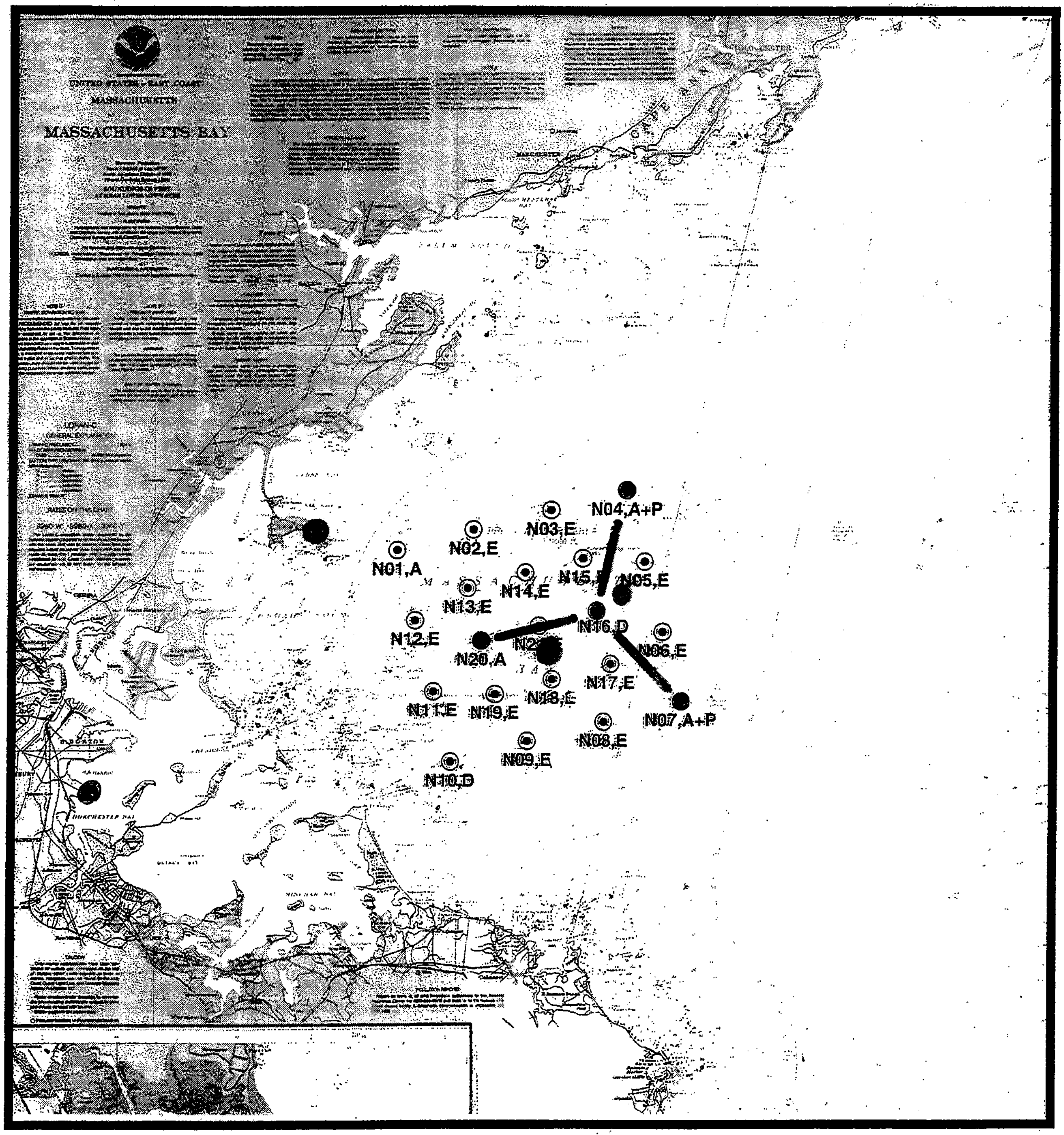


FIGURE 4-262
1996 Nearfield Nutrient Cycles
Surface, Bottom, Surface Averages, Mid-Depth Averages, and Bottom Averages

Nearfield Average Nutrient Concentrations



Station Map



LEGEND

N01	Sampling Location Name
A,D,E	Sampling Type

0 5 10

Nautical Miles

● • P2, B03,

● • 8

● • Light

● 1992 - 1996 ave.

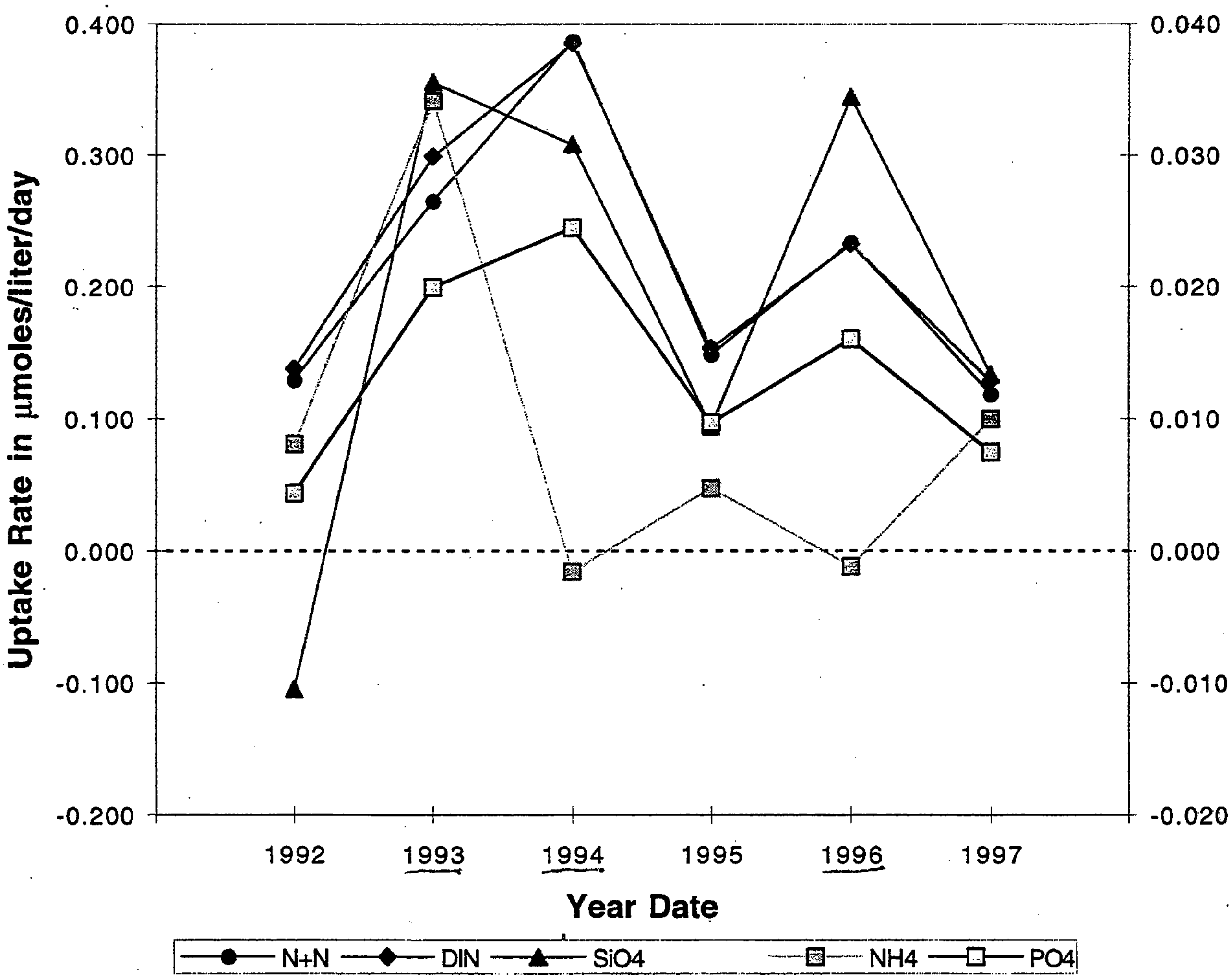
Station Map courtesy of ENSR Consulting & Engineering

Average Nutrient Uptake Rates for 1992 - 1997 Spring Bloom Period

All Uptake Rates in µmoles/liter/day

	Year	Julian Day Start	Julian Day End	Days	DIN	NH4	N+N	PO4	SiO4
#	1997	33	90	57	0.128	0.010	0.118	0.007	0.133
*	1996	40	79	39	0.232	-0.001	0.233	0.016	0.344
#	1995	99	136	37	0.153	0.005	0.148	0.010	0.094
*	1994	66	83	17	0.385	-0.002	0.387	0.024	0.308
*	1993	84	100	16	0.298	0.034	0.264	0.020	0.355
#	1992	57	102	45	0.137	0.008	0.129	0.004	-0.105

	DIN	NH4	N+N	PO4	SiO4
***Rapid** growth years. Average:	0.305	0.010	0.295	0.020	0.336
#**Slow** growth years. Average:	0.140	0.008	0.132	0.007	0.041



Spring Bloom Production Rates and Totals based on 1996 data

Nutrient Basis	Total Days	Total Daily Prod (mg C/m²/d)	Total Prod/ Period(g C/m²)	Total Spring Prod (g C/m²)
N+N	18	753	13.6	**25.3**
	21	561	11.8	
DIN	18	742	13.4	**25.2**
	21	562	11.8	
PO4	18	988	17.8	**28.3**
	21	502	10.5	
				1:1 (0.7:1)
SiO4	18	1034	18.6	**37.5 (26.2)**
	21	899	18.9	

These calculations assume Carbon to Nutrient ratios (C:N:P:Si) of **106:16:1:16**. Note that this implies a DIN : Si ratio of 1:1 which may be too high. If a DIN : Si ratio of 0.7:1 (actual observed is 0.67:1) is used so that the C:Si ratio ends up at 106:22.9, then Carbon production based on SiO4 uptake is: 26.2 g C/m^2.

Survey #	Date	Δ Days	Aver. N+N (μM)	Δ N+N (μM)	Δ N+N per day (μM/d)	Est Prim Prod (mg C/m³/d)	Avg Dep (M)	Est Prim Prod (mg C/m²/d)	Total Water Col Prod(mg C/m²/d)
Surf 1	2/9/96		8.90				15.9		
Surf 2	2/27/96	18	4.24	-4.67	-0.259	20.6	16.2	334	
Surf 3	3/19/96	21	0.14	-4.10	-0.195	15.5	17.2	267	
Bot 1	2/9/96		10.49				19.6		Surf + Bottom
Bot 2	2/27/96	18	5.60	-4.89	-0.272	21.6	19.3	419	753
Bot 3	3/19/96	21	1.32	-4.28	-0.204	16.2	18.1	294	561

Survey #	Date	Δ Days	Aver. DIN (μM)	Δ DIN (μM)	Δ DIN per day (μM/d)	Est Prim Prod (mg C/m³/d)	Avg Dep (M)	Est Prim Prod (mg C/m²/d)	Total Water Col Prod(mg C/m²/d)
Surf 1	2/9/96		9.71				15.9		
Surf 2	2/27/96	18	4.85	-4.86	-0.270	21.5	16.2	348	
Surf 3	3/19/96	21	0.49	-4.36	-0.208	16.5	17.2	284	
Bot 1	2/9/96		11.02				19.6		Surf + Bottom
Bot 2	2/27/96	18	6.41	-4.61	-0.256	20.4	19.3	394	742
Bot 3	3/19/96	21	2.36	-4.05	-0.193	15.4	18.1	278	562

Survey #	Date	Δ Days	Aver. PO_4 (μM)	Δ PO_4 (μM)	Δ PO_4 per day (μM/d)	Est Prim Prod (mg C/m³/d)	Avg Dep (M)	Est Prim Prod (mg C/m²/d)	Total Water Col Prod(mg C/m²/d)
Surf 1	2/9/96		0.85				15.9		
Surf 2	2/27/96	18	0.51	-0.34	-0.019	24.3	16.2	394	
Surf 3	3/19/96	21	0.23	-0.28	-0.013	17.0	17.2	293	
Bot 1	2/9/96		1.05				19.6		Surf + Bottom
Bot 2	2/27/96	18	0.61	-0.43	-0.024	30.7	19.3	594	988
Bot 3	3/19/96	21	0.42	-0.19	-0.009	11.5	18.1	209	502

Survey #	Date	Δ Days	Aver. SiO_4 (μM)	Δ SiO_4 (μM)	Δ SiO_4 per day (μM/d)	Est Prim Prod (mg C/m³/d)	Avg Dep (M)	Est Prim Prod (mg C/m²/d)	Total Water Col Prod(mg C/m²/d)
Surf 1	2/9/96		13.67				15.9		
Surf 2	2/27/96	18	6.62	-7.05	-0.392	31.2	16.2	505	
Surf 3	3/19/96	21	0.22	-6.40	-0.305	24.3	17.2	417	
Bot 1	2/9/96		14.19				19.6		Surf + Bottom
Bot 2	2/27/96	18	8.01	-6.18	-0.343	27.3	19.3	529	1034
Bot 3	3/19/96	21	0.98	-7.03	-0.335	26.6	18.1	482	899

TABLE 4-1

Spring bloom primary production estimates based on different nutrient removal rates during Surveys 1-3 for all nearfield stations, 1996. See text for calculation details.

Winter Nutrient Setup Concentrations Pre- and Post- Discharge

Nutrient	Feb '96 Conc. Ave. Bottom (µM)	Estimated Effluent Conc* (µM)	Dilution Factor 150	300	500	700	900	150
N+N	10.49	60	10.8	10.7	10.6	10.6	10.5	1x
DIN	11.02	3060	31.3	21.2	17.1	15.4	14.4	3x
TN	20	3435	42.8	31.4	26.8	24.9	23.8	2x
PO4	1.05	150	2.0	1.5	1.3	1.3	1.2	2x
Si04	14.19	600	18.2	16.1	15.4	15.0	14.8	1.3x

Nutrient Ratios

Ratios	Feb '96 Conc. Bottom Water	Effluent*	Dilution Factor 150	300	500	700	900
DIN/PO4	10.5	20.4	15.4	13.7	12.7	12.2	11.9
DIN/SiO4	0.8	5.1	1.7	1.3	1.1	1.0	1.0
TN/PO4	19.1	22.9	21.0	20.3	20.0	19.8	19.6

*Estimated from Butler et al. 1997 (DEC) data for primary effluent concentrations

NOTE: This assumes that the average bottom water concentrations for 1996 represent the winter nutrient concentrations of GOM dilution waters prior to the outfall going on line. It also assumes that dilution is occurring between the effluent and fresh GOM waters.

Dilution contours, new Bay outfall location

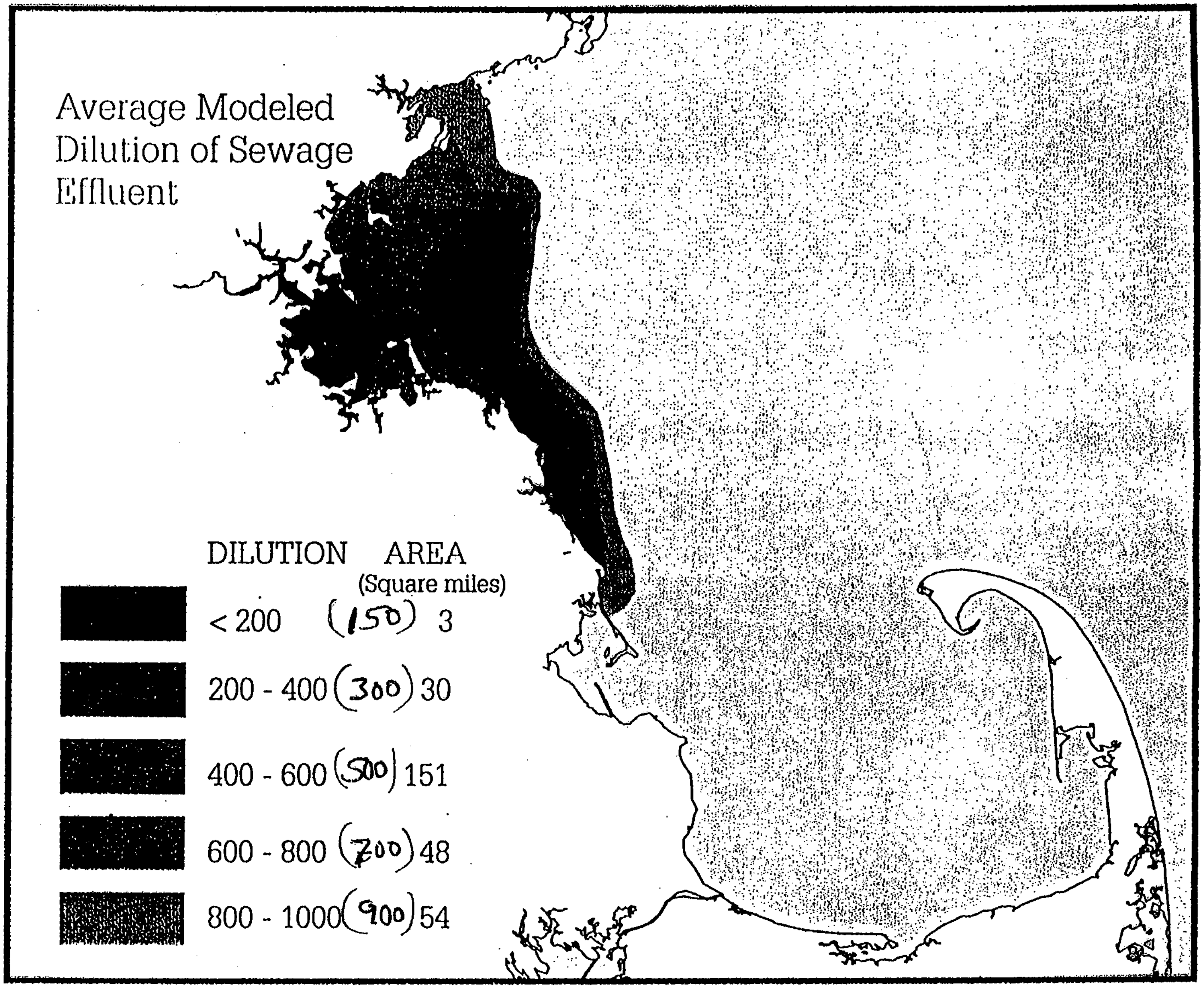
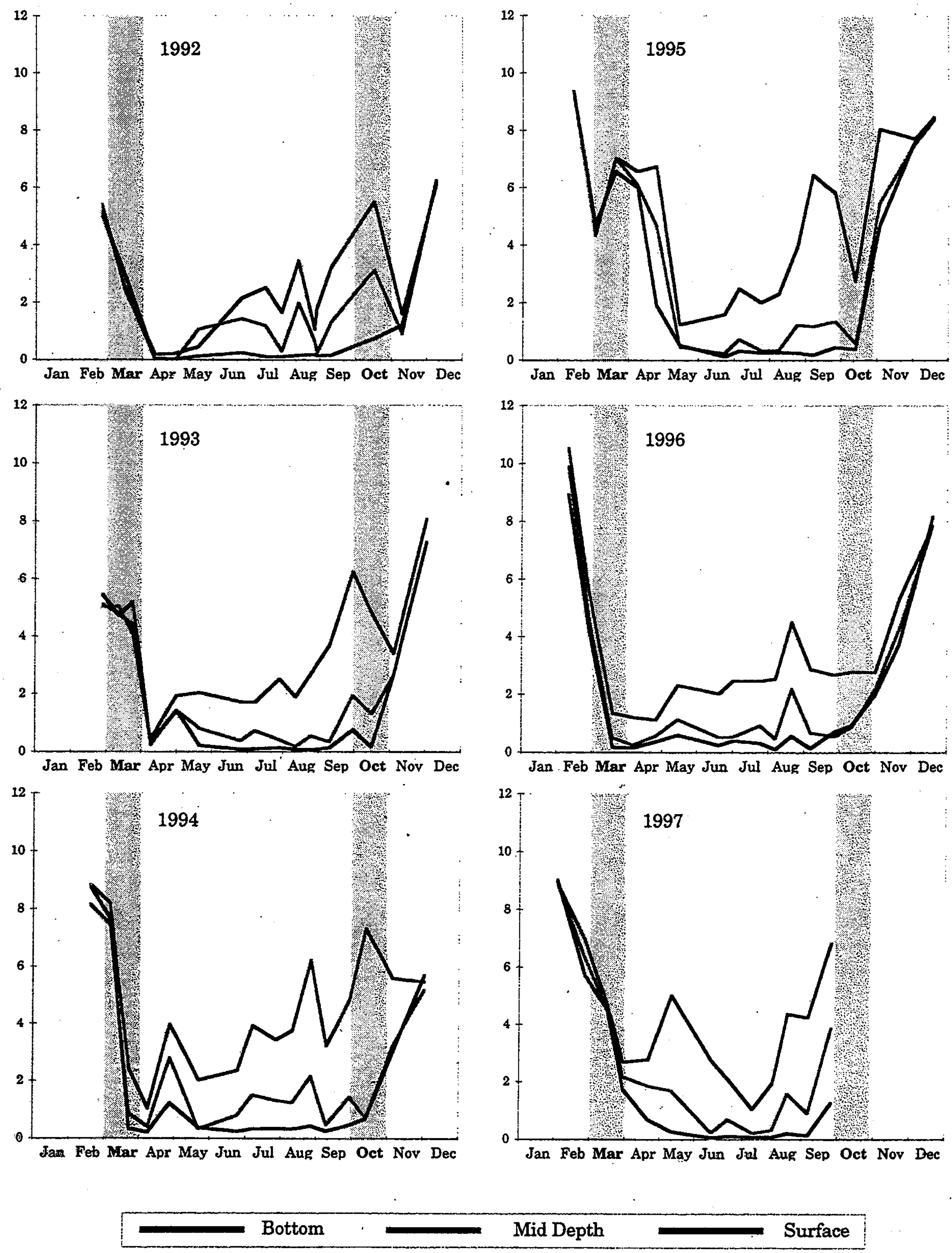
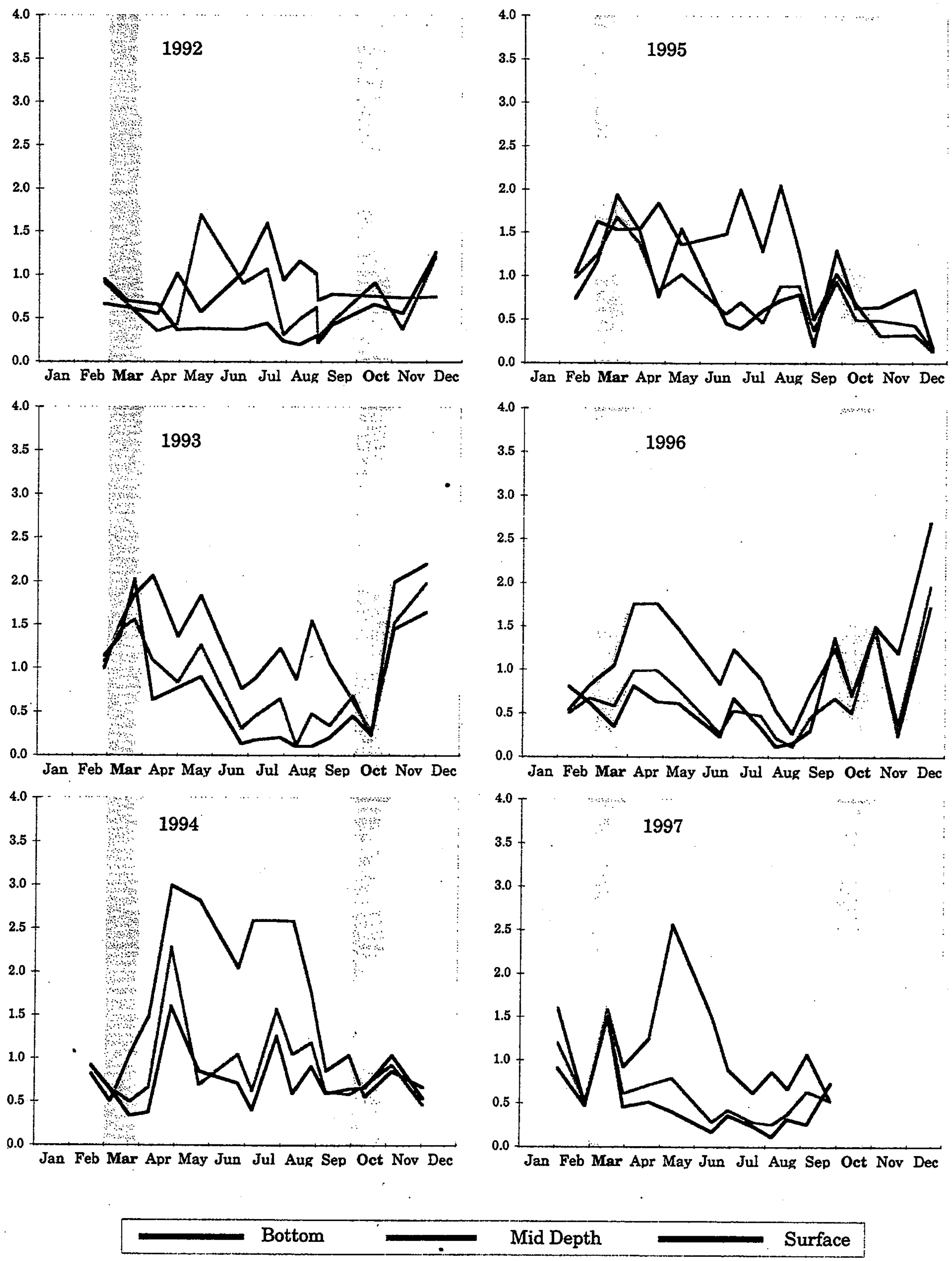


Figure 12b.

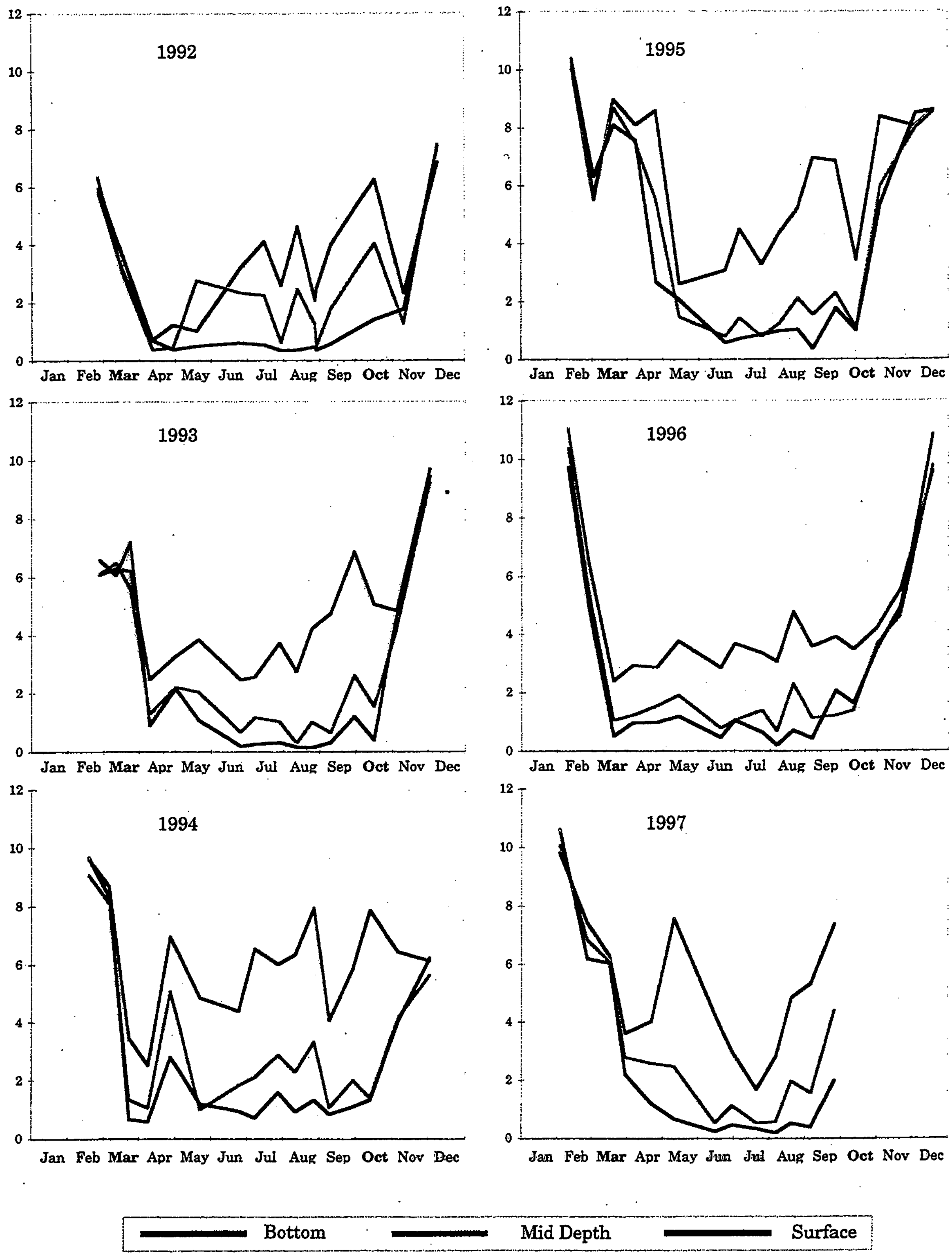
Nitrate plus Nitrite (μM)
All Stations, Nearfield Region



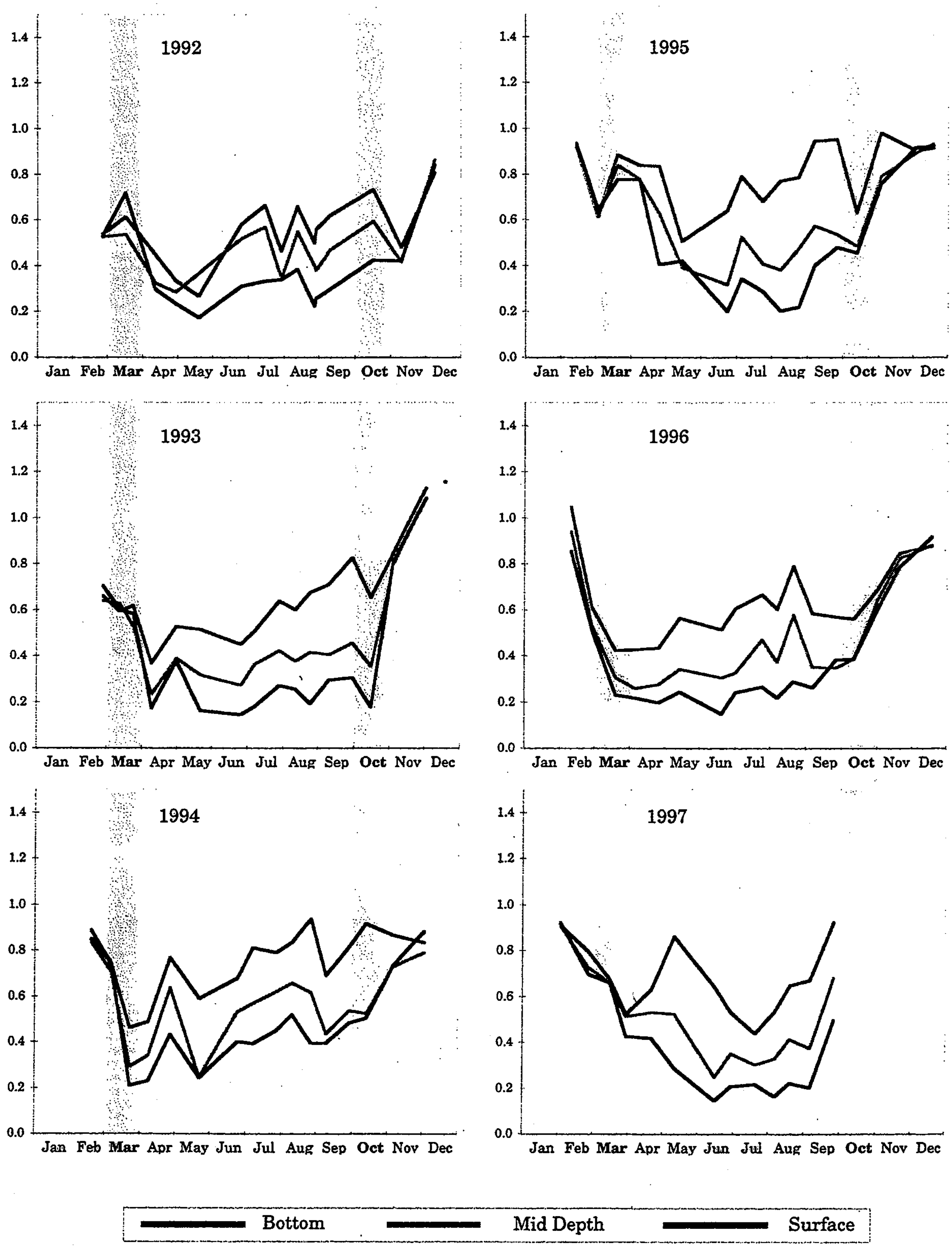
Ammonium (μM)
All Stations, Nearfield Region



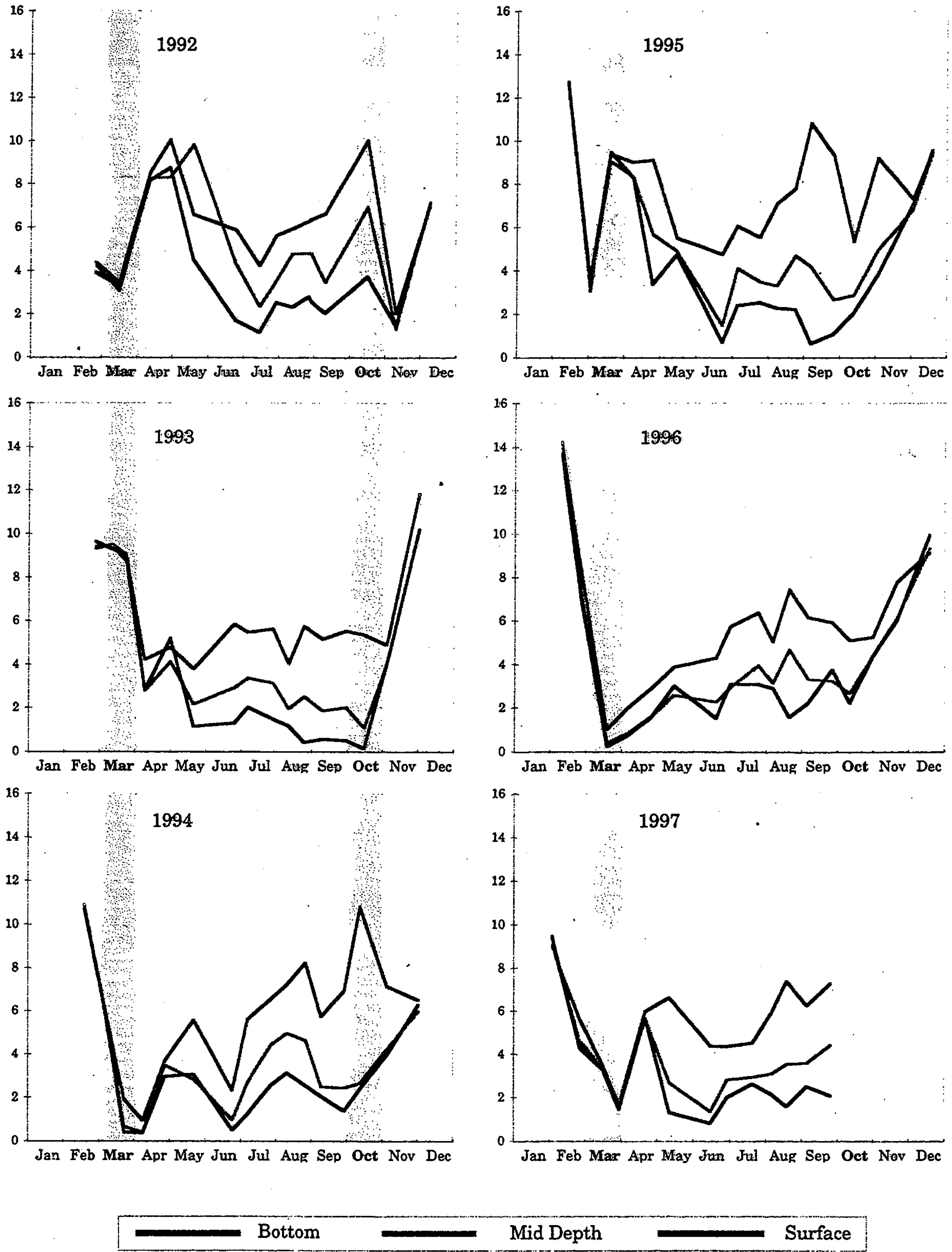
Dissolved Inorganic Nitrogen (μM)
All Stations, Nearfield Region



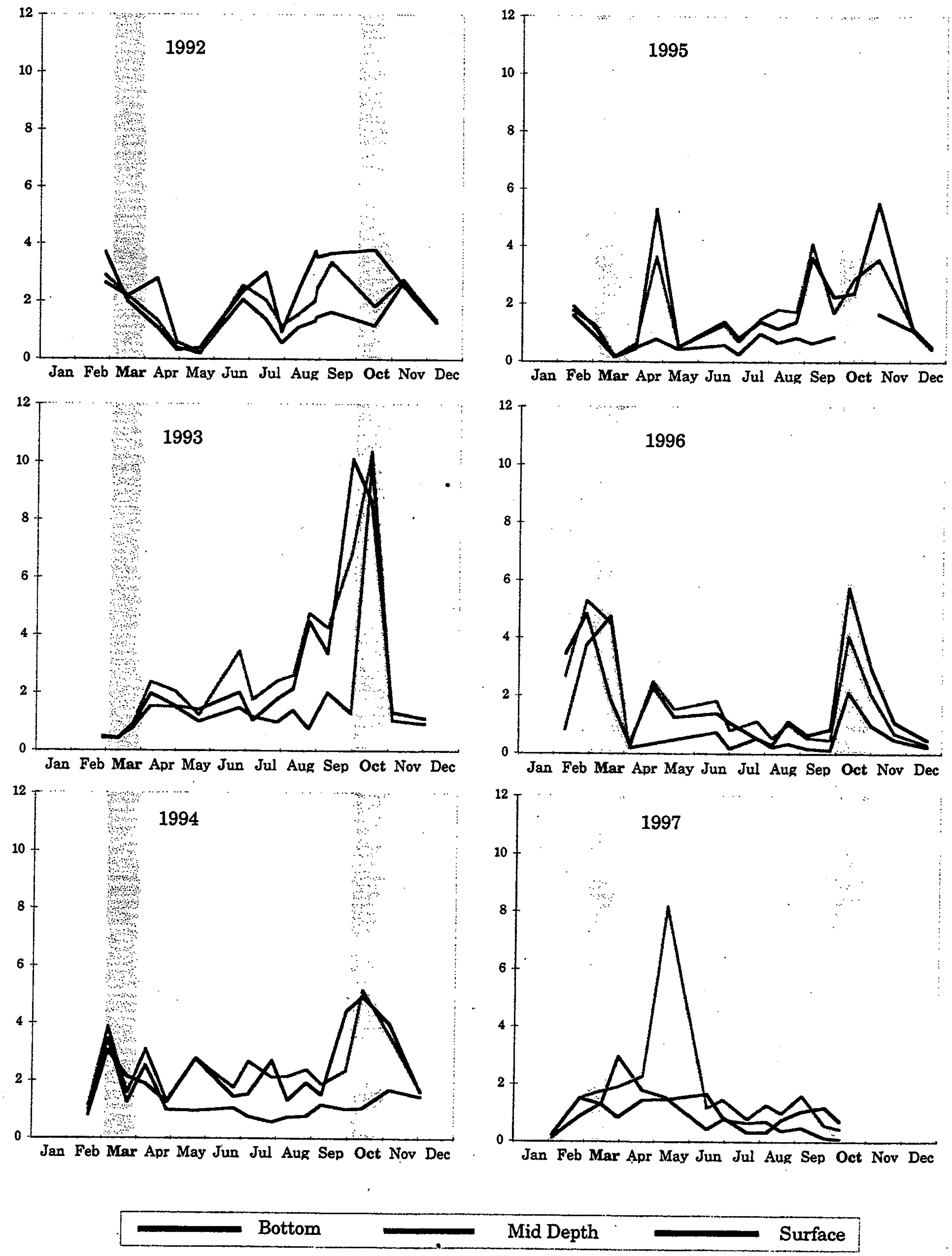
Phosphate (µM)
All Stations, Nearfield Region



Silicate (µM)
All Stations, Nearfield Region



Fluorescence (µg/L)
All Stations, Nearfield Region



Replacement times and removal rates for nutrients in each Dilution Factor region

Region (DF)	Area (Sq miles)	Volume (liters)	Pre -Discharge Winter Conc. (µM)	Winter Setup (µM)	Outfall Added (µM)	Time to rplc Outfall water (days)	Nut/L rmvd /rplc time by Phyto (µM)	Nut/L rmvd /rplc time by Phyto (%)
DIN								
150	3	2.80E+11	11.02	31.35	20.33	1.1	0.30	**1**
300	30	2.80E+12	11.02	21.19	10.16	5.6	1.52	**15**
500	151	1.41E+13	11.02	17.12	6.10	17.1	4.60	**75**
700	48	4.48E+12	11.02	15.38	4.36	3.9	1.05	**24**
900	54	5.03E+12	11.02	14.41	3.39	3.4	0.91	**27**
PO4								
150	3	2.80E+11	1.05	2.04	0.99	1.1	0.02	**2**
300	30	2.80E+12	1.05	1.54	0.50	5.6	0.11	**22**
500	151	1.41E+13	1.05	1.34	0.30	17.1	0.33	**109**
700	48	4.48E+12	1.05	1.26	0.21	3.9	0.07	**35**
900	54	5.03E+12	1.05	1.21	0.17	3.4	0.06	**39**
SiO4								
150	3	2.80E+11	14.19	18.19	4.00	1.1	0.44	**11**
300	30	2.80E+12	14.19	16.15	1.95	5.6	2.21	**113**
500	151	1.41E+13	14.19	15.36	1.17	17.1	6.68	**570**
700	48	4.48E+12	14.19	15.03	0.84	3.9	1.52	**181**
900	54	5.03E+12	14.19	14.84	0.65	3.4	1.33	**204**

Conclusions:

Spring bloom plankton uptake rates only remove a small fraction of the outfall added nutrients in ZID area (3 sq mi) per replacement time. More N and P are removed in the 30 sq mi area and all of the added SiO4 meaning there can be a removal of the GOM sourced SiO4. The low SiO4 concentrations in effluent means that this added SiO4 will be removed quickly relative to the DIN and PO4.

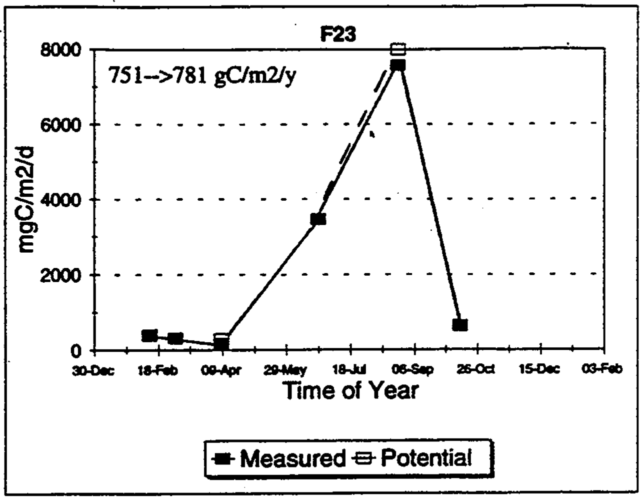
Calculations assume that:

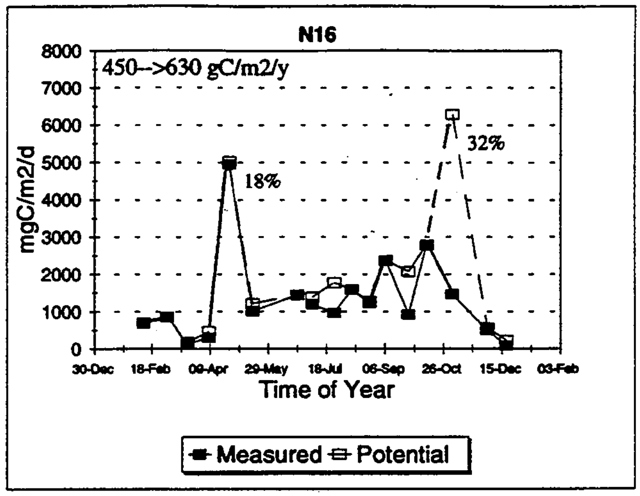
average depth (used to calculate area volumes) = 36 m
average uptake rates are calc. from 2/9/96 to 2/29/96 for surface values and used for whole water column
outfall flow rate = 436 MGD

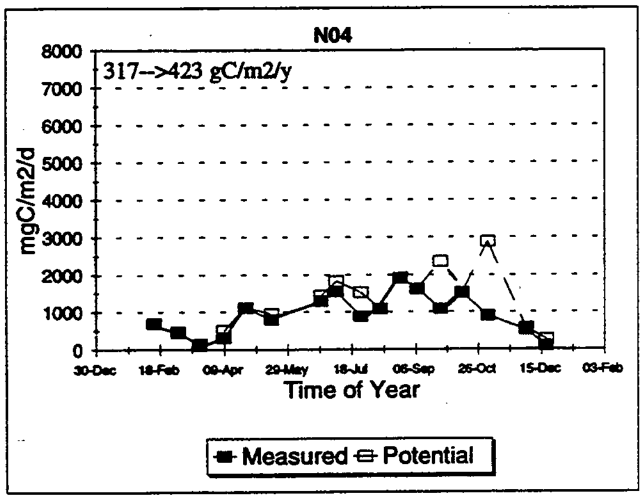
APPENDIX B-6
Primary Productivity: Craig Taylor

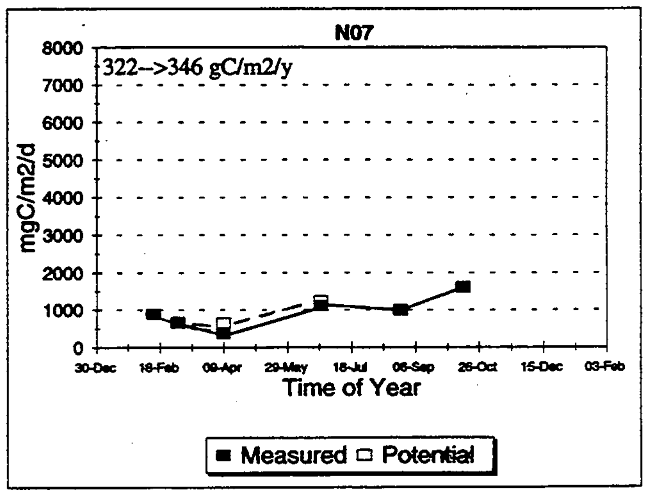
1995

Phytoplankton Production

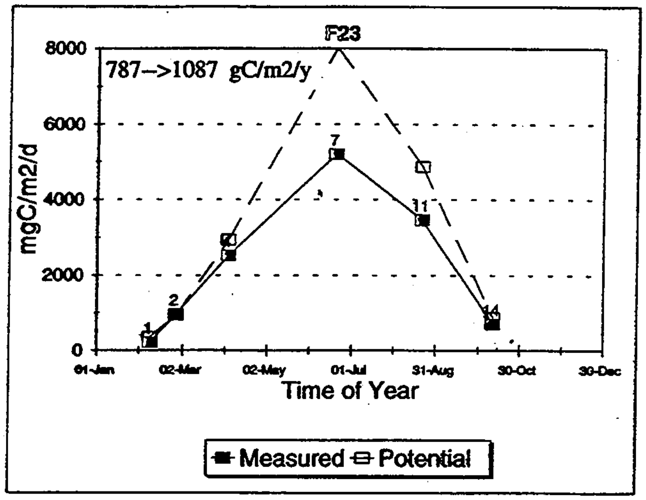


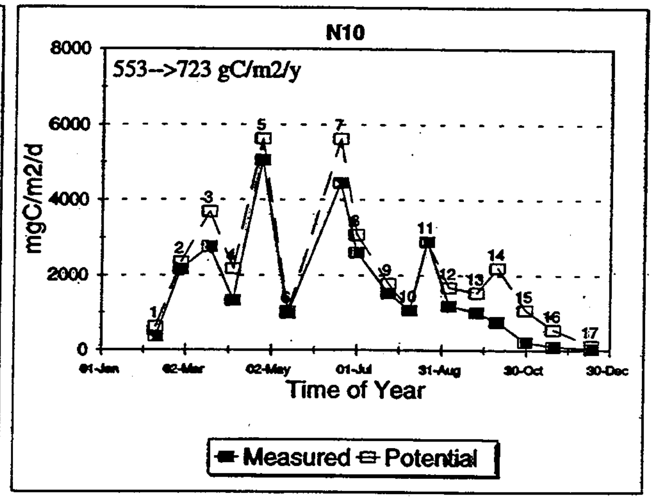


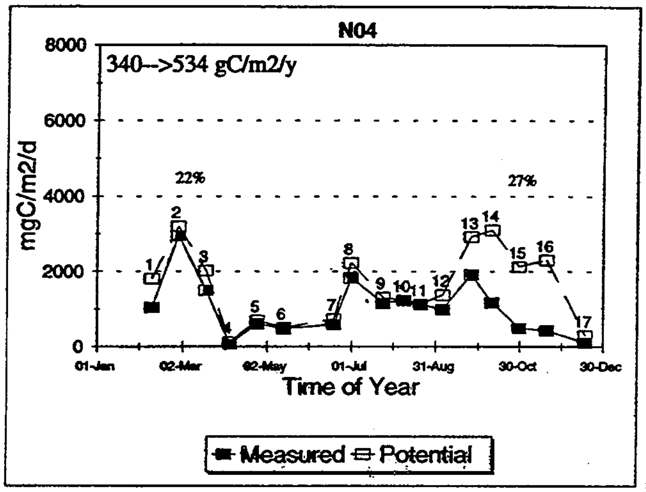


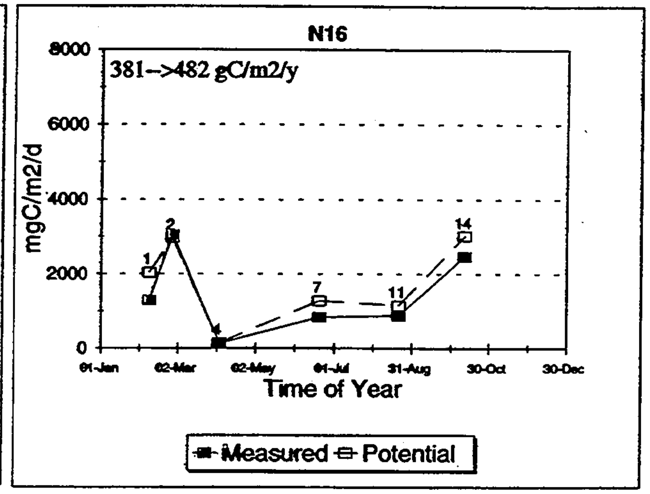


1996

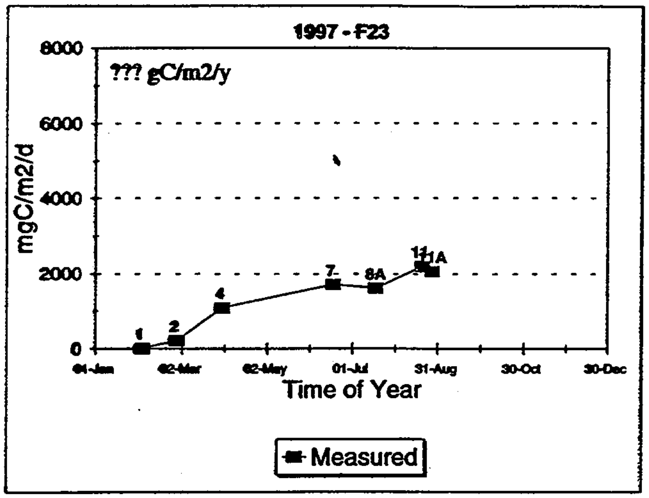

F23
787-->1087 gC/m2/y
mgC/m2/d
Time of Year
01-Jan 02-Mar 02-May 01-Jul 31-Aug 30-Oct 30-Dec
Measured
Potential


N10
553-->723 gC/m2/y
mgC/m2/d
Time of Year
01-Jan 02-Mar 02-May 01-Jul 31-Aug 30-Oct 30-Dec
Measured
Potential

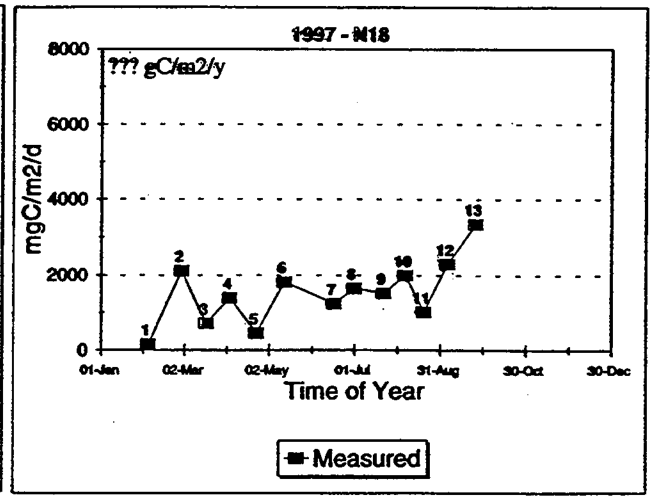

N04
340-->534 gC/m2/y
22%
27%
mgC/m2/d
Time of Year
01-Jan 02-Mar 02-May 01-Jul 31-Aug 30-Oct 30-Dec
Measured
Potential


N16
381-->482 gC/m2/y
mgC/m2/d
Time of Year
01-Jan 02-Mar 02-May 01-Jul 31-Aug 30-Oct 30-Dec
Measured
Potential

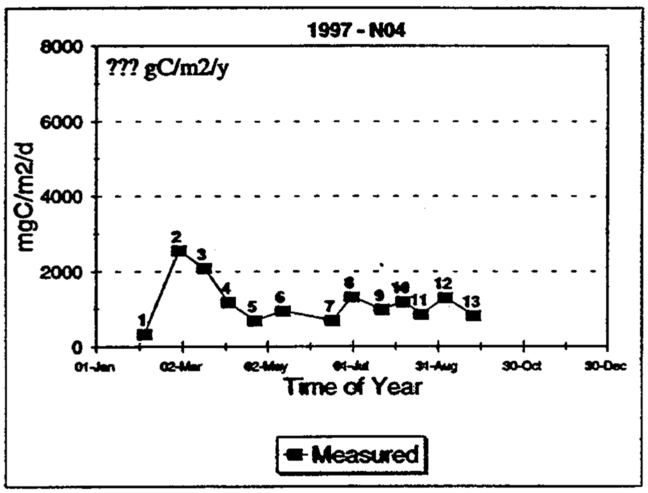
1997



1997 - F23
??? gC/m2/y
mgC/m2/d
Time of Year
Measured

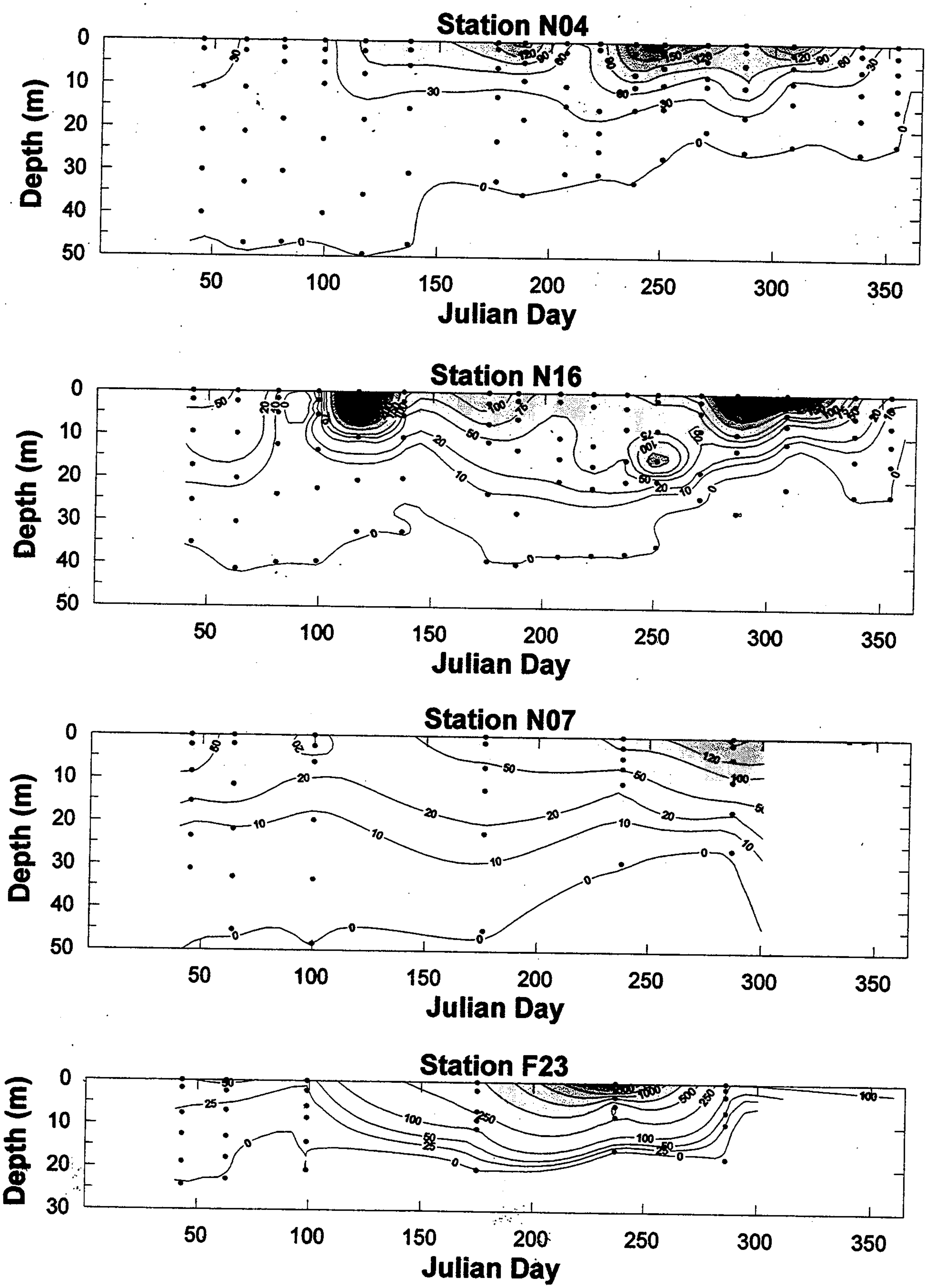


1997 - N18
??? gC/m2/y
mgC/m2/d
Time of Year
Measured

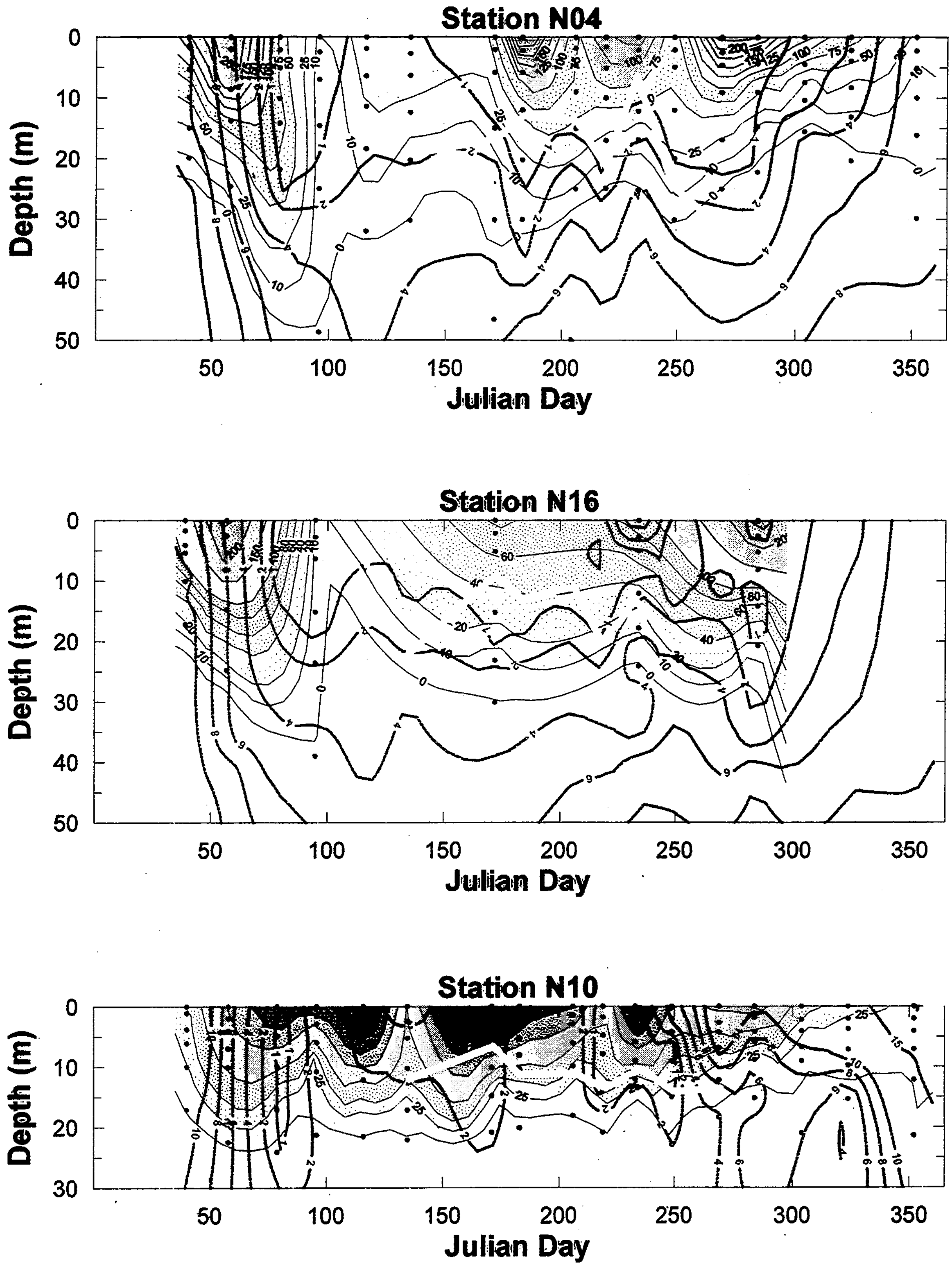


1997 - N04
??? gC/m2/y
mgC/m2/d
Time of Year
Measured

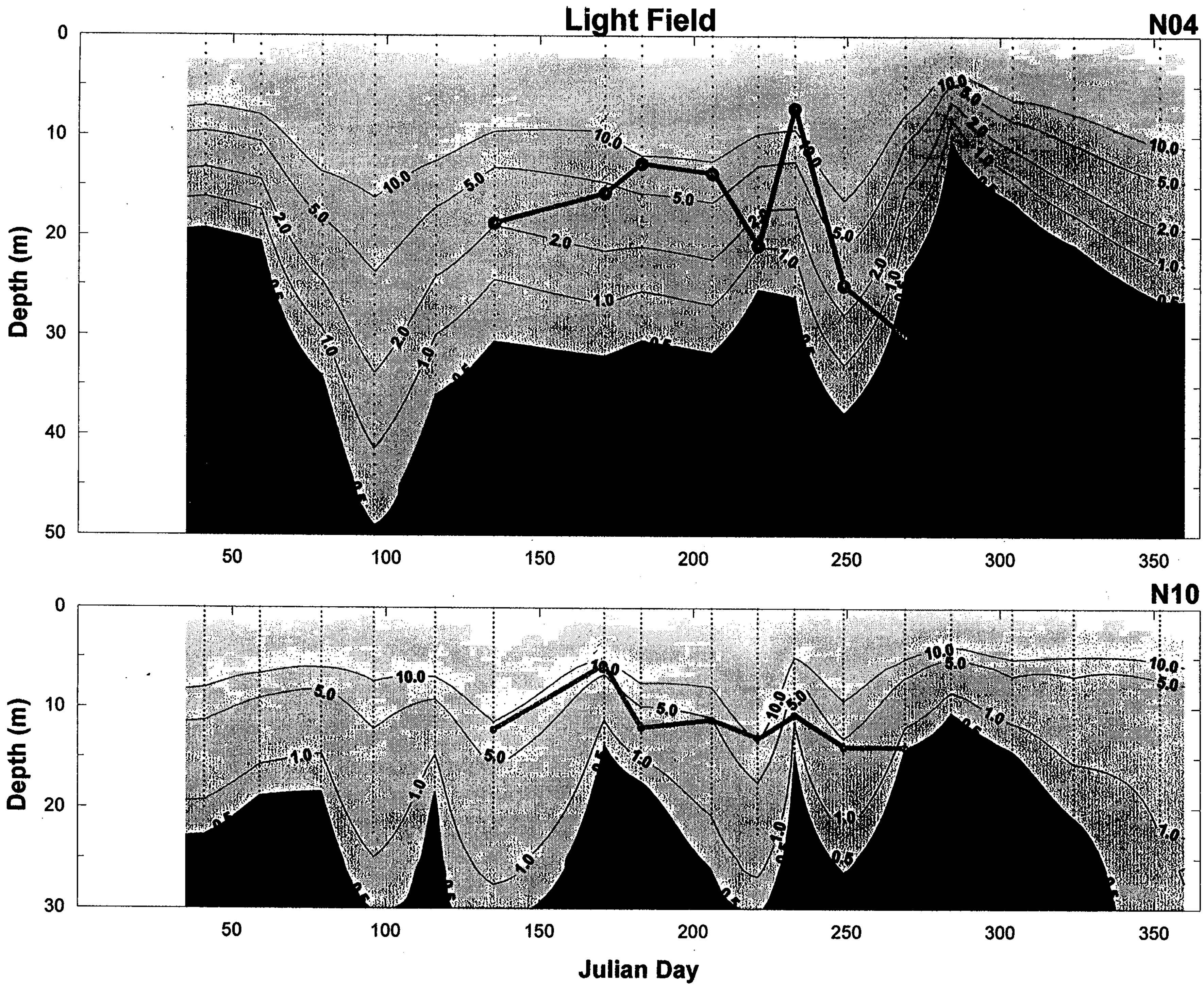
1995



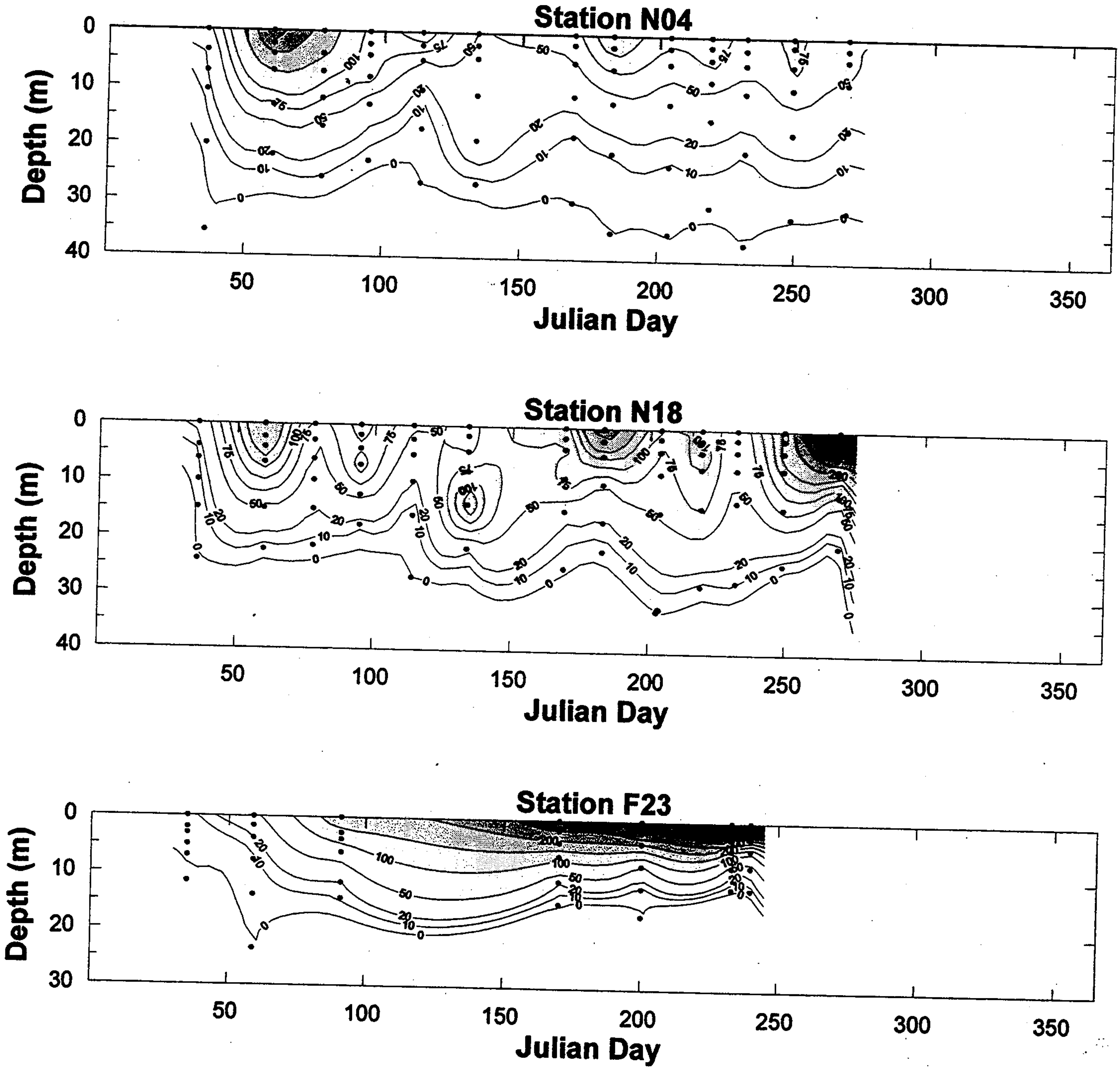
Daily Production. Contour values expressed in mgC/m3/d.



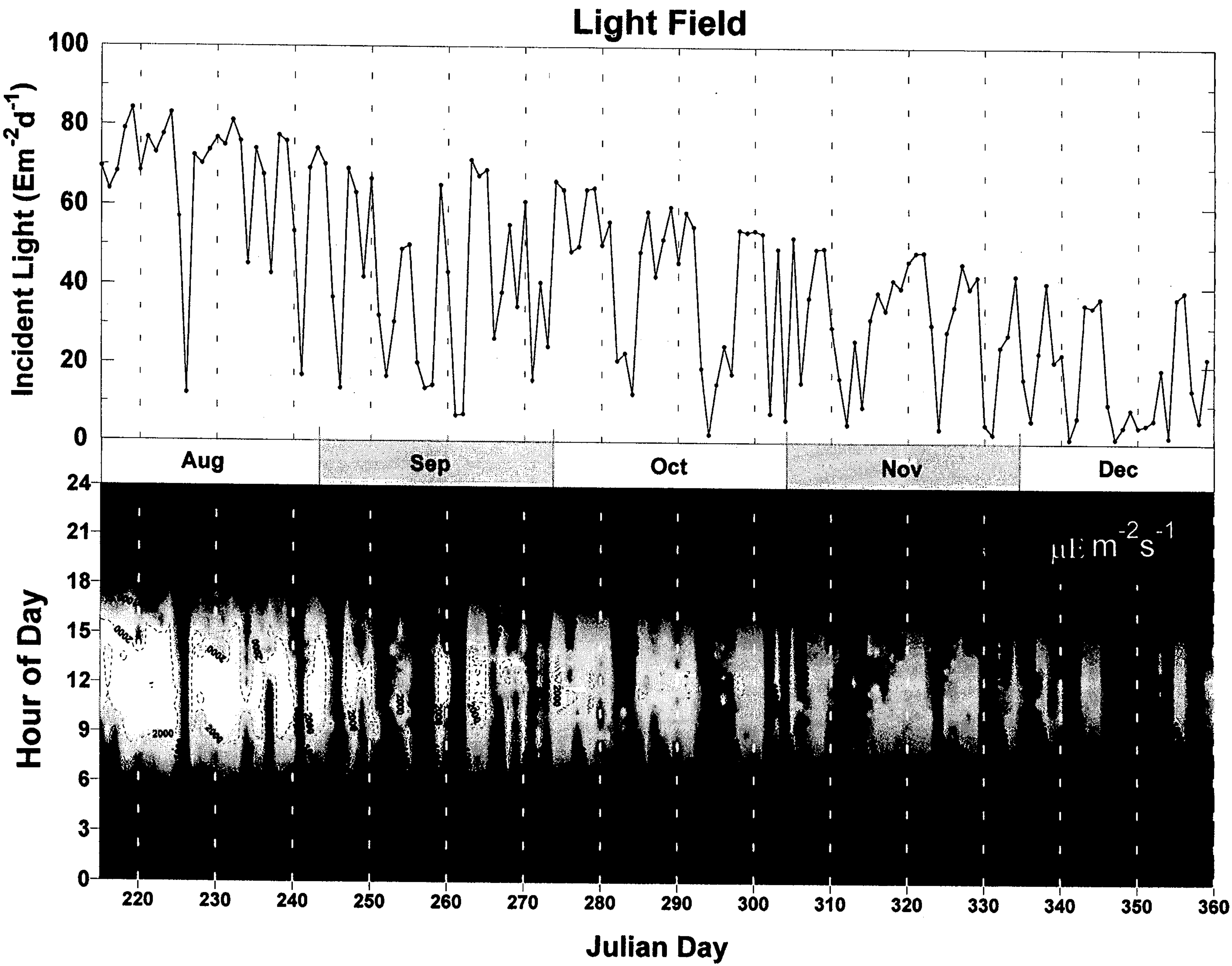
1996 Daily Production. Contour values expressed in mgC/m3/d.


Light Field
N04
N10
Depth (m)
Julian Day
0
10
20
30
40
50
100
150
200
250
300
350
10.0
5.0
2.0
1.0

1997

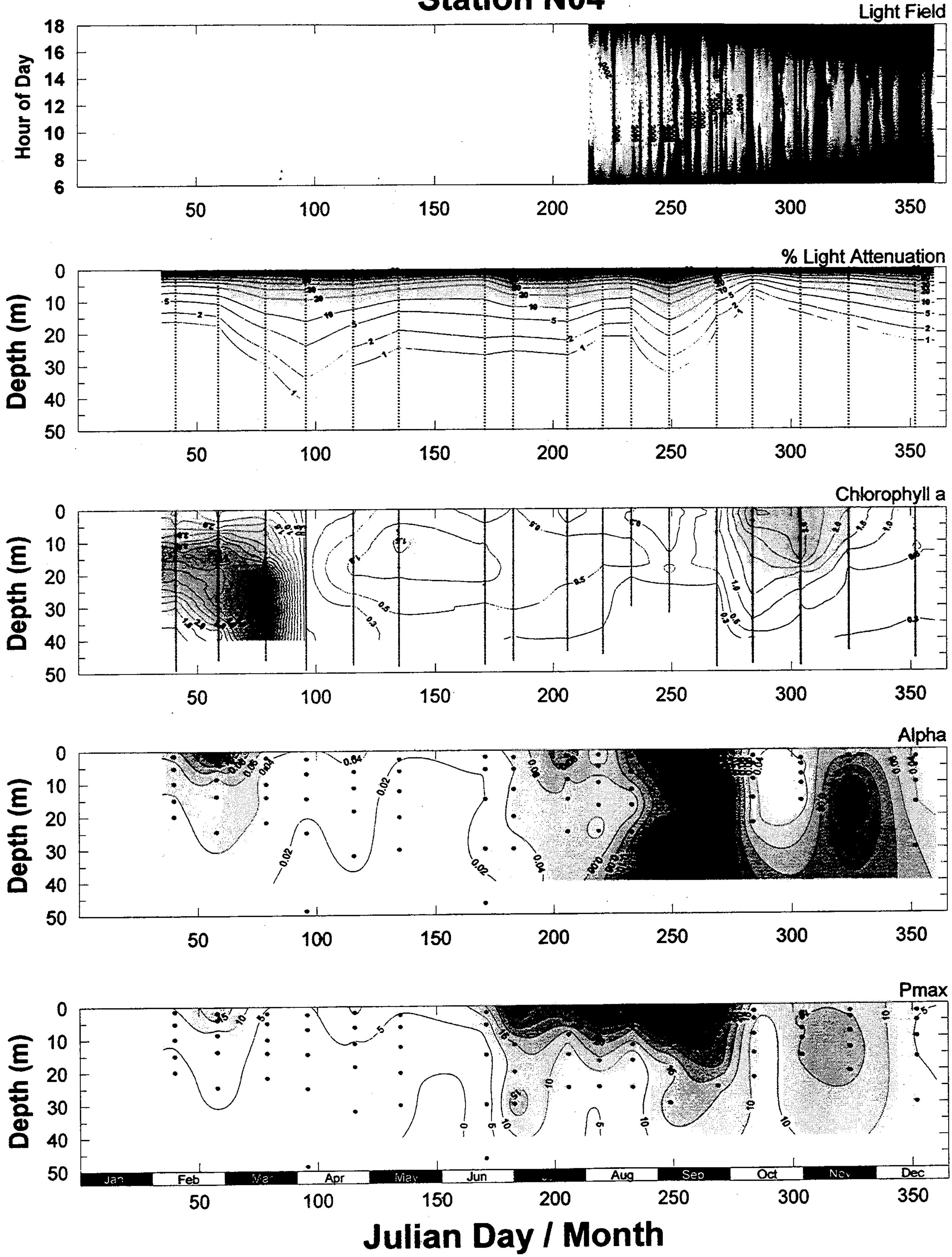


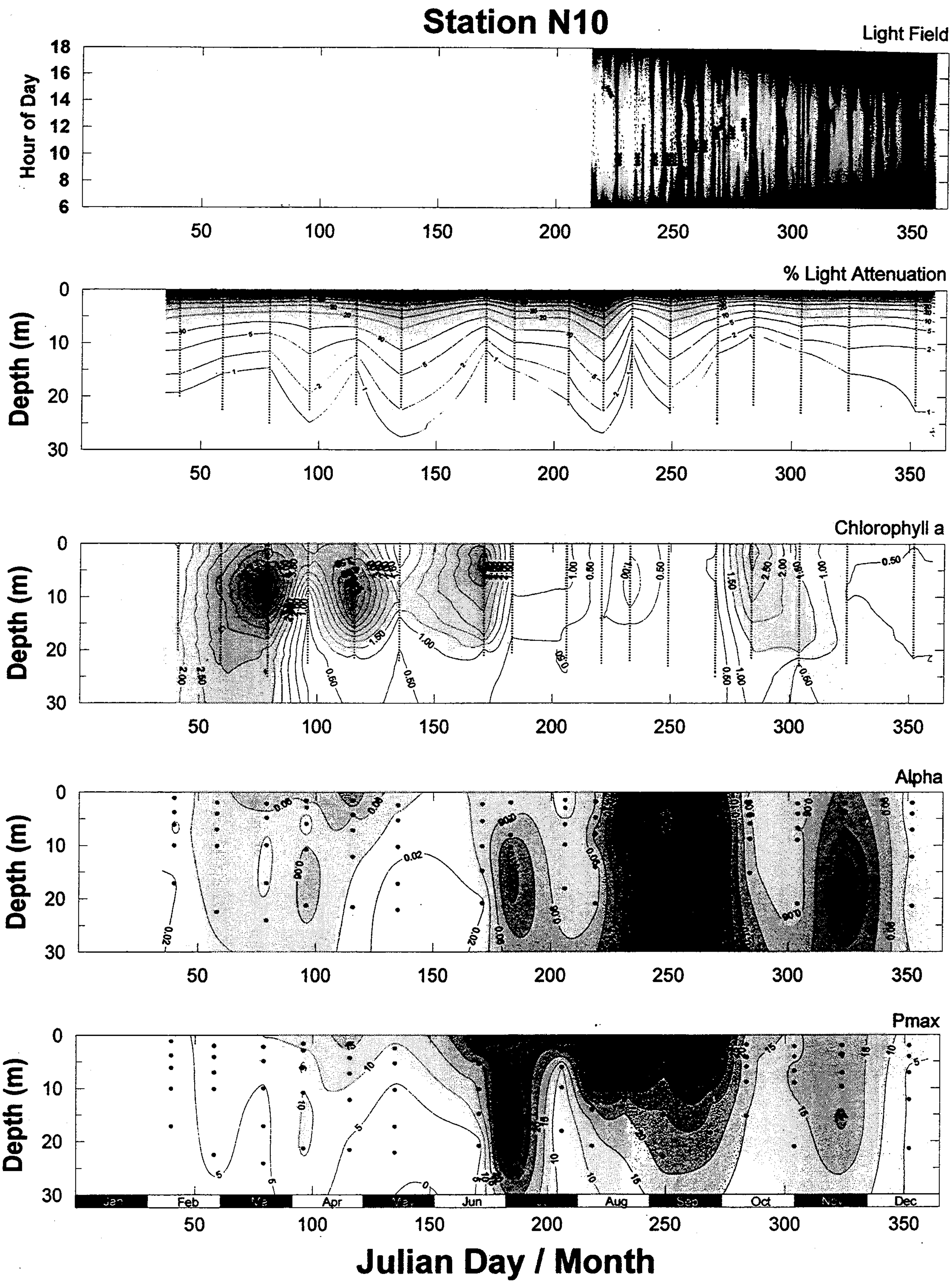
Daily Production. Contour values expressed in mgC/m3/d.



Light Field
Incident Light (Em-2d-1)
100
80
60
40
20
0
Aug
Sep
Oct
Nov
Dec
Hour of Day
24
21
18
15
12
9
6
3
0
μE m-2s-1
2000
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
Julian Day

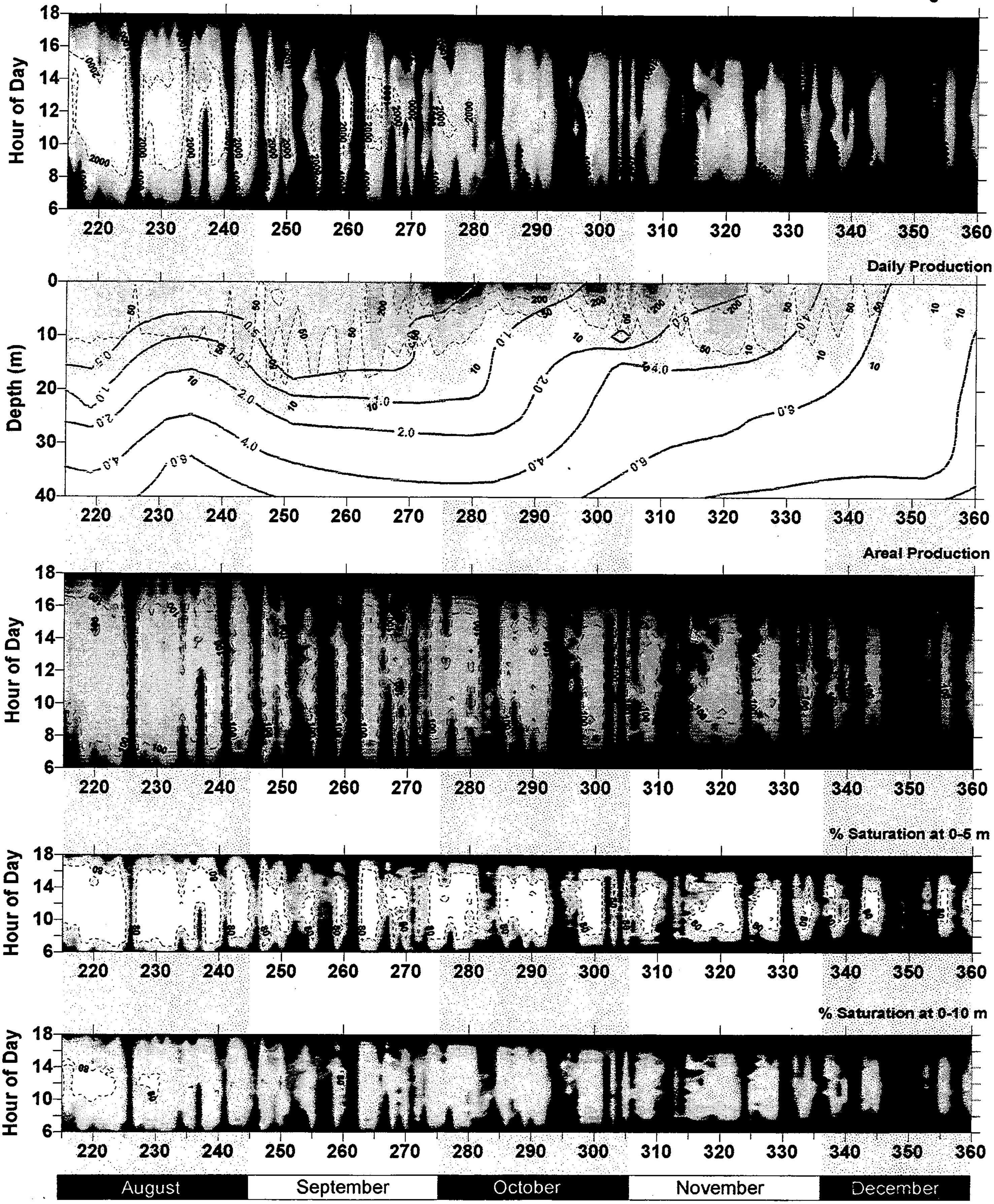
Station N04


Light Field
Hour of Day
% Light Attenuation
Depth (m)
Chlorophyll a
Alpha
Pmax
Jan
Feb
Mar
Apr
May
Jun
Aug
Sep
Oct
Nov
Dec
Julian Day / Month

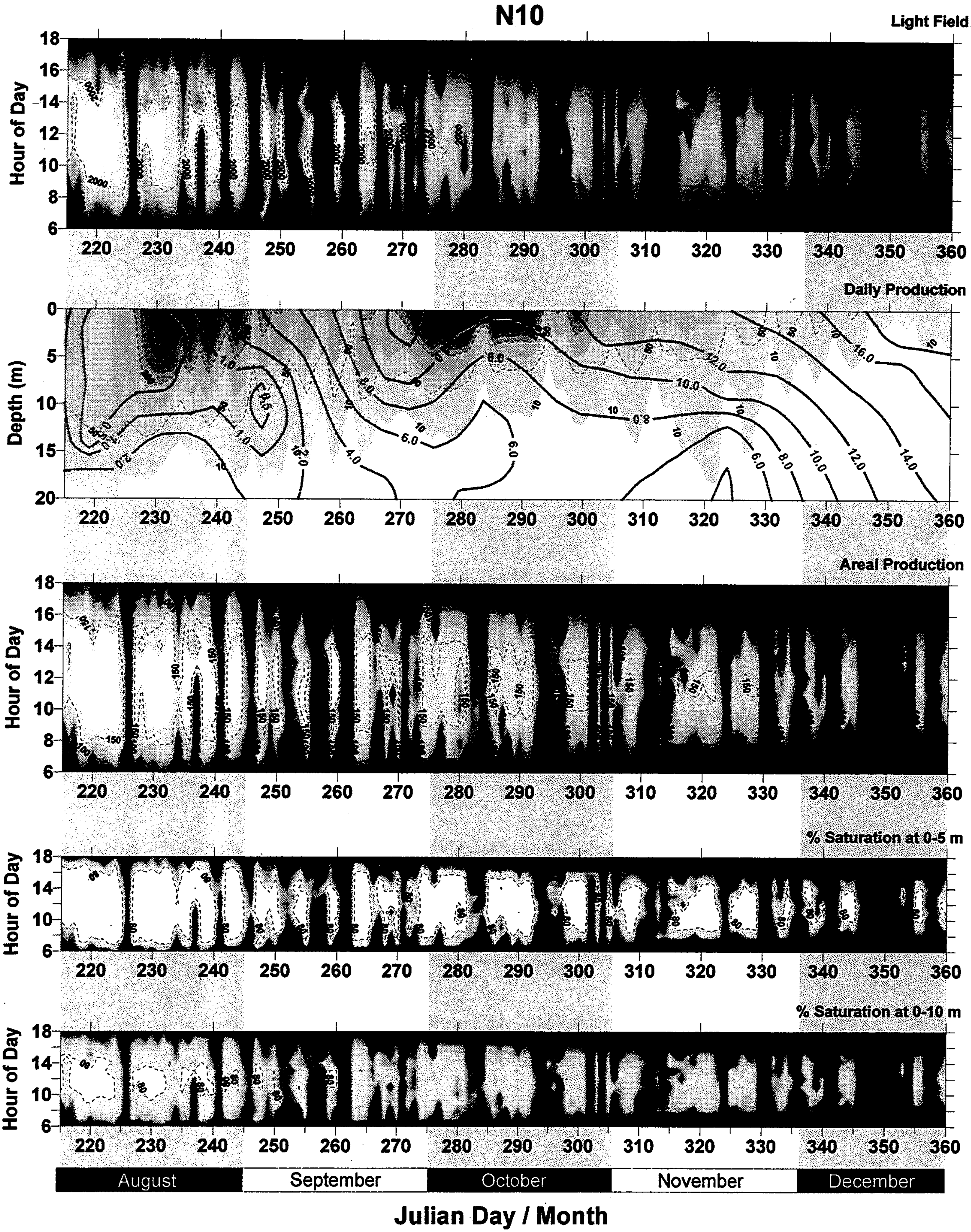


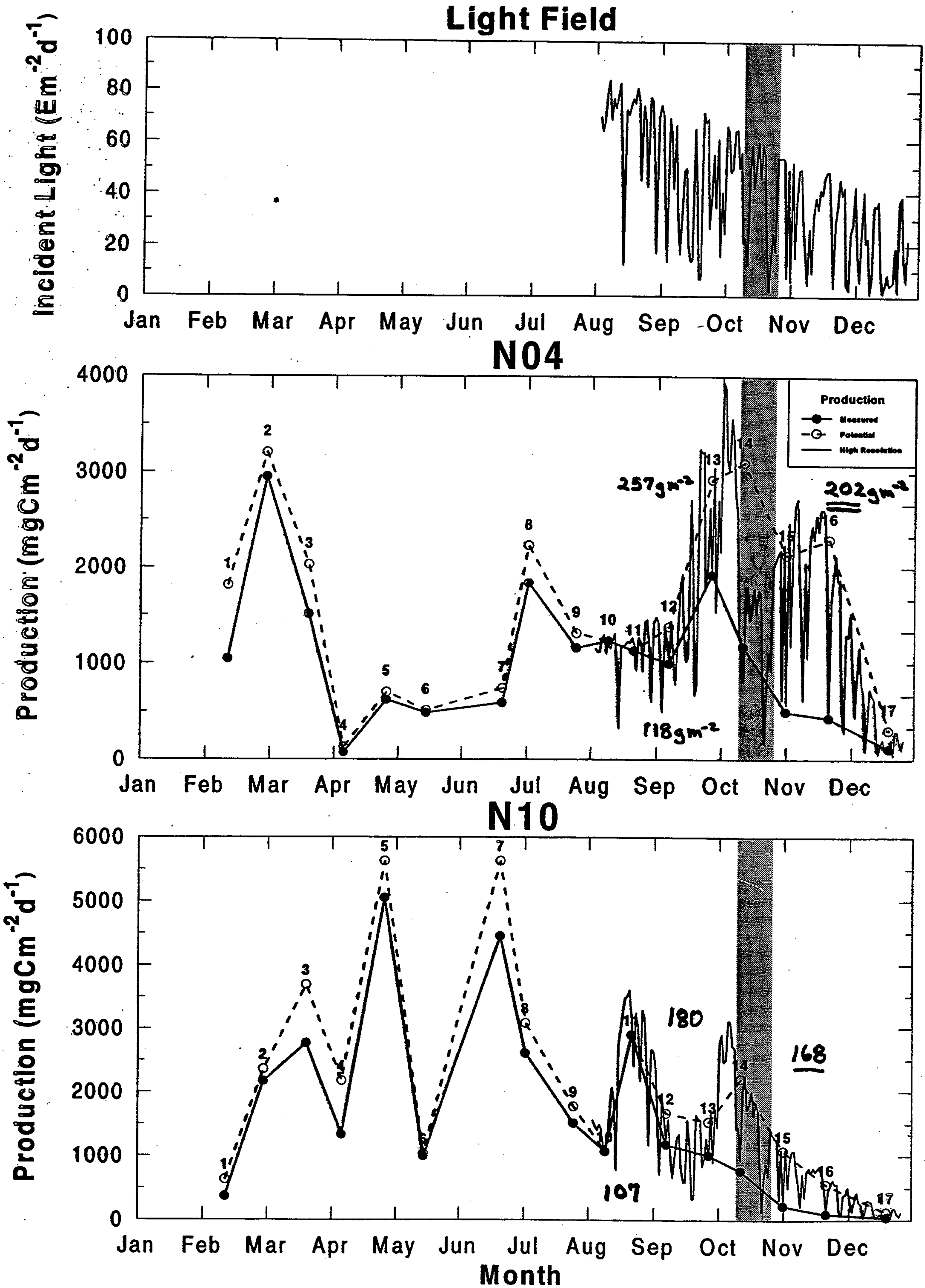
Station N10
Light Field
Hour of Day
% Light Attenuation
Chlorophyll a
Alpha
Pmax
Depth (m)
Jan
Feb
Apr
Jun
Aug
Sep
Oct
Dec
Julian Day / Month

N04

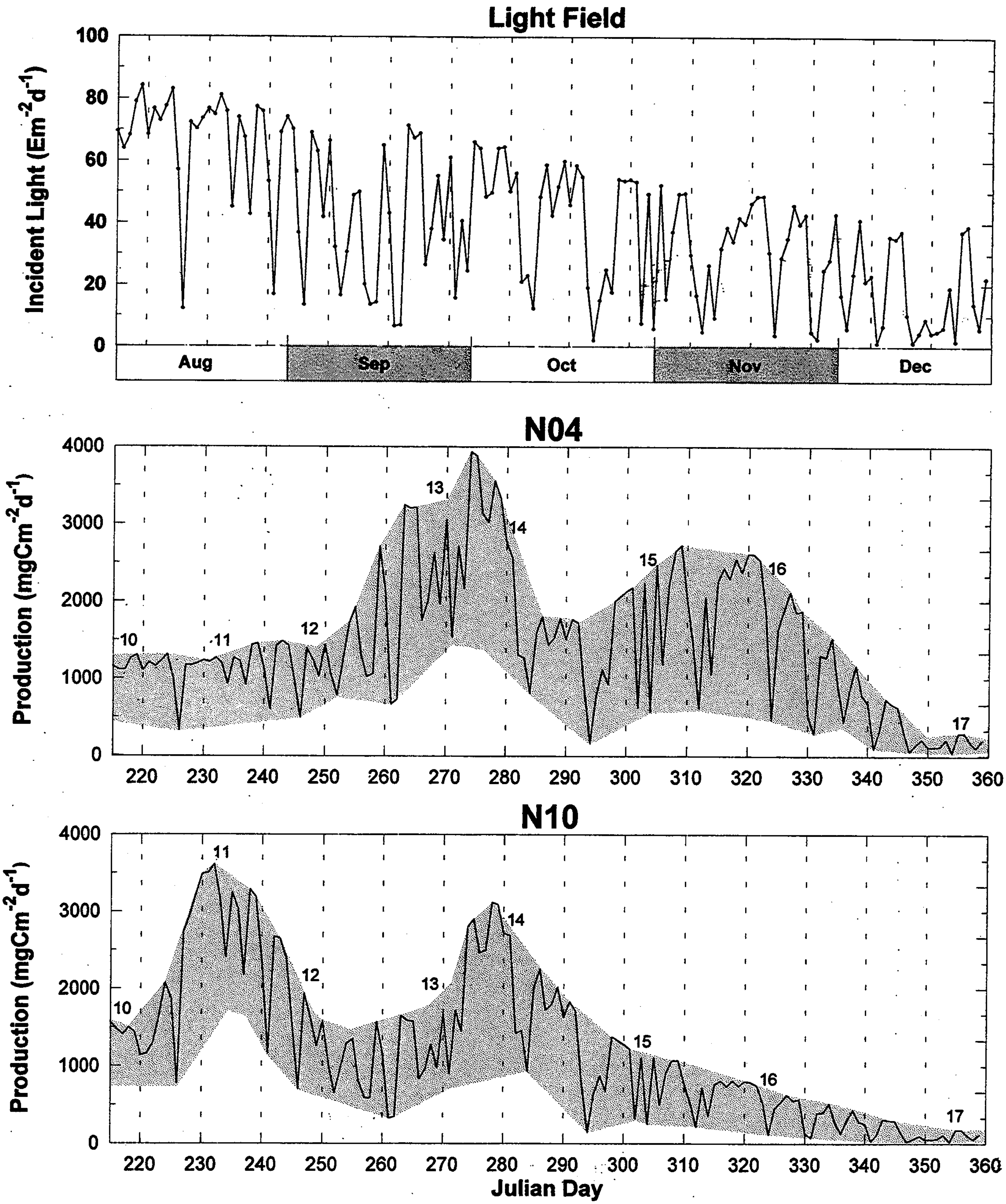


Julian Day / Month

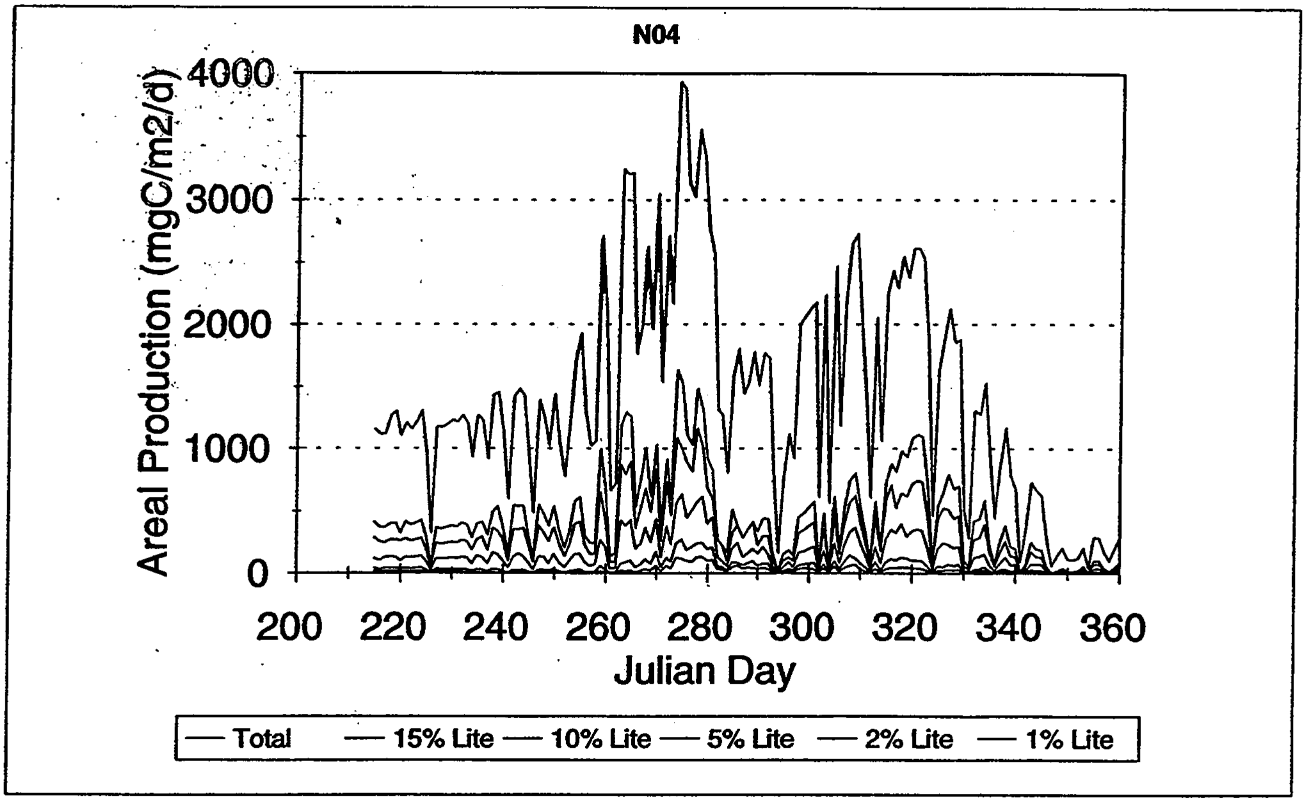

N10
Light Field
Hour of Day
Daily Production
Depth (m)
Areal Production
Hour of Day
% Saturation at 0-5 m
Hour of Day
% Saturation at 0-10 m
Hour of Day
August
September
October
November
December
Julian Day / Month

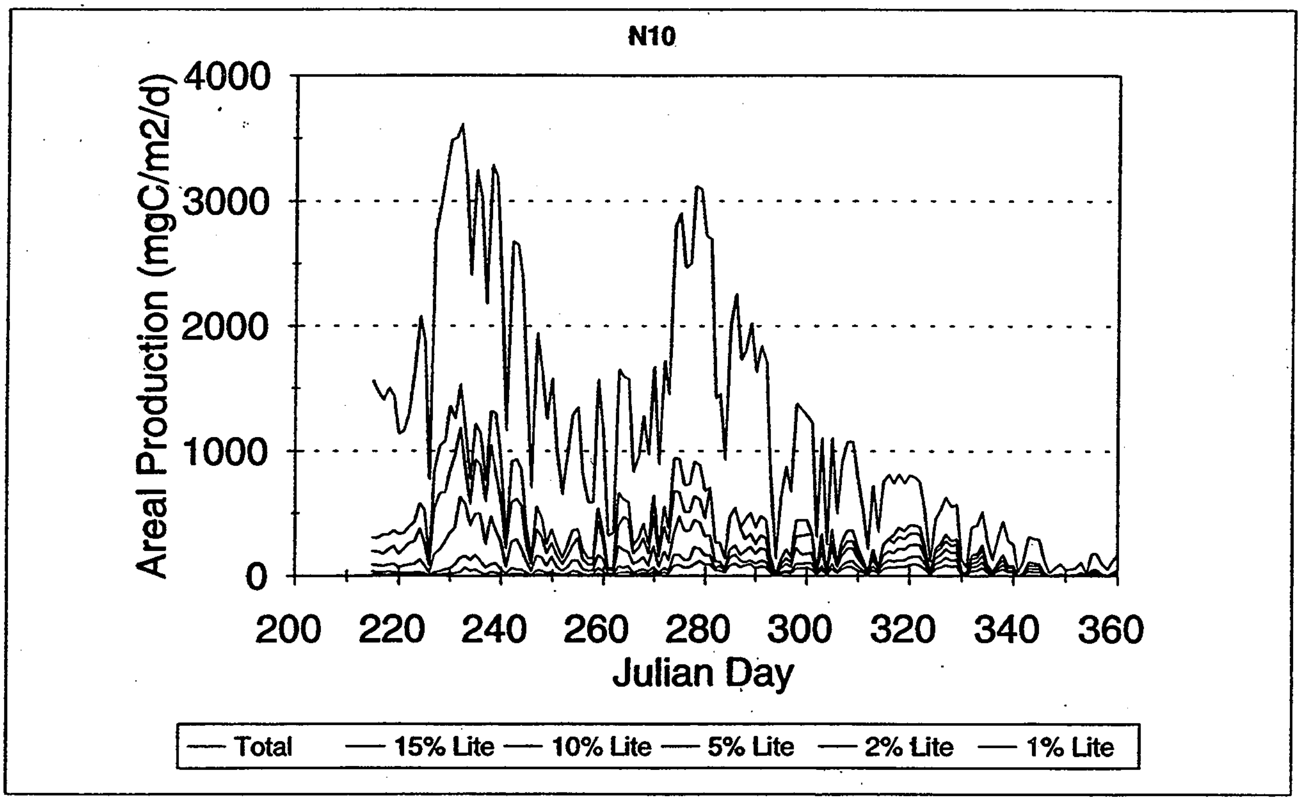


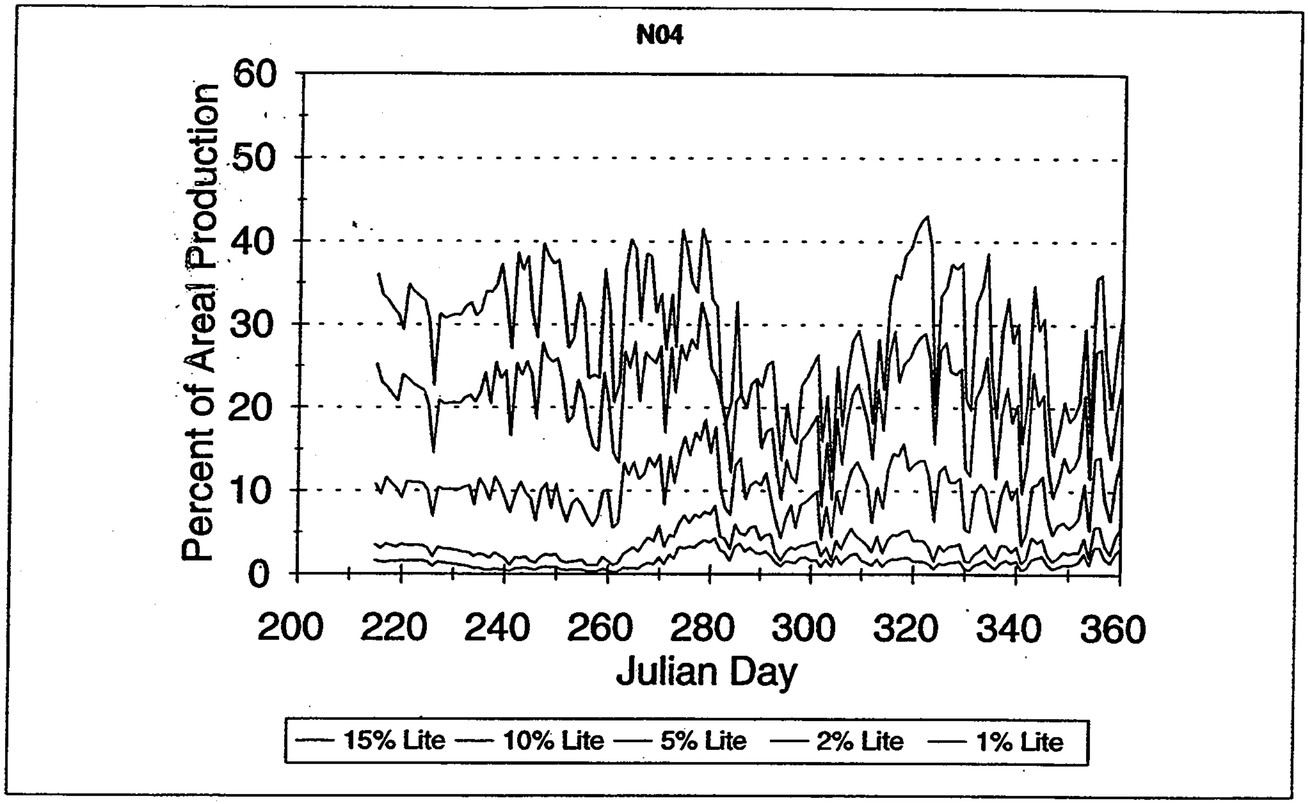
Light Field
Incident Light (Em-2d-1)
N04
Production (mgCm-2d-1)
Production
Measured
Potential
High Resolution
257gm-2
202gm-2
118gm-2
N10
180
168
107
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month

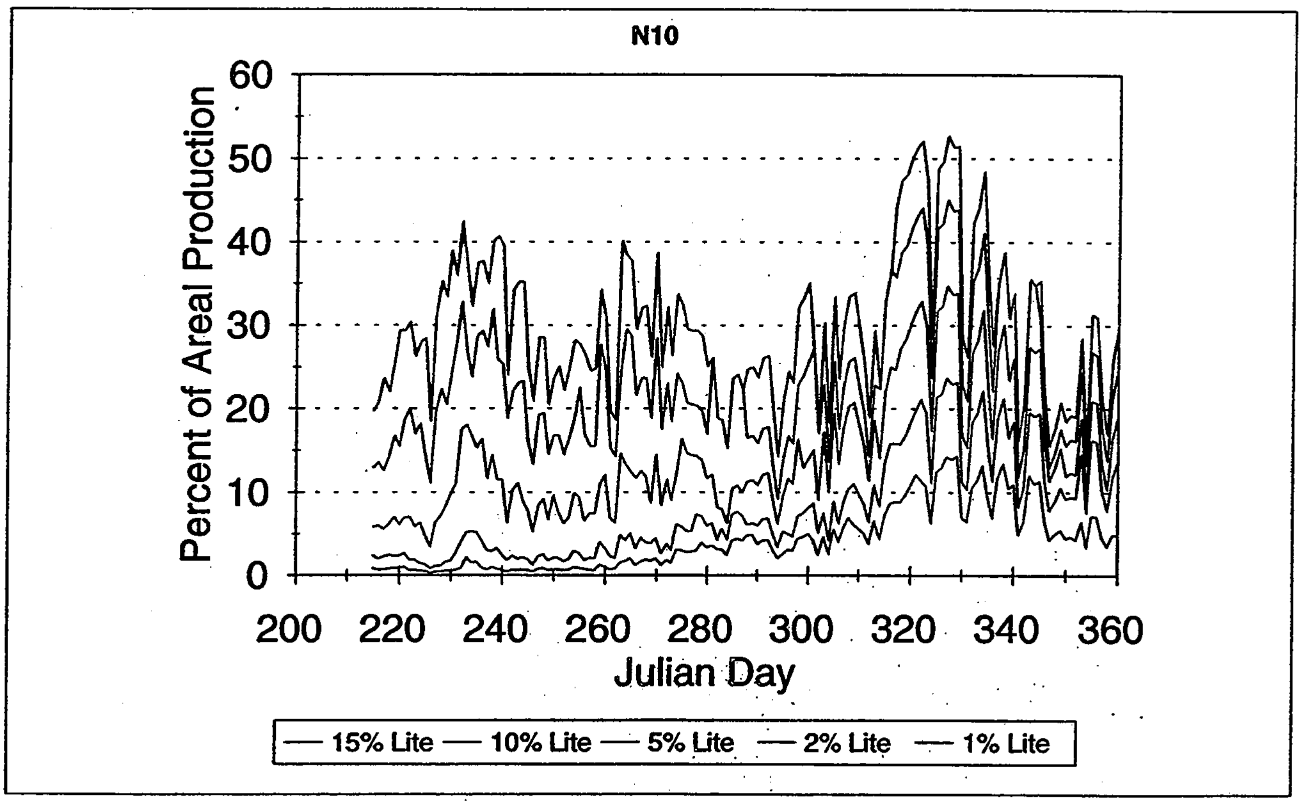


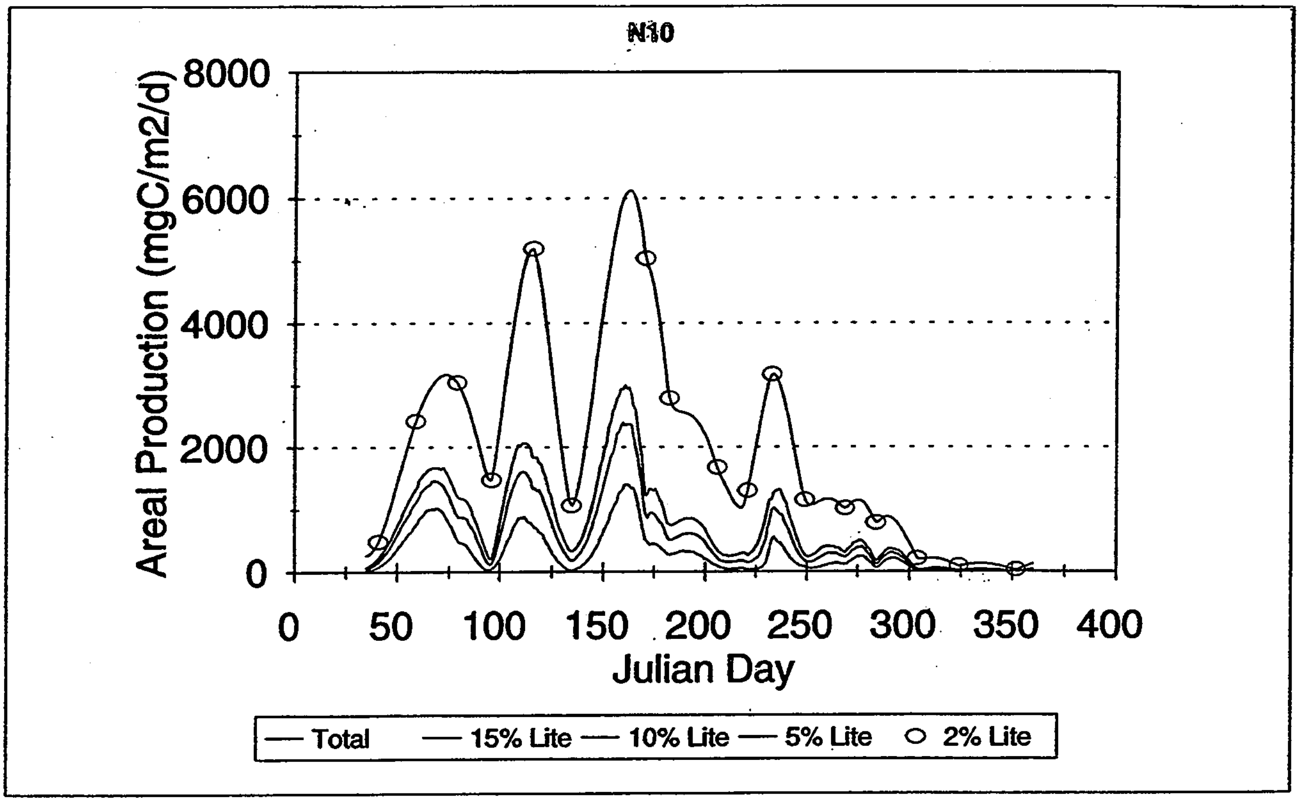
Light Field
Incident Light (Em^{-2}d^{-1})
100
80
60
40
20
0
Aug
Sep
Oct
Nov
Dec
N04
Production (mgCm^{-2}d^{-1})
4000
3000
2000
1000
0
10
11
12
13
14
15
16
17
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
N10
Production (mgCm^{-2}d^{-1})
Julian Day


N04
Areal Production (mgC/m2/d)
4000
3000
2000
1000
0
200
220
240
260
280
300
320
340
360
Julian Day
Total
15% Lite
10% Lite
5% Lite
2% Lite
1% Lite

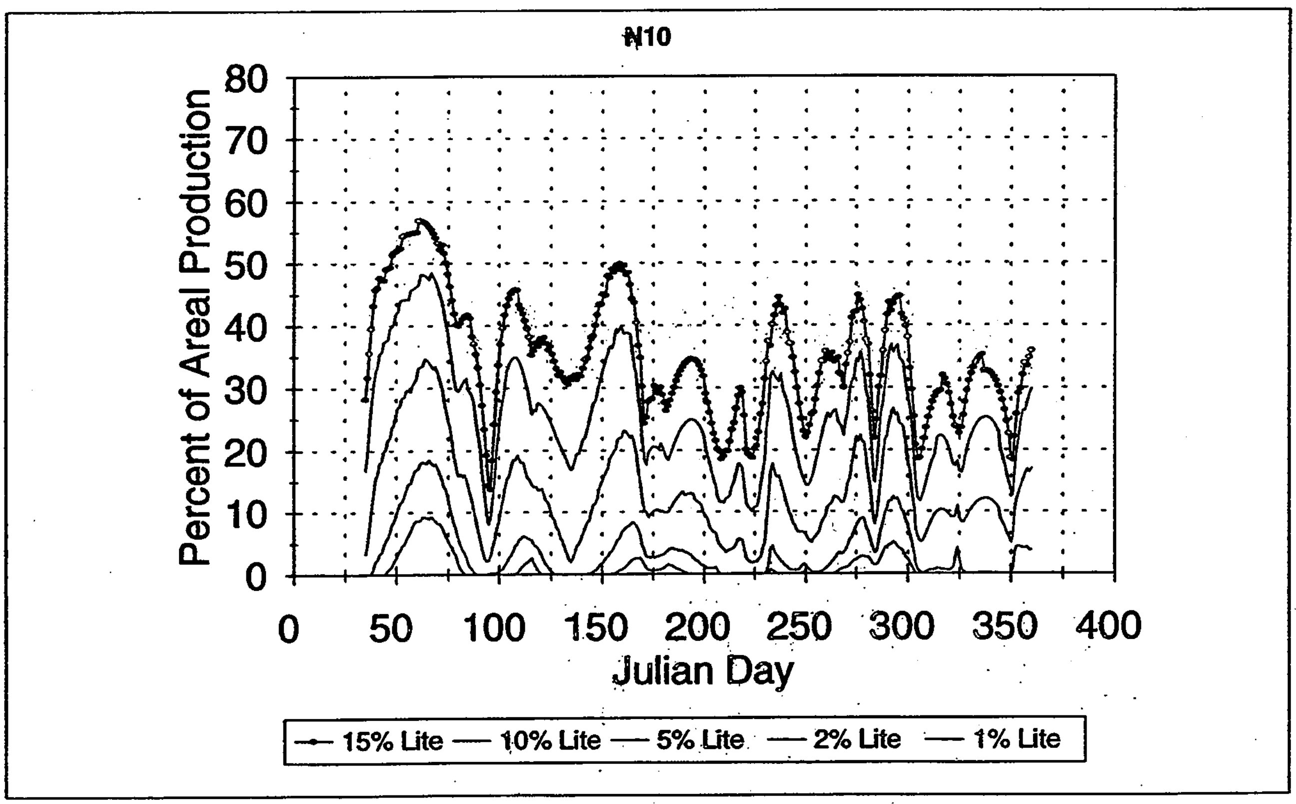

N10
Areal Production (mgC/m2/d)
4000
3000
2000
1000
0
200
220
240
260
280
300
320
340
360
Julian Day
Total
15% Lite
10% Lite
5% Lite
2% Lite
1% Lite


N04
Percent of Areal Production
60
50
40
30
20
10
0
200
220
240
260
280
300
320
340
360
Julian Day
15% Lite
10% Lite
5% Lite
2% Lite
1% Lite


N10
Percent of Areal Production
60
50
40
30
20
10
0
200
220
240
260
280
300
320
340
360
Julian Day
15% Lite
10% Lite
5% Lite
2% Lite
1% Lite



N10
Areal Production (mgC/m2/d)
8000
6000
4000
2000
0
0
50
100
150
200
250
300
350
400
Julian Day
Total
15% Lite
10% Lite
5% Lite
2% Lite

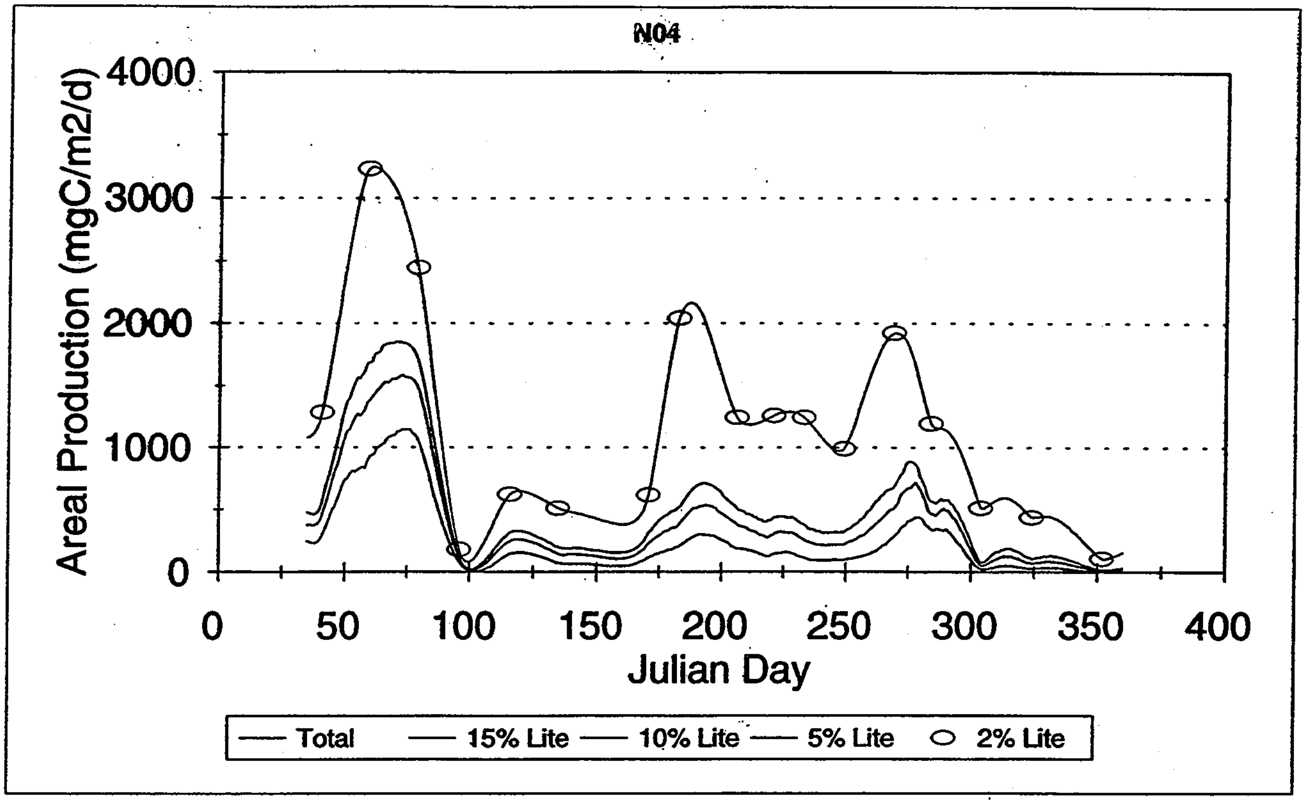


N10
Percent of Areal Production
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
400
Julian Day
15% Lite
10% Lite
5% Lite
2% Lite
1% Lite

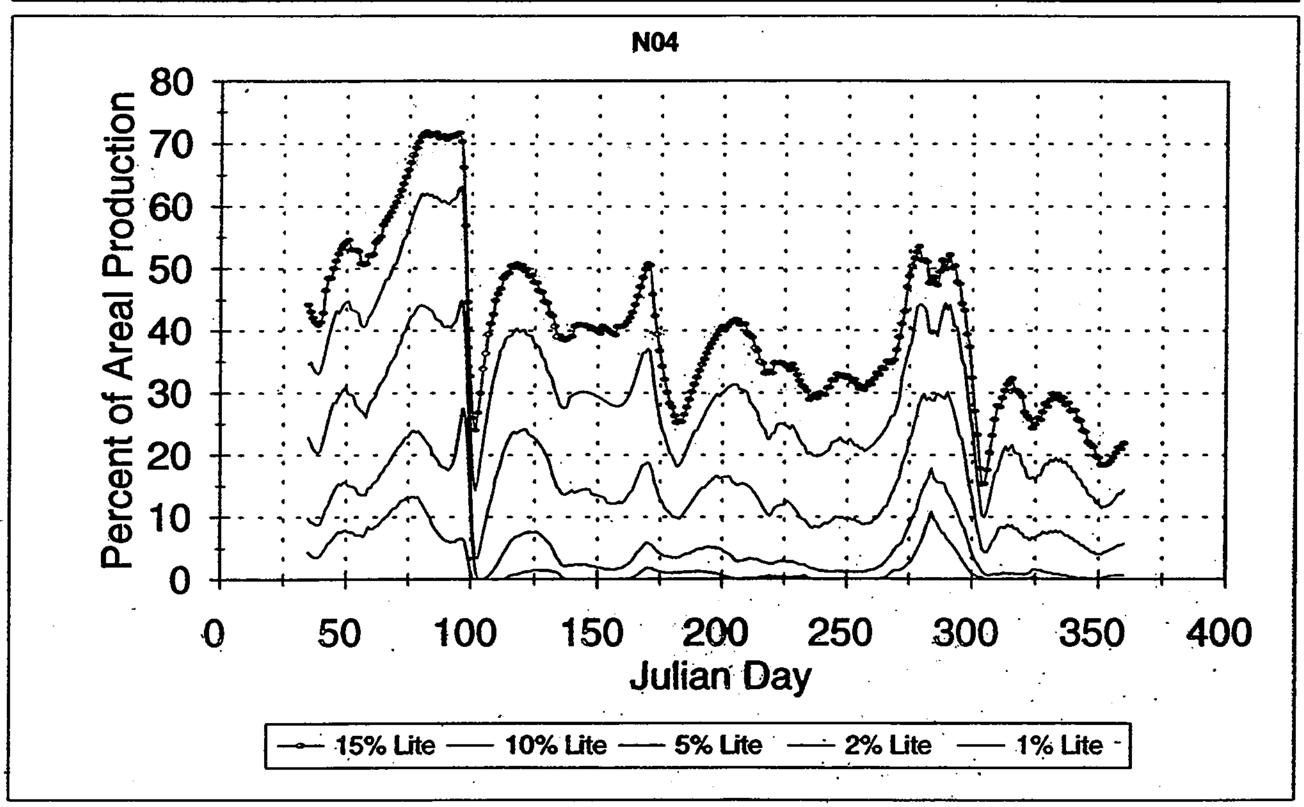
$$^{14}C\text{-}P = m \cdot BZ_pI_o$$

$$m = mgCm^2\ (mgChla)^{-1}E^{-1}$$

$$\Delta\ \Phi max = (Fm - Fo)/Fm \approx (F_{DCMU} - Fo)/F_{DCMU}$$

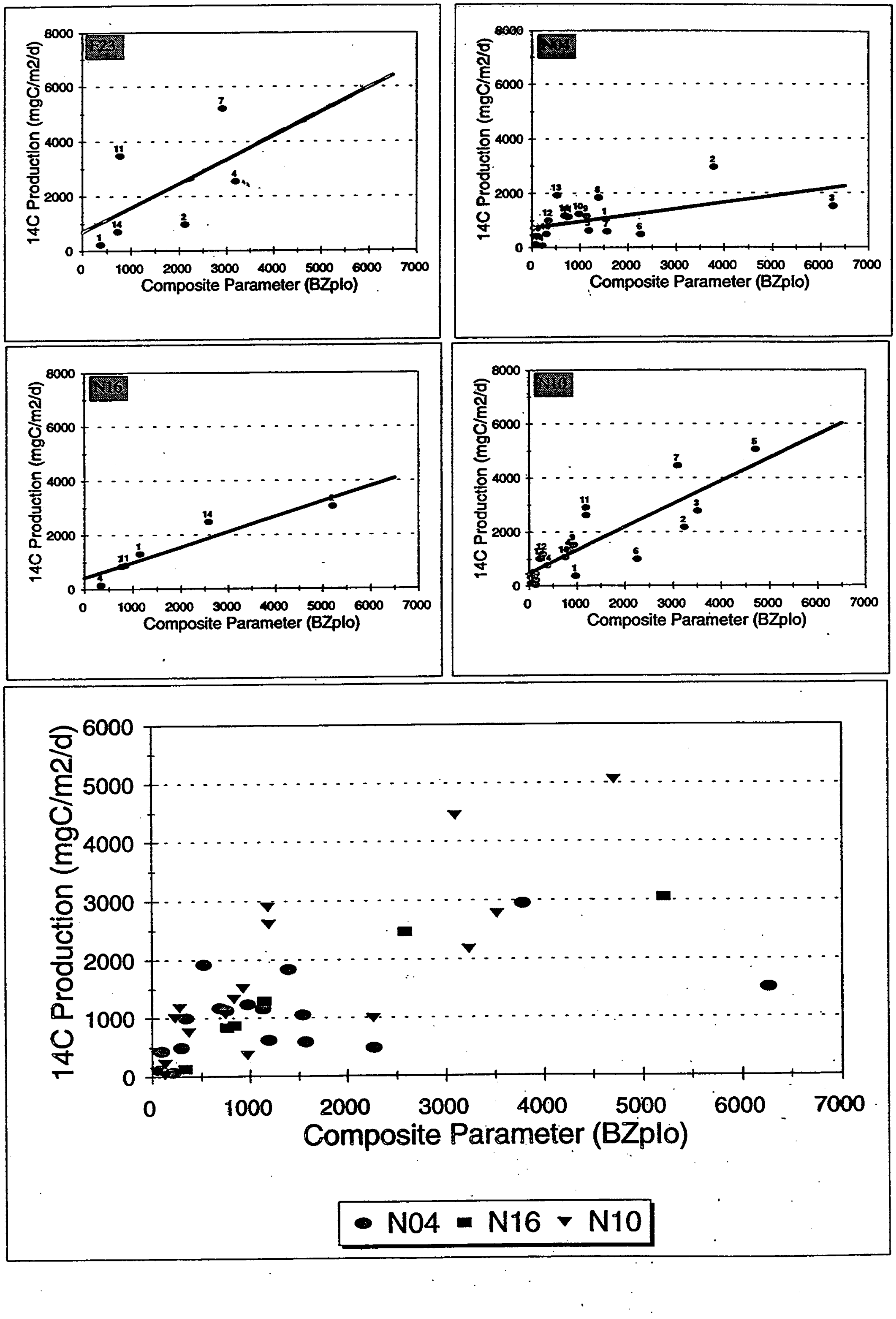


N04
Areal Production (mgC/m2/d)
4000
3000
2000
1000
0
0
50
100
150
200
250
300
350
400
Julian Day
Total
15% Lite
10% Lite
5% Lite
2% Lite

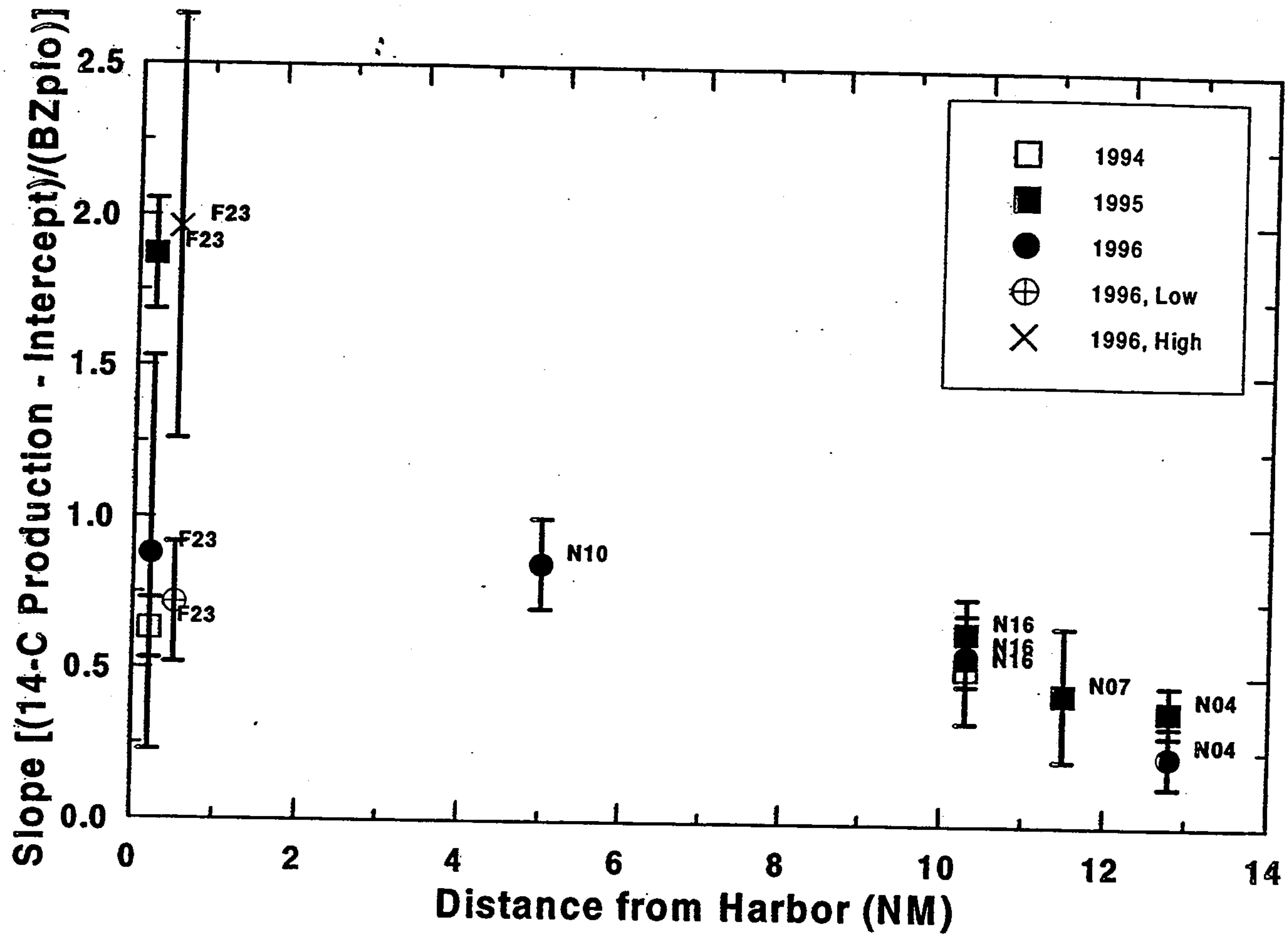


N04
Percent of Areal Production
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
400
Julian Day
15% Lite
10% Lite
5% Lite
2% Lite
1% Lite

1996

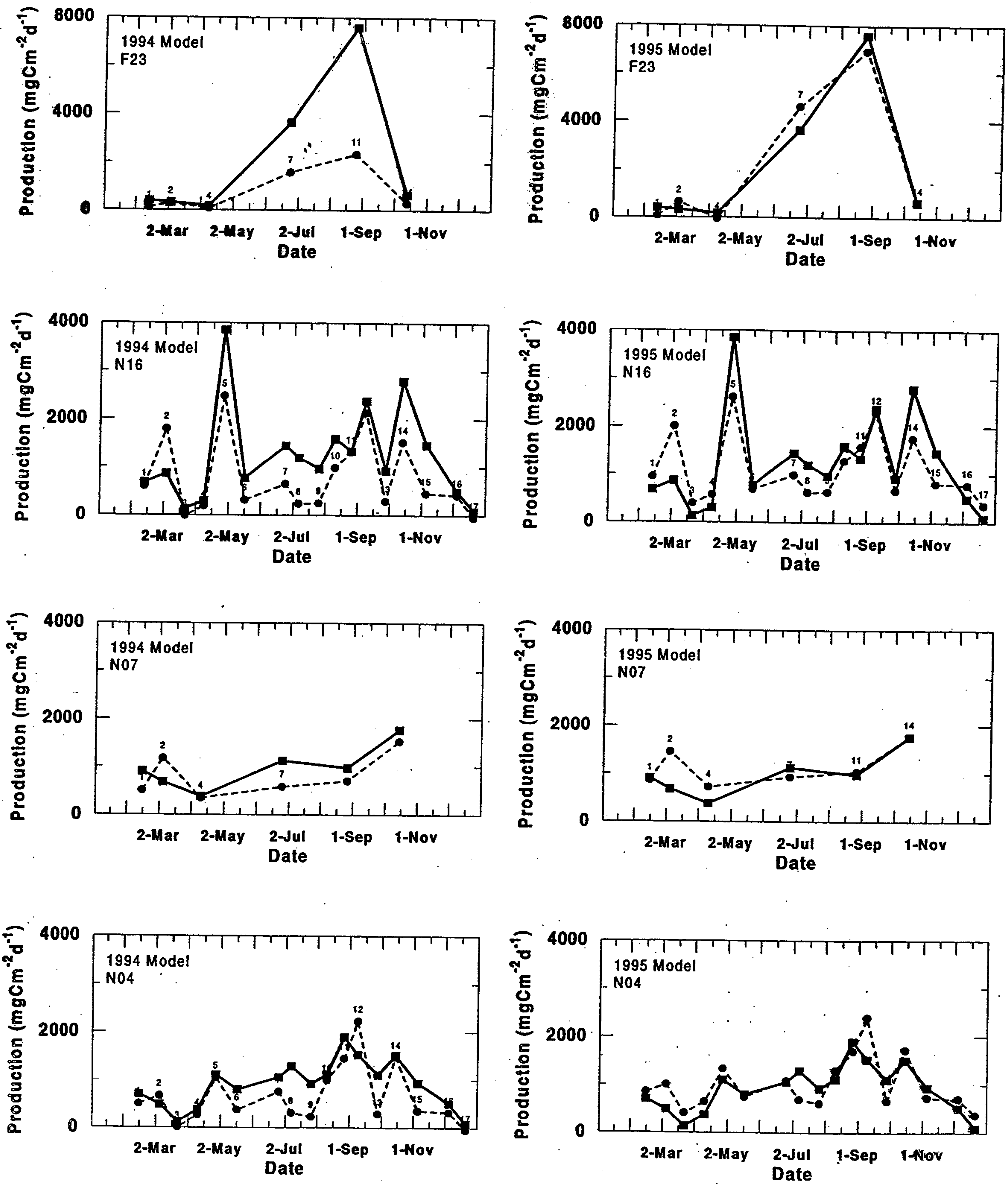


E23
N03
N16
N10
14C Production (mgC/m2/d)
Composite Parameter (BZplo)
N04
N16
N10



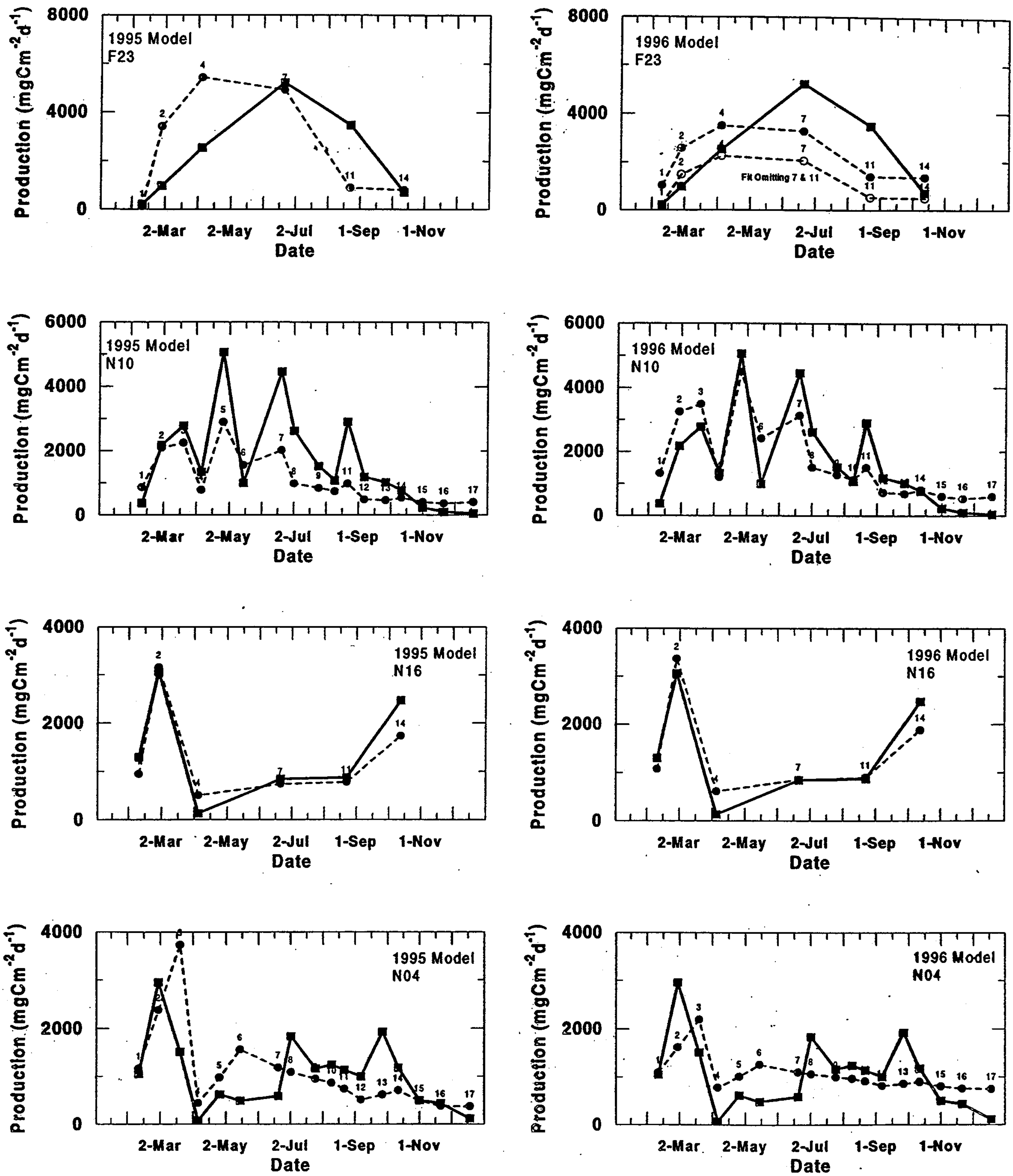
Slope [(14-C Production - Intercept)/(BZpIo)]
Distance from Harbor (NM)
0.0
0.5
1.0
1.5
2.0
2.5
0
2
4
6
8
10
12
14
1994
1995
1996
1996, Low
1996, High
F23
F23
F23
F23
N10
N16
N16
N16
N07
N04
N04

1995

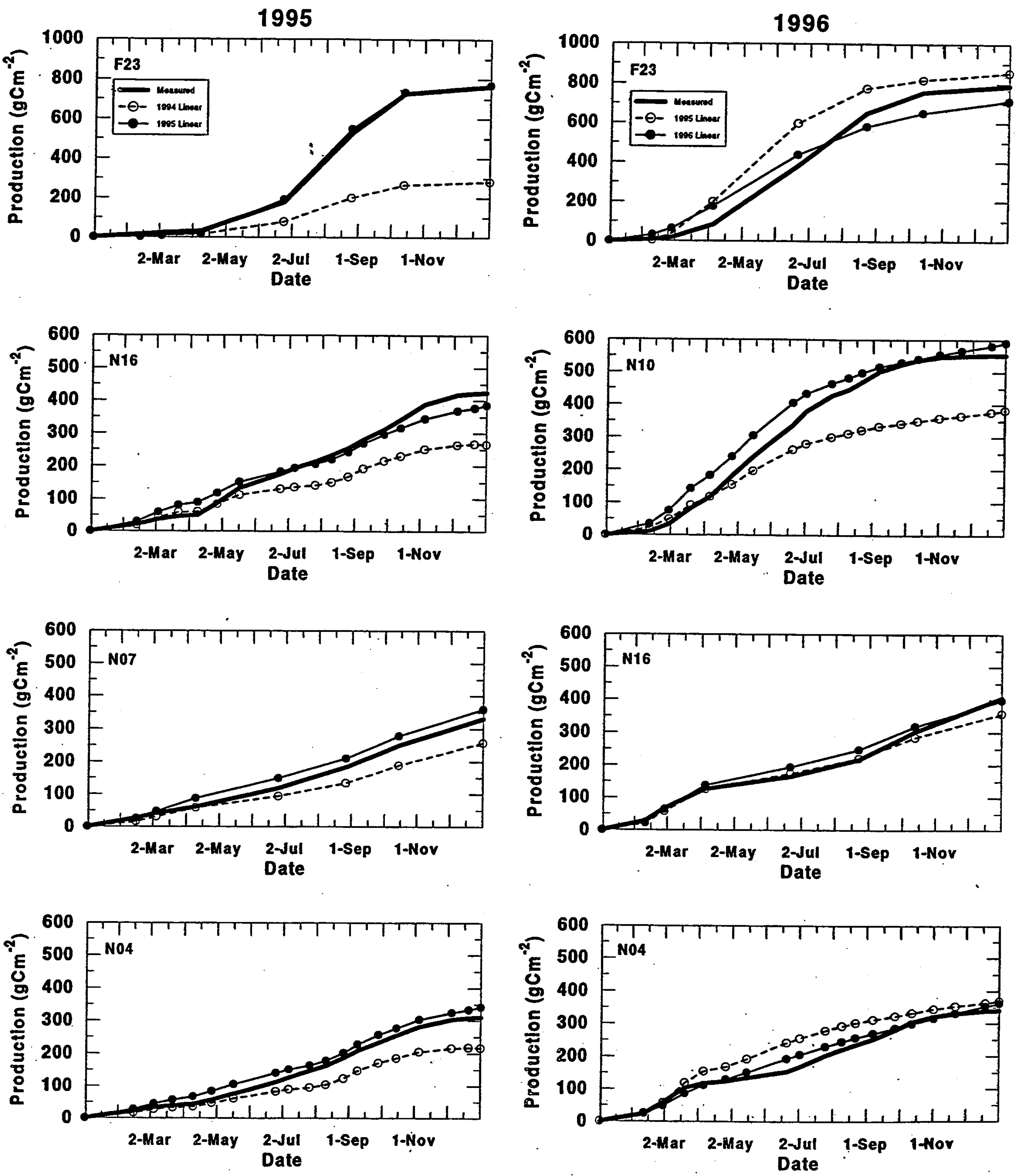


1994 Model
F23
1995 Model
F23
1994 Model
N16
1995 Model
N16
1994 Model
N07
1995 Model
N07
1994 Model
N04
1995 Model
N04
Production (mgCm^{-2}d^{-1})
Date
2-Mar
2-May
2-Jul
1-Sep
1-Nov
0
2000
4000
8000

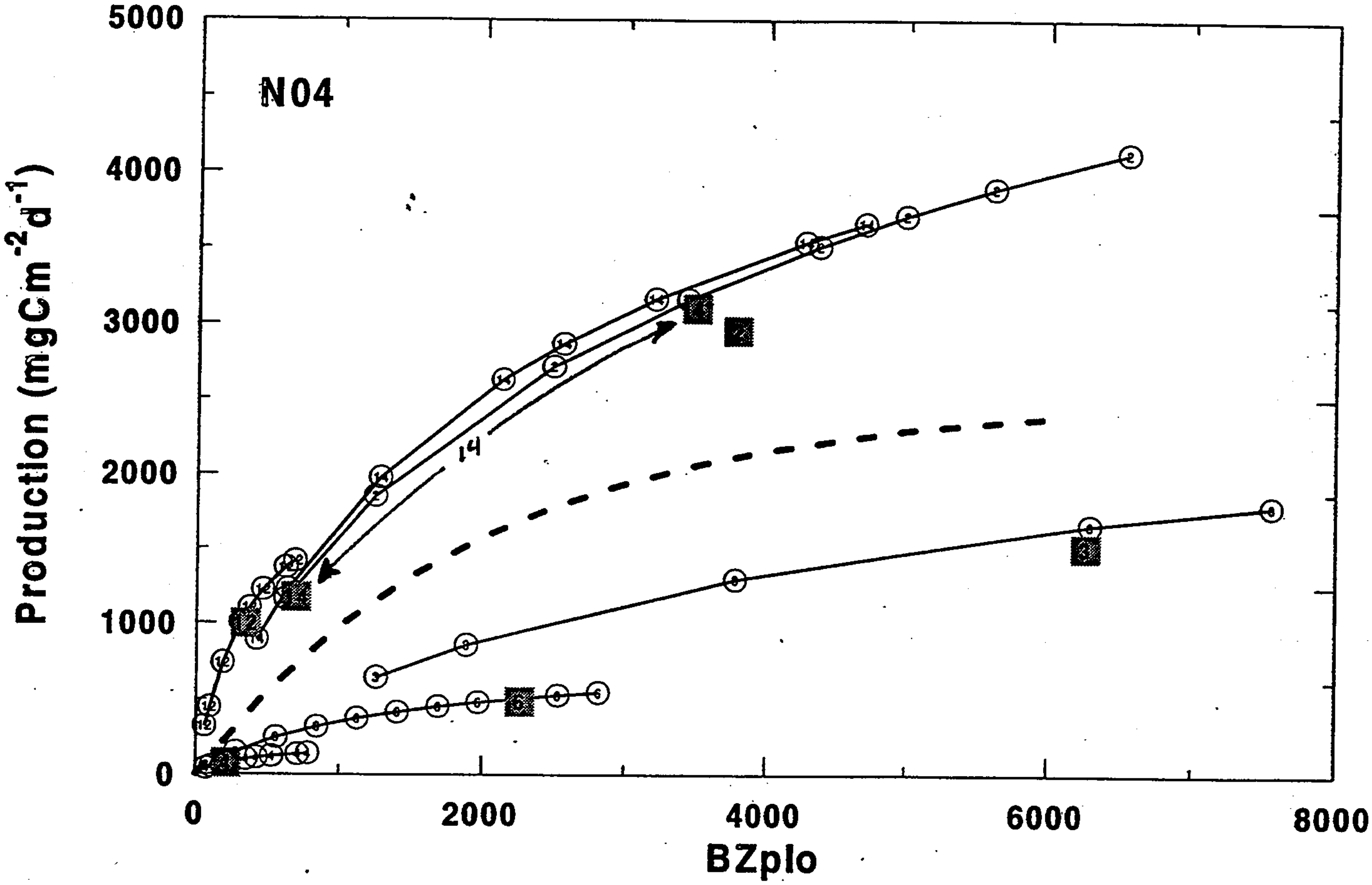
1996

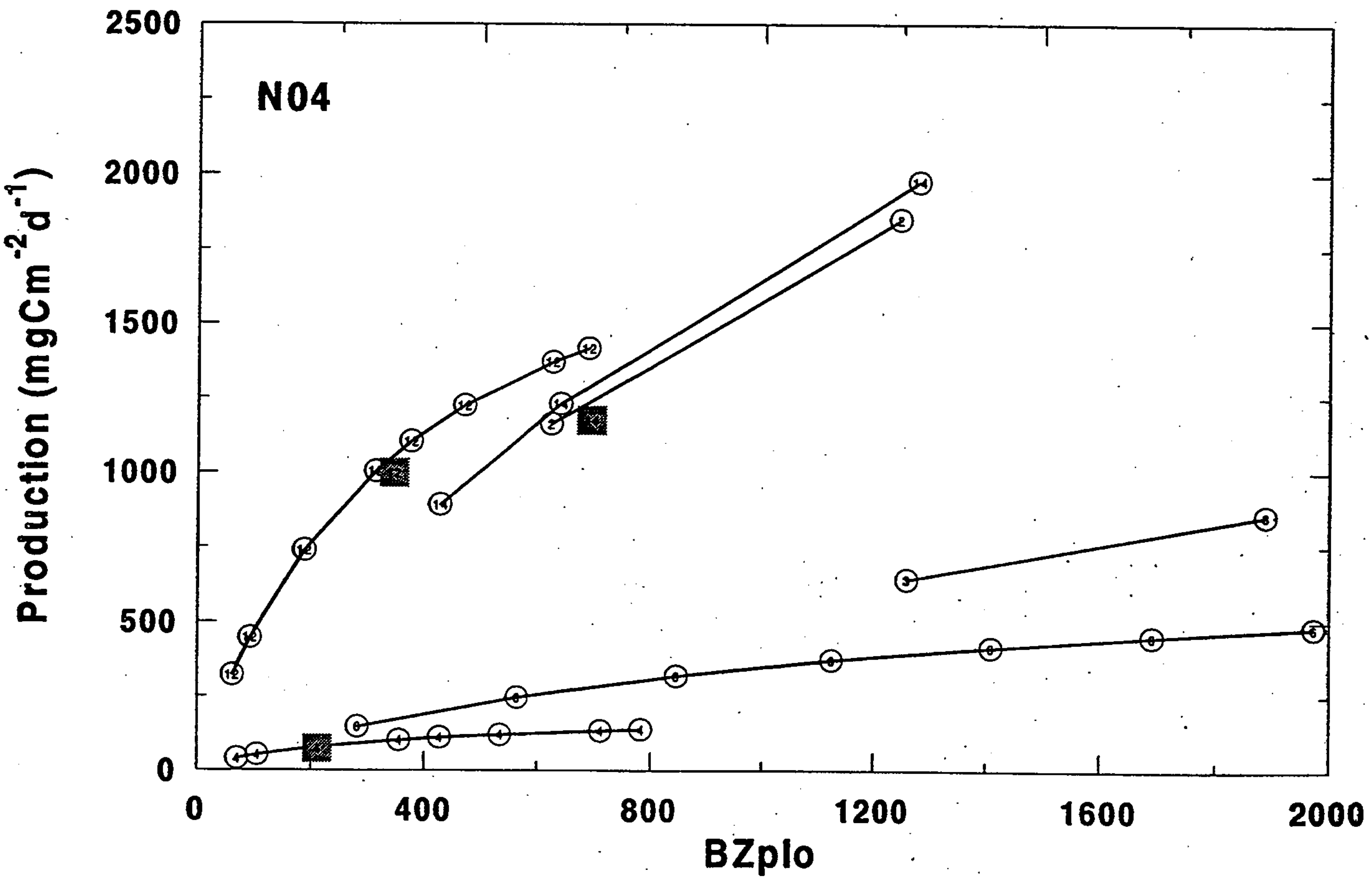


1995 Model
F23
1996 Model
F23
Fit Omitting 7 & 11
1995 Model
N10
1996 Model
N10
1995 Model
N16
1996 Model
N16
1995 Model
N04
1996 Model
N04
Production (mgCm-2d-1)
Date
2-Mar
2-May
2-Jul
1-Sep
1-Nov

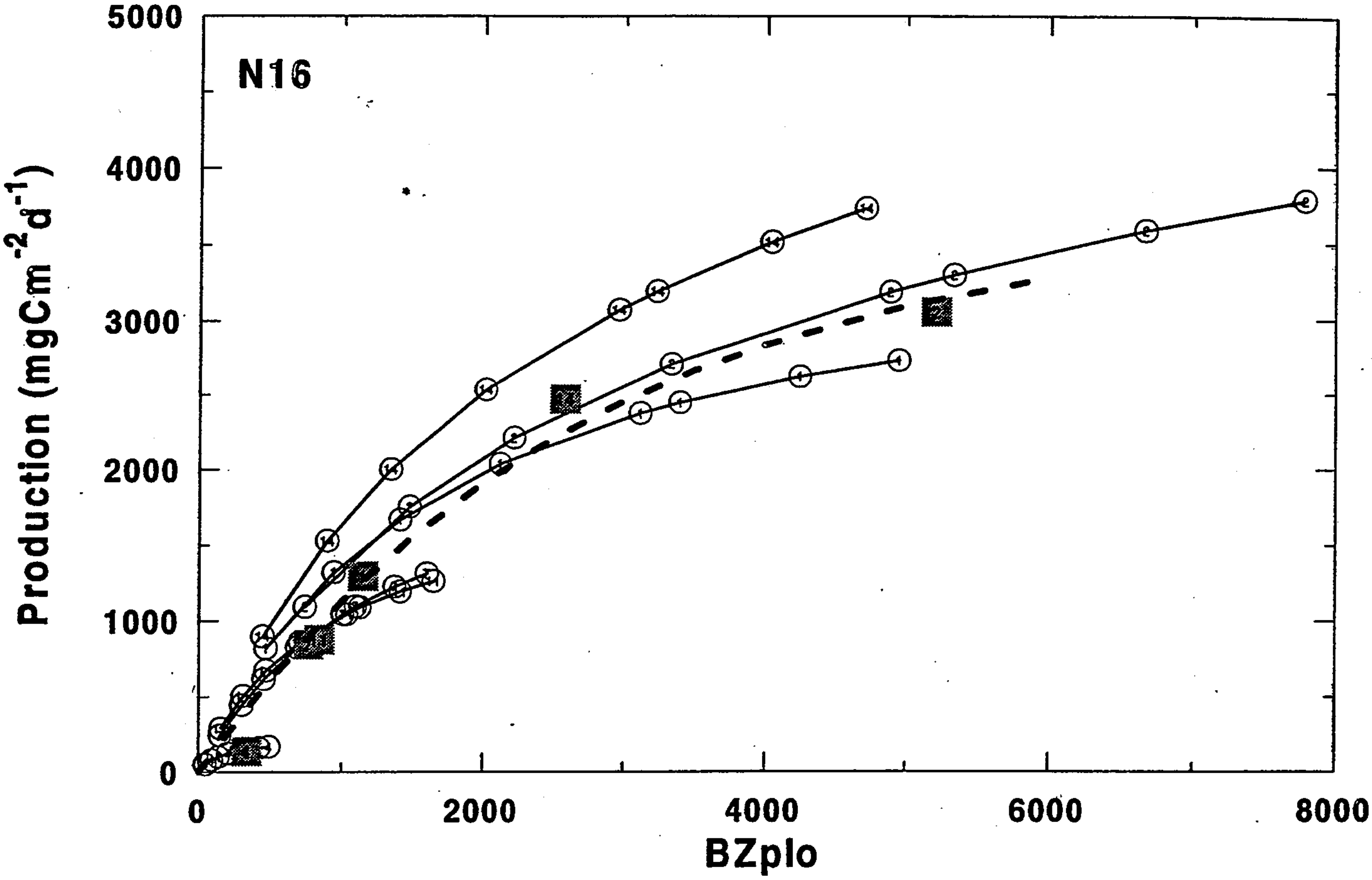

1995
1996
F23
Measured
1994 Linear
1995 Linear
1996 Linear
N16
N10
N07
N04
Production (gCm-2)
Date
2-Mar
2-May
2-Jul
1-Sep
1-Nov
0
100
200
300
400
500
600
800
1000

1996

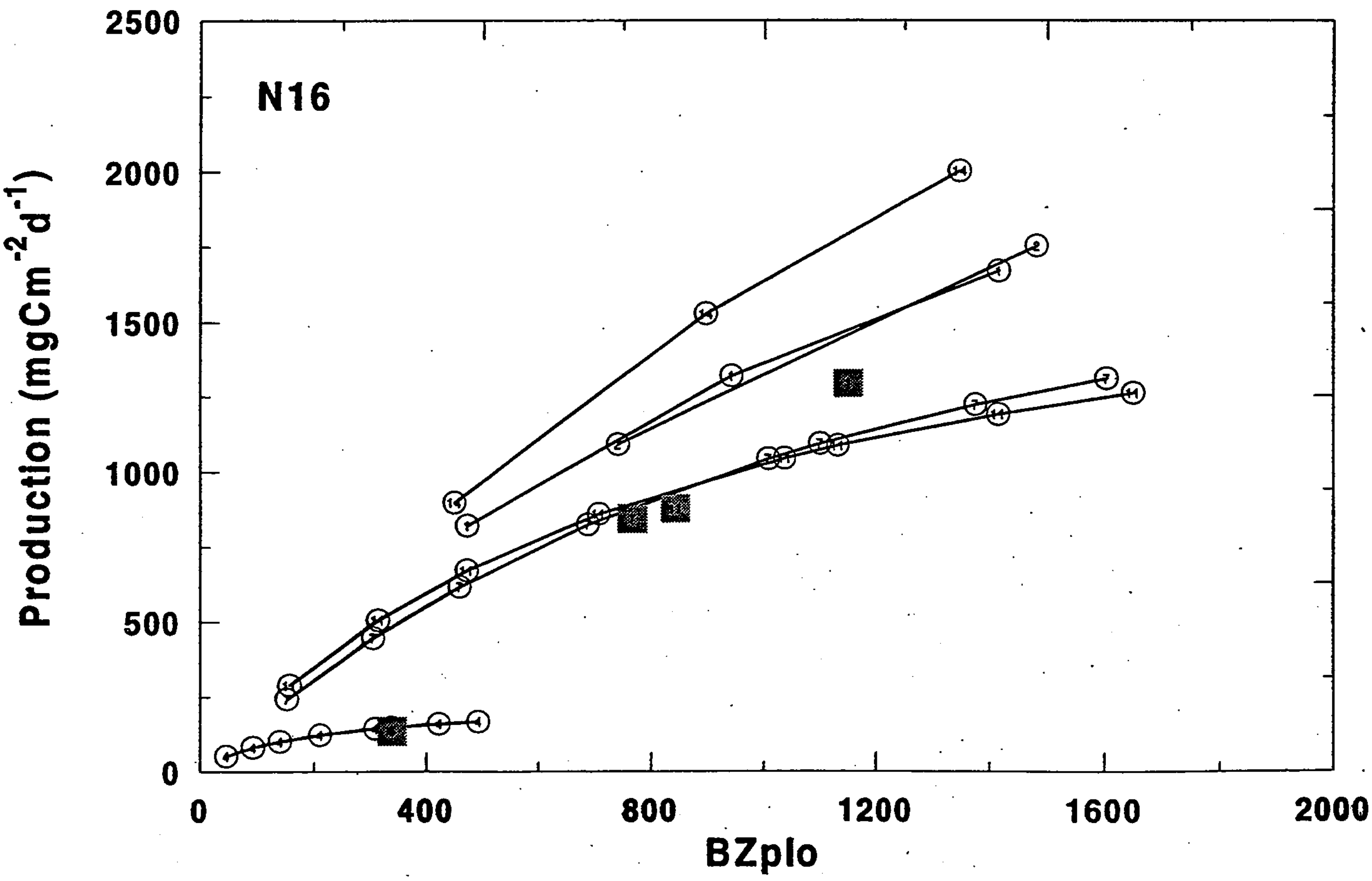

N04
Production (mgCm^{-2}d^{-1})
BZplo
14


N04
Production (mgCm^{-2}d^{-1})
BZplo

1996

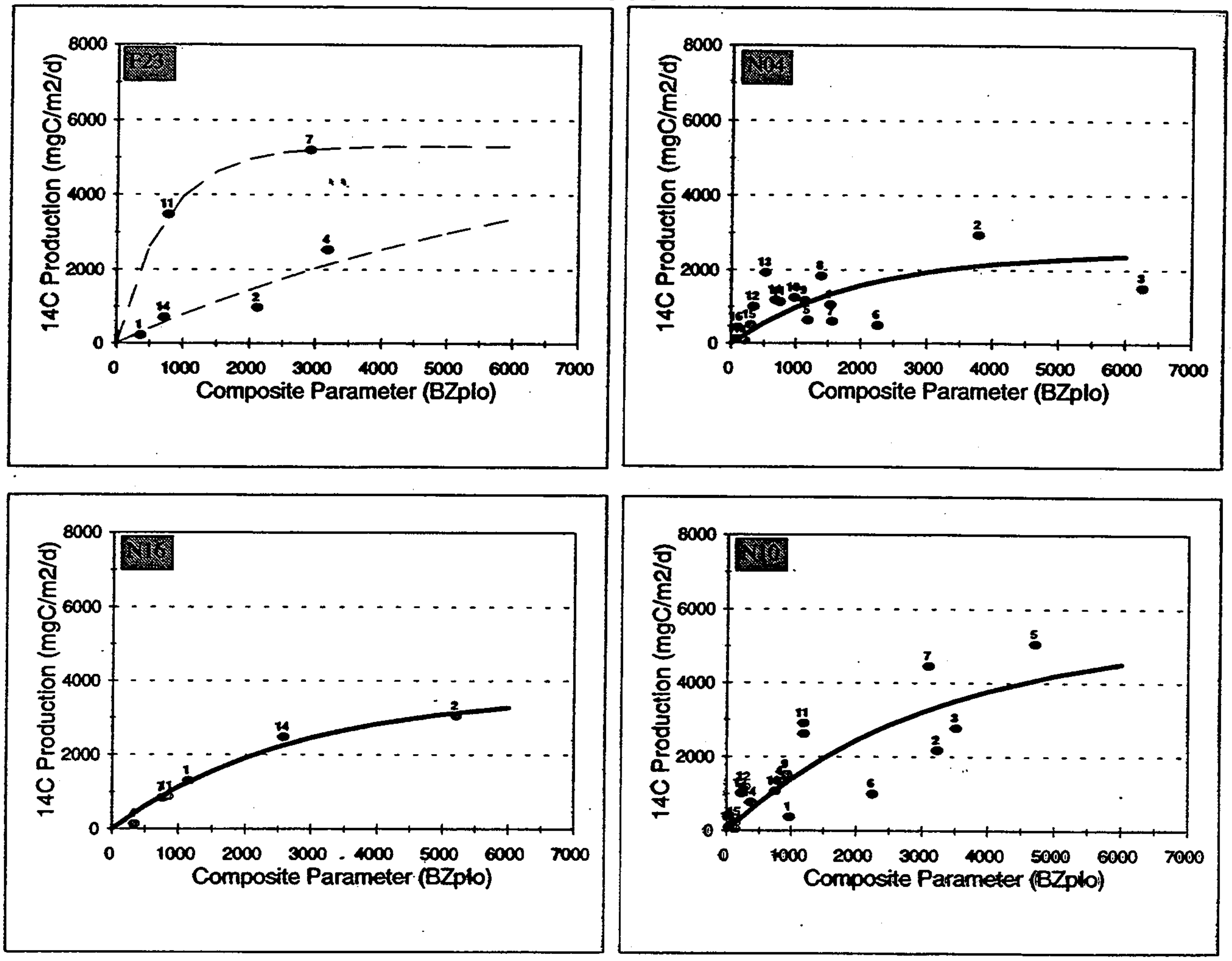


N16
Production (mgCm-2d-1)
0
1000
2000
3000
4000
5000
0
2000
4000
6000
8000
BZplo



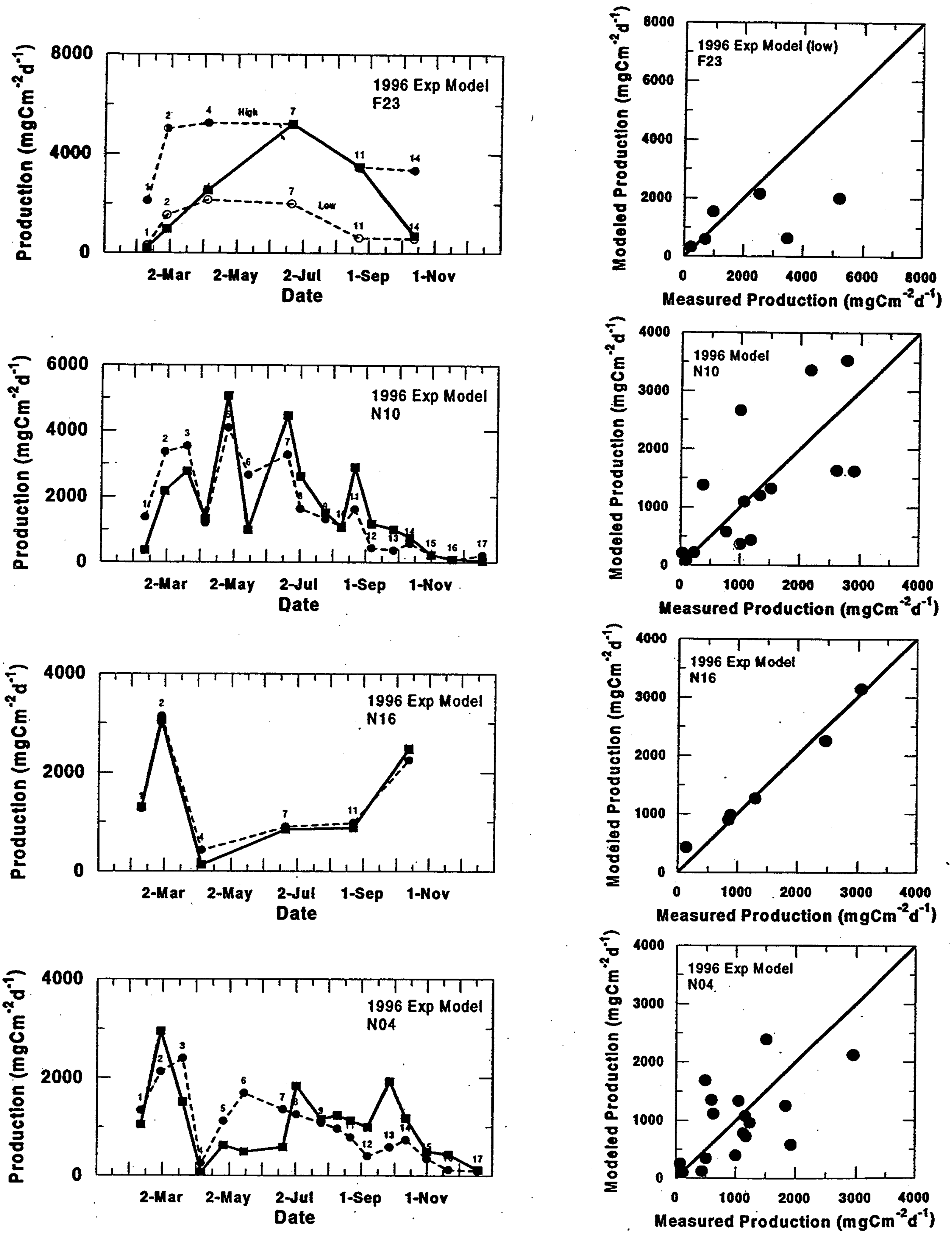
N16
Production (mgCm-2d-1)
0
500
1000
1500
2000
2500
0
400
800
1200
1600
2000
BZplo

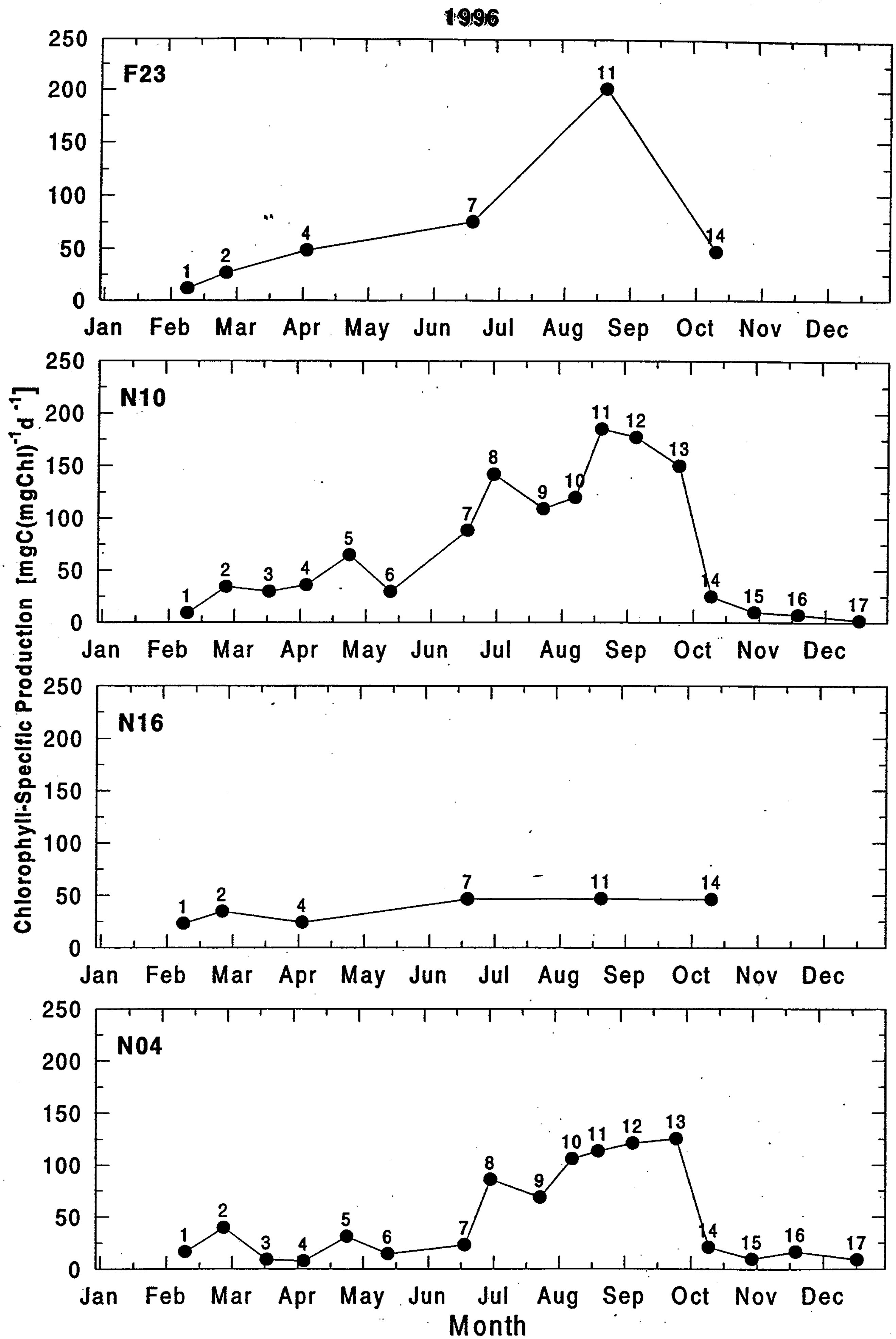
1996

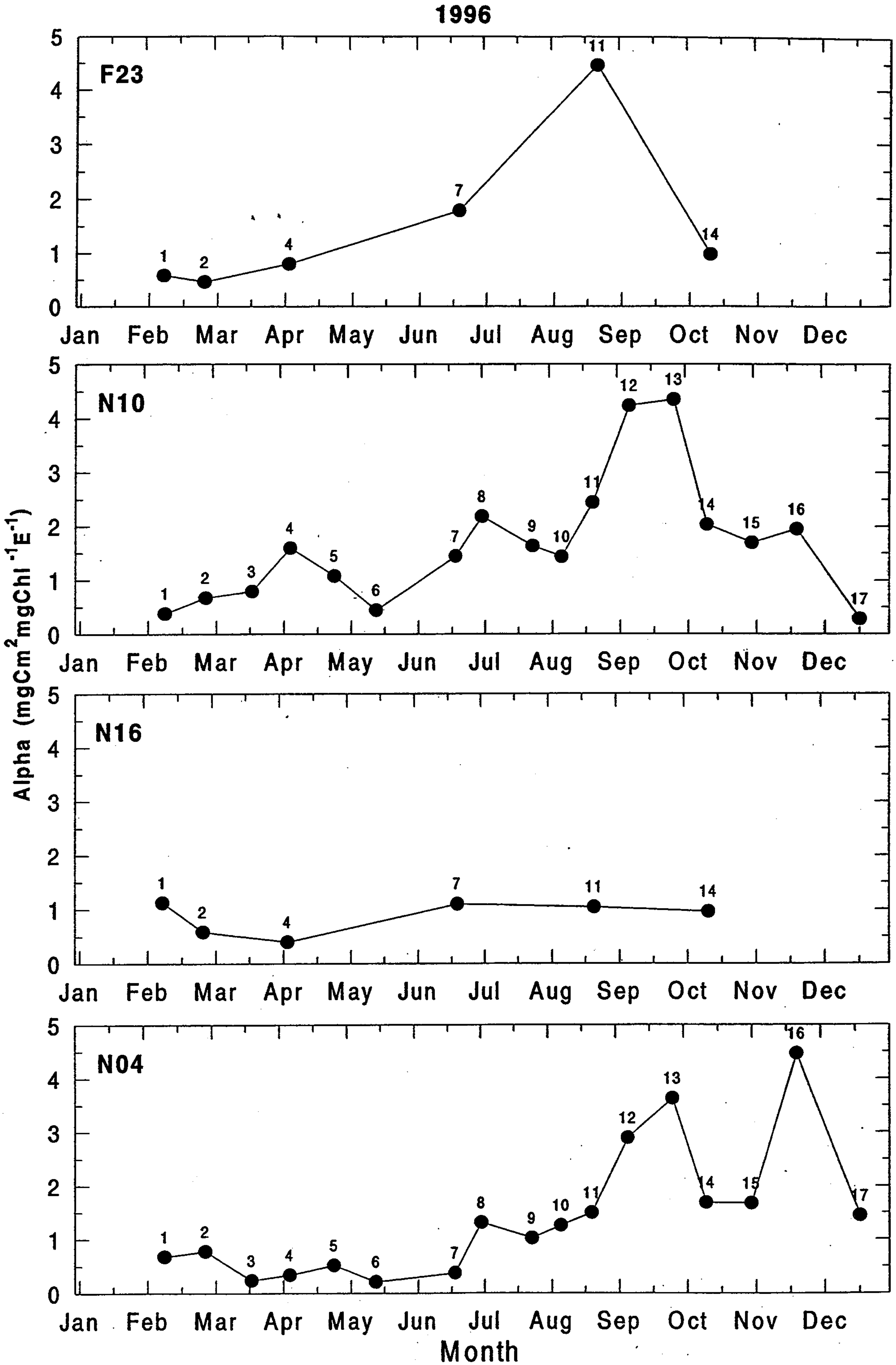


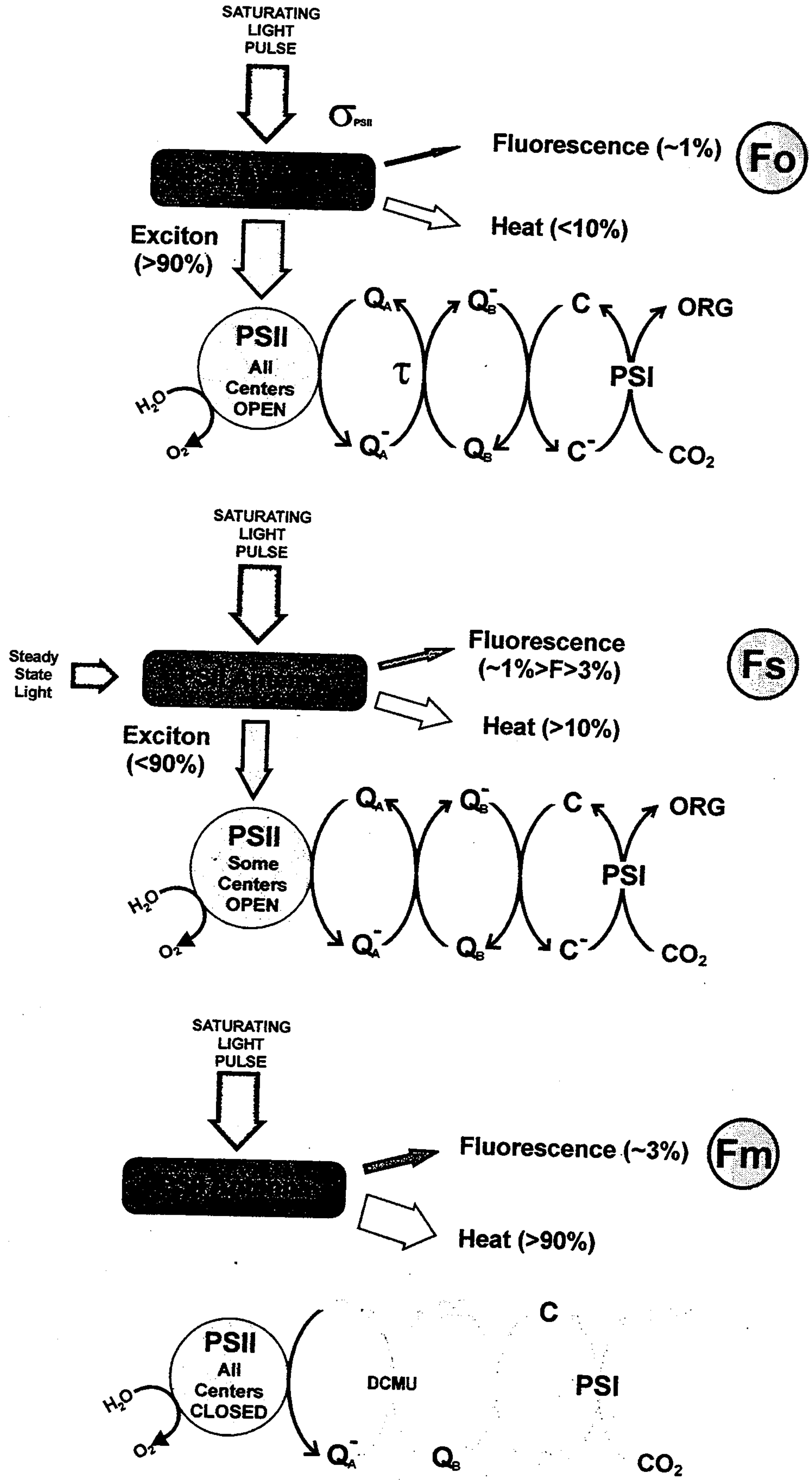
P23
N04
N16
N10
14C Production (mgC/m2/d)
Composite Parameter (BZplo)
0
2000
4000
6000
8000
0
1000
2000
3000
4000
5000
6000
7000

1996

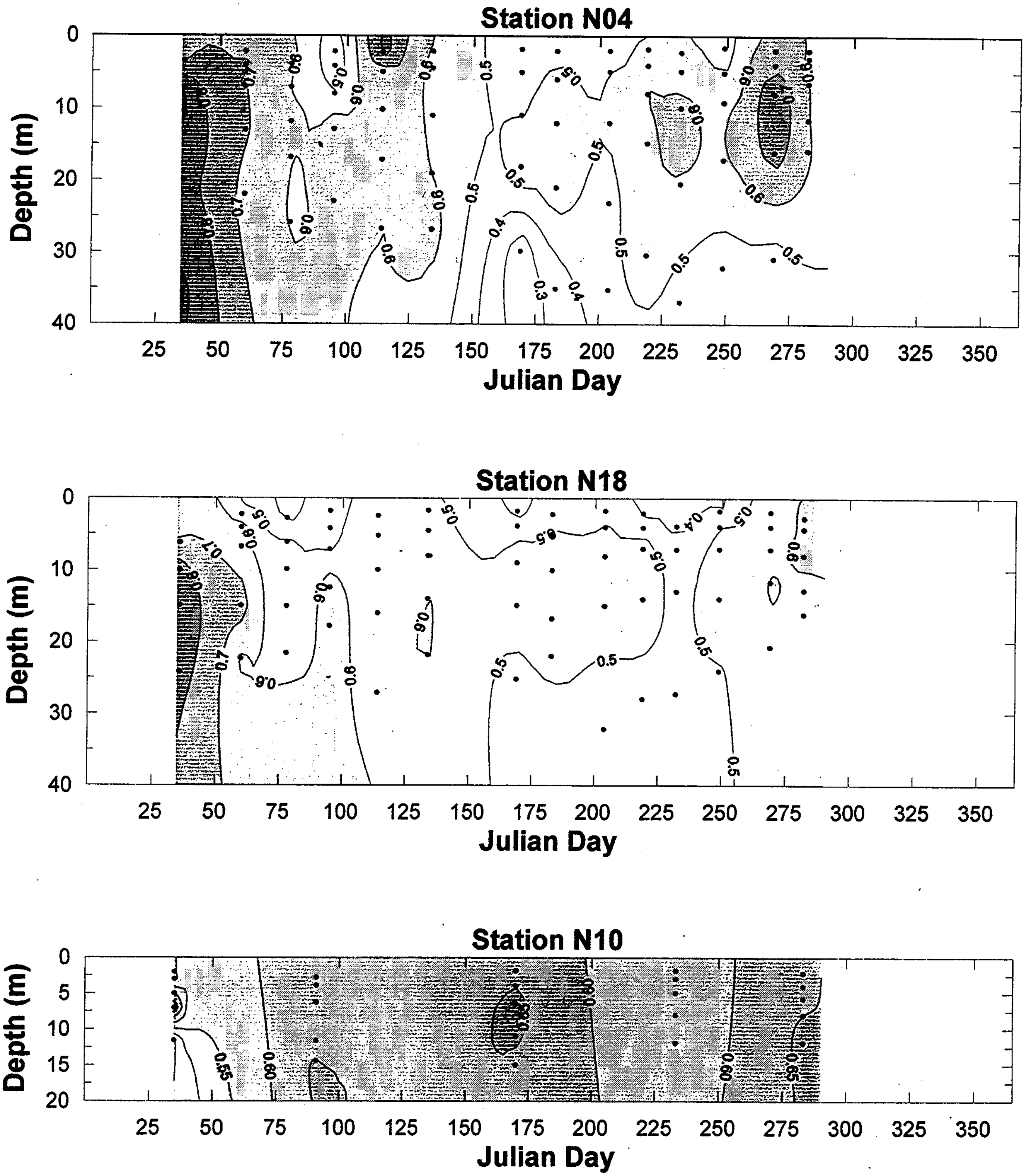

1996 Exp Model
F23
High
Low
Production (mgCm^{-2}d^{-1})
Date
2-Mar
2-May
2-Jul
1-Sep
1-Nov
1996 Exp Model (low)
F23
Modeled Production (mgCm^{-2}d^{-1})
Measured Production (mgCm^{-2}d^{-1})
1996 Exp Model
N10
1996 Model
N10
1996 Exp Model
N16
1996 Exp Model
N16
1996 Exp Model
N04
1996 Exp Model
N04


1996
F23
N10
N16
N04
Chlorophyll-Specific Production [mgC(mgChl)-1 d-1]
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
0 50 100 150 200 250

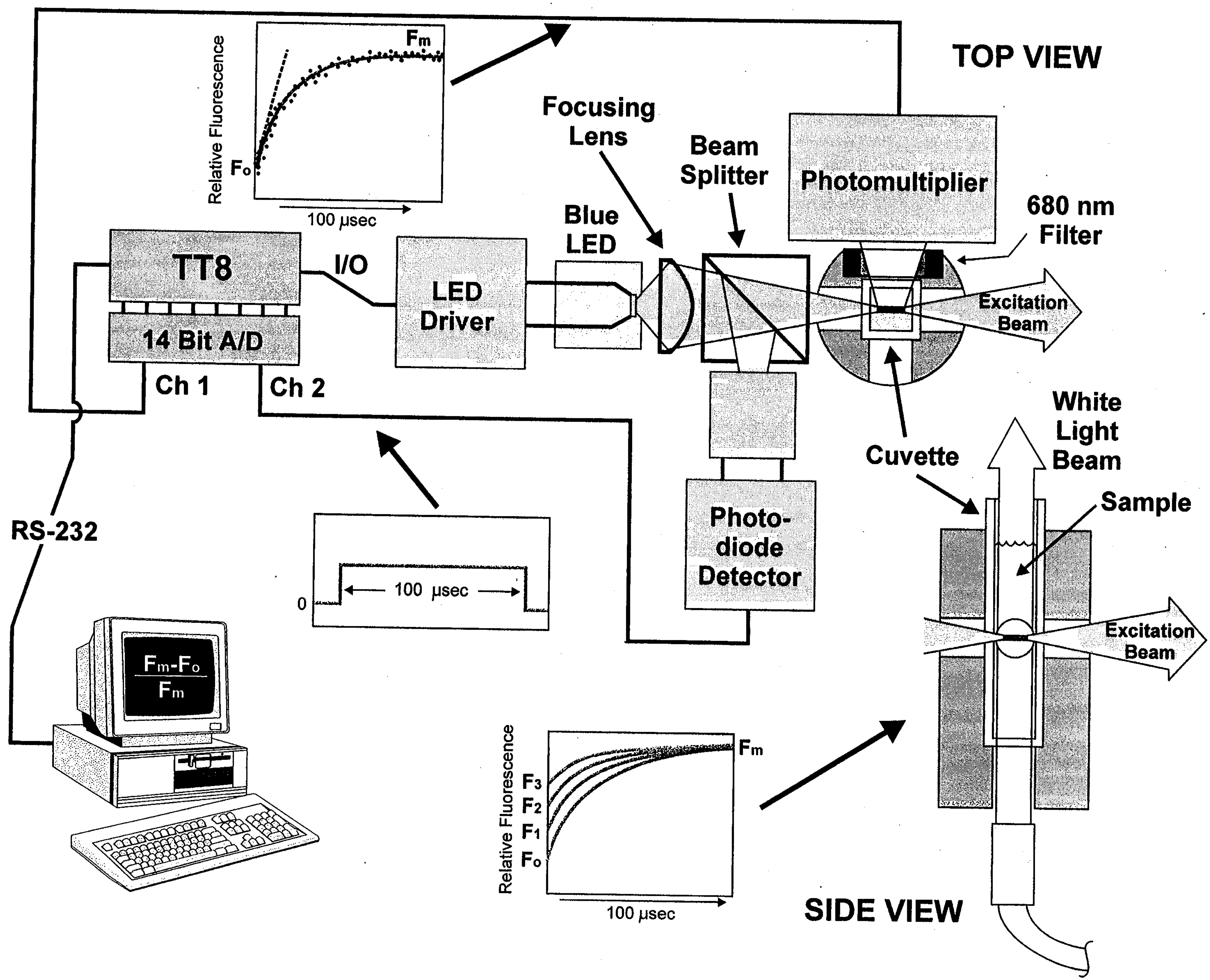

1996
F23
N10
N16
N04
Alpha (mgCm2mgChl-1E-1)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month



$$\Delta\Phi_{max} = \frac{Fm - Fo}{Fm} = \frac{F_{DCMU} - Fo}{F_{DCMU}}$$


Station N04
Depth (m)
Julian Day
Station N18
Depth (m)
Julian Day
Station N10
Depth (m)
Julian Day

(Fm-Fo)/Fm


TOP VIEW
Relative Fluorescence
Fo
Fm
100 µsec
Focusing Lens
Beam Splitter
Photomultiplier
680 nm Filter
Blue LED
TT8
14 Bit A/D
I/O
LED Driver
Excitation Beam
Ch 1
Ch 2
Cuvette
White Light Beam
Sample
RS-232
Photo-diode Detector
0
100 µsec
Fm-Fo
Fm
Relative Fluorescence
F3
F2
F1
Fo
Fm
100 µsec
Excitation Beam
SIDE VIEW

APPENDIX B-7
Carbon and Dissolved Oxygen: Brian Howes

Focus of Massachusetts Bay Oxygen-Respiration-Production Program:

The Potential for Oxygen Decline is among the Central Concerns
involving Nutrient Loading

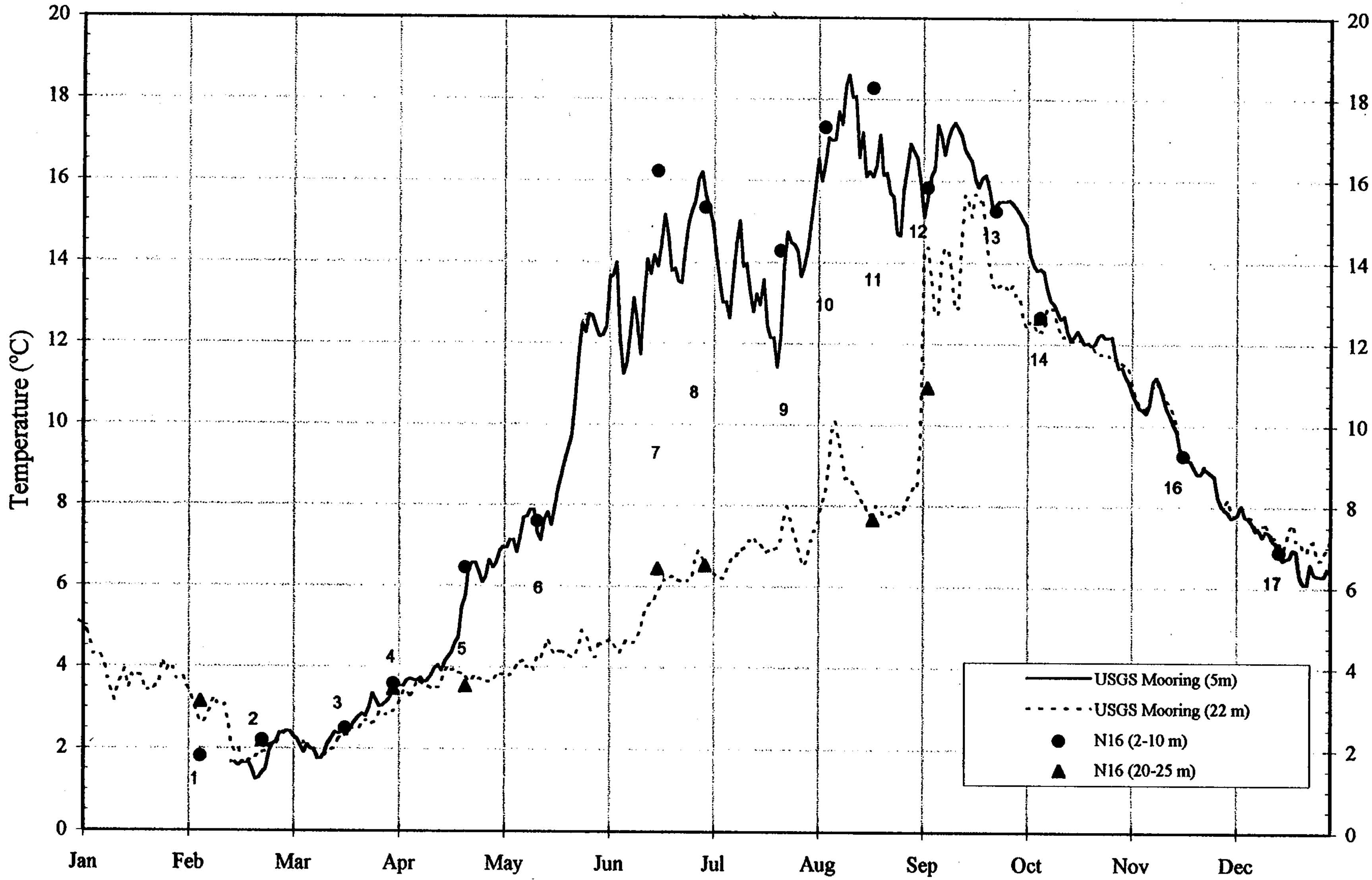
A. Approaches to detect oxygen changes <u>and</u> identify the causes

B. To predict watercolumn oxygen decline

C. To verify "proportional" oxygen models
(eg. 10% increase in organic matter, 10% greater decline)

D. To provide quantitative information on the "fate" of organic matter within the Near/Farfield: in situ decay versus export

E. To derive an independent estimate of bottom water ventilation


Temperature (°C)
20
18
16
14
12
10
8
6
4
2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1
2
3
4
5
6
7
8
9
10
11
12
13
14
16
17
USGS Mooring (5m)
USGS Mooring (22 m)
N16 (2-10 m)
N16 (20-25 m)

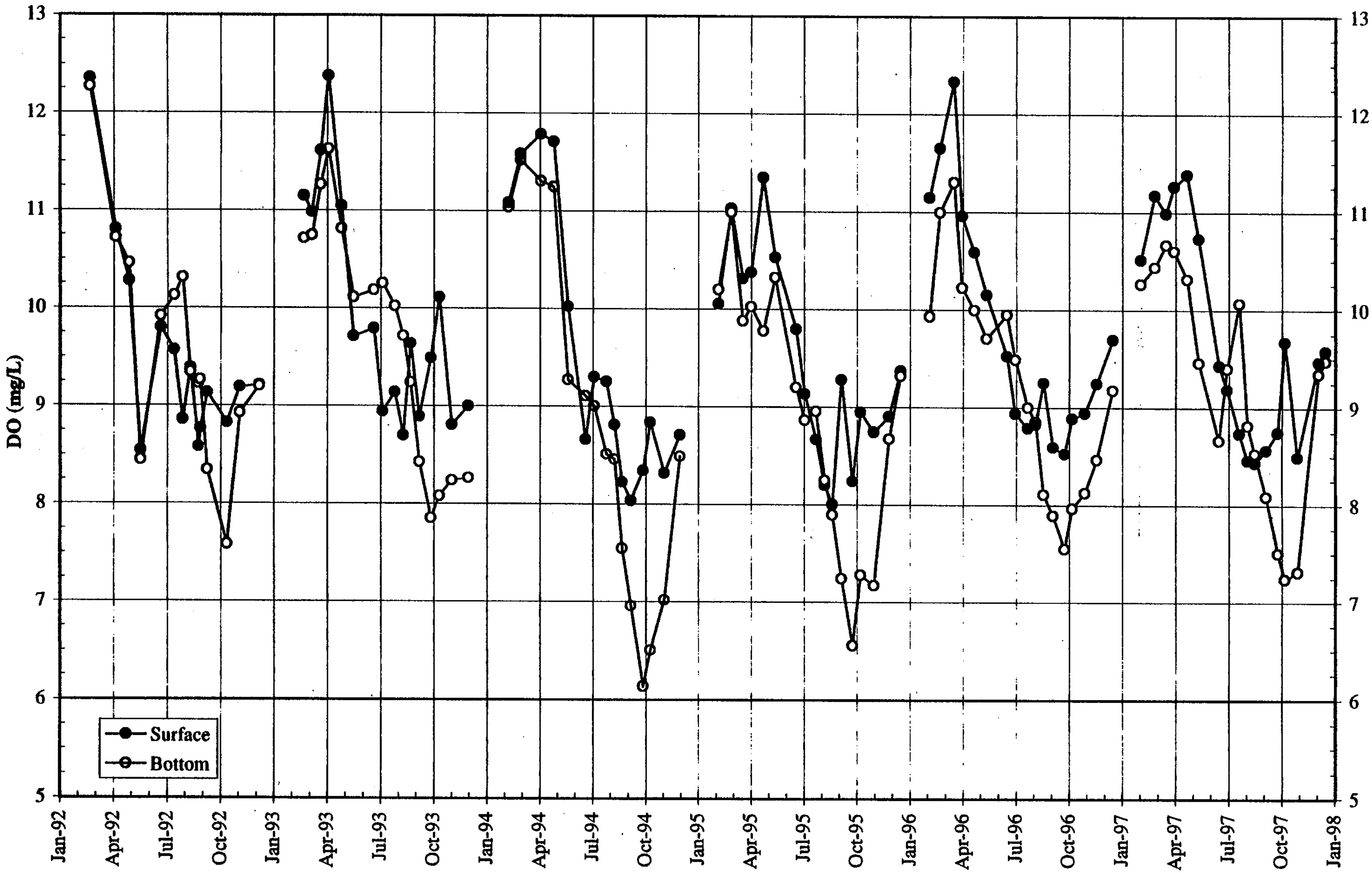
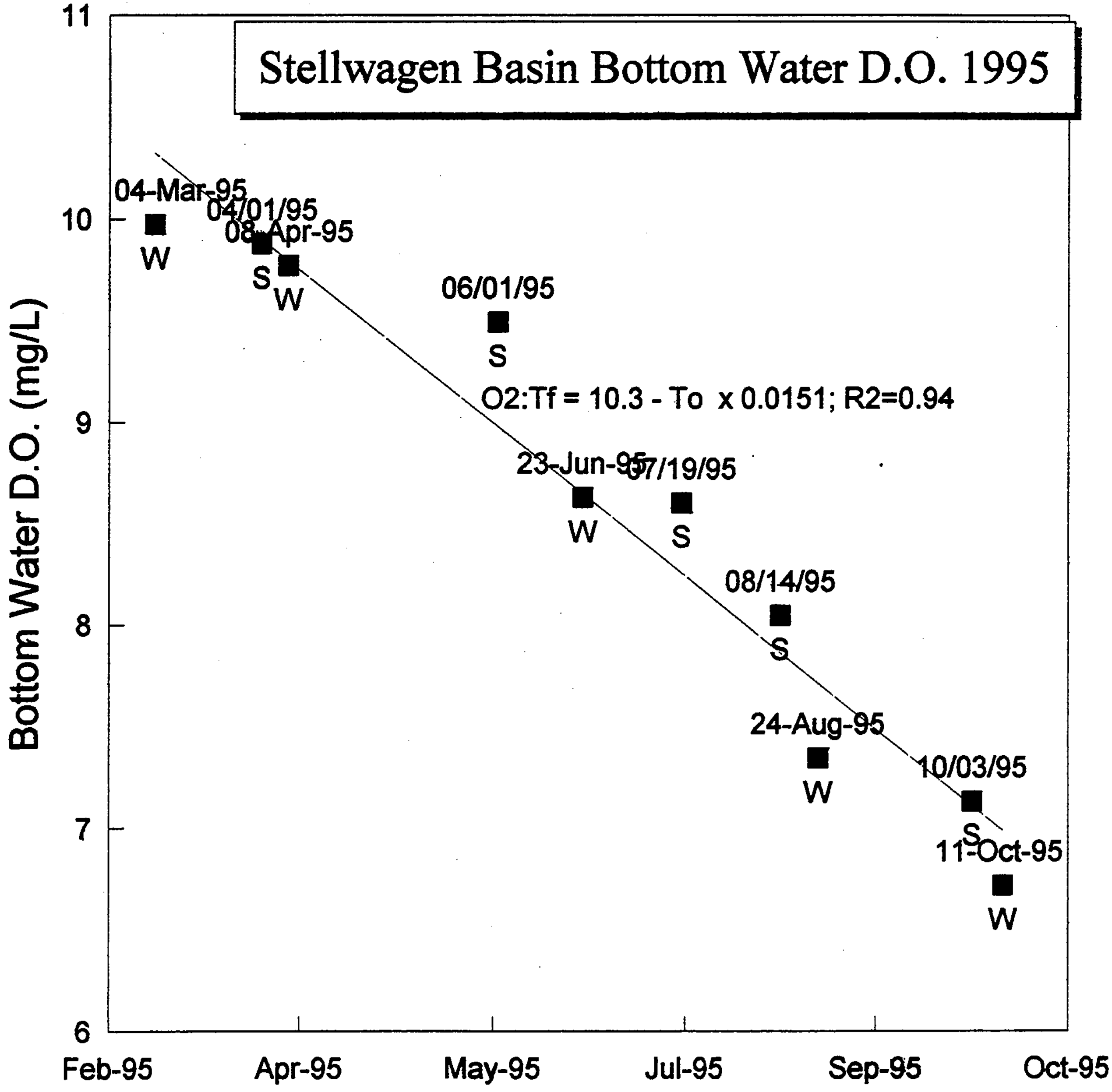


FIGURE 1a

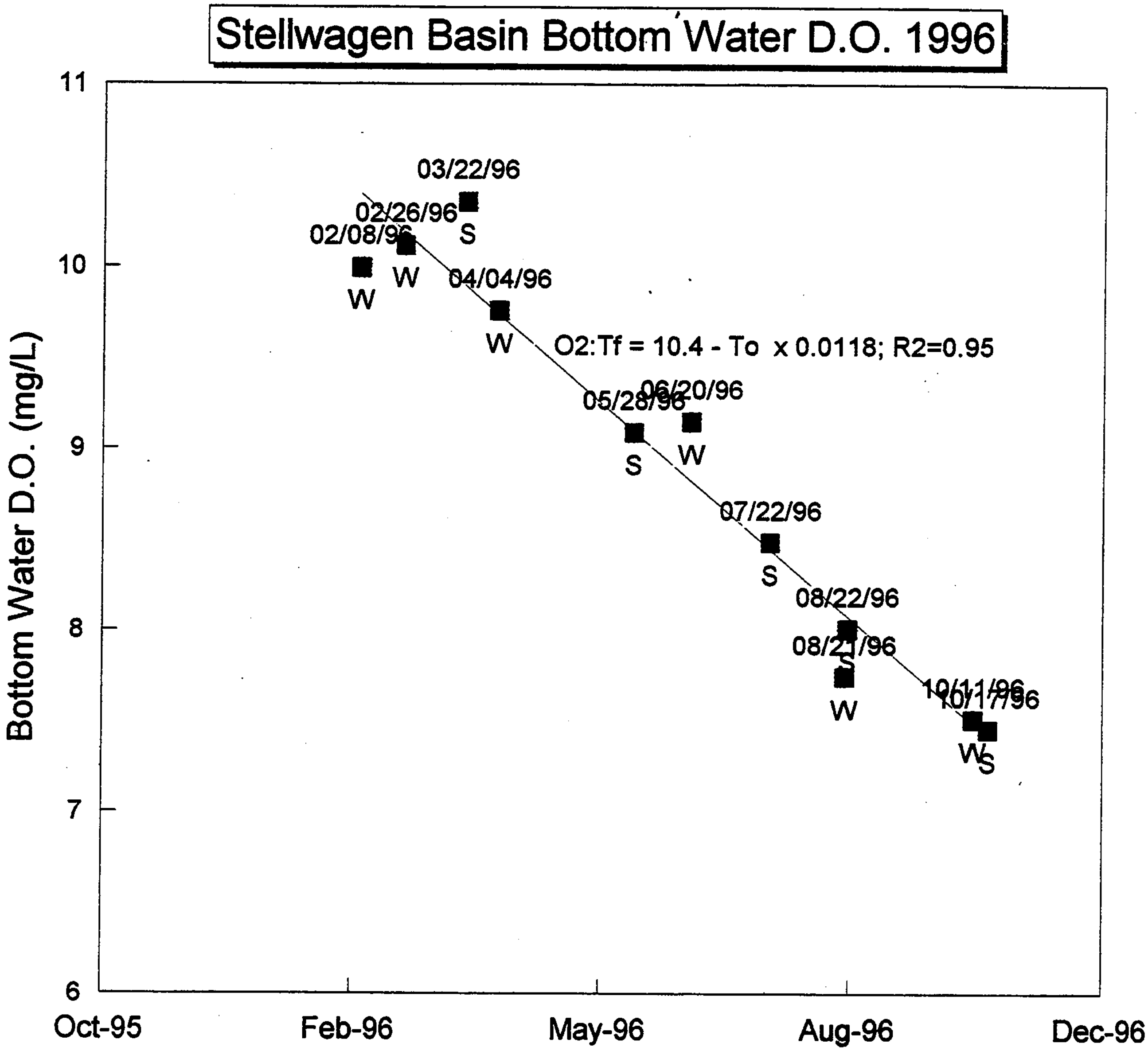
Interannual Nearfield Dissolved Oxygen Cycle in Surface and Bottom Waters

Symbols indicate the mean of 17 nearfield stations; error bars represent +/- one standard deviation.

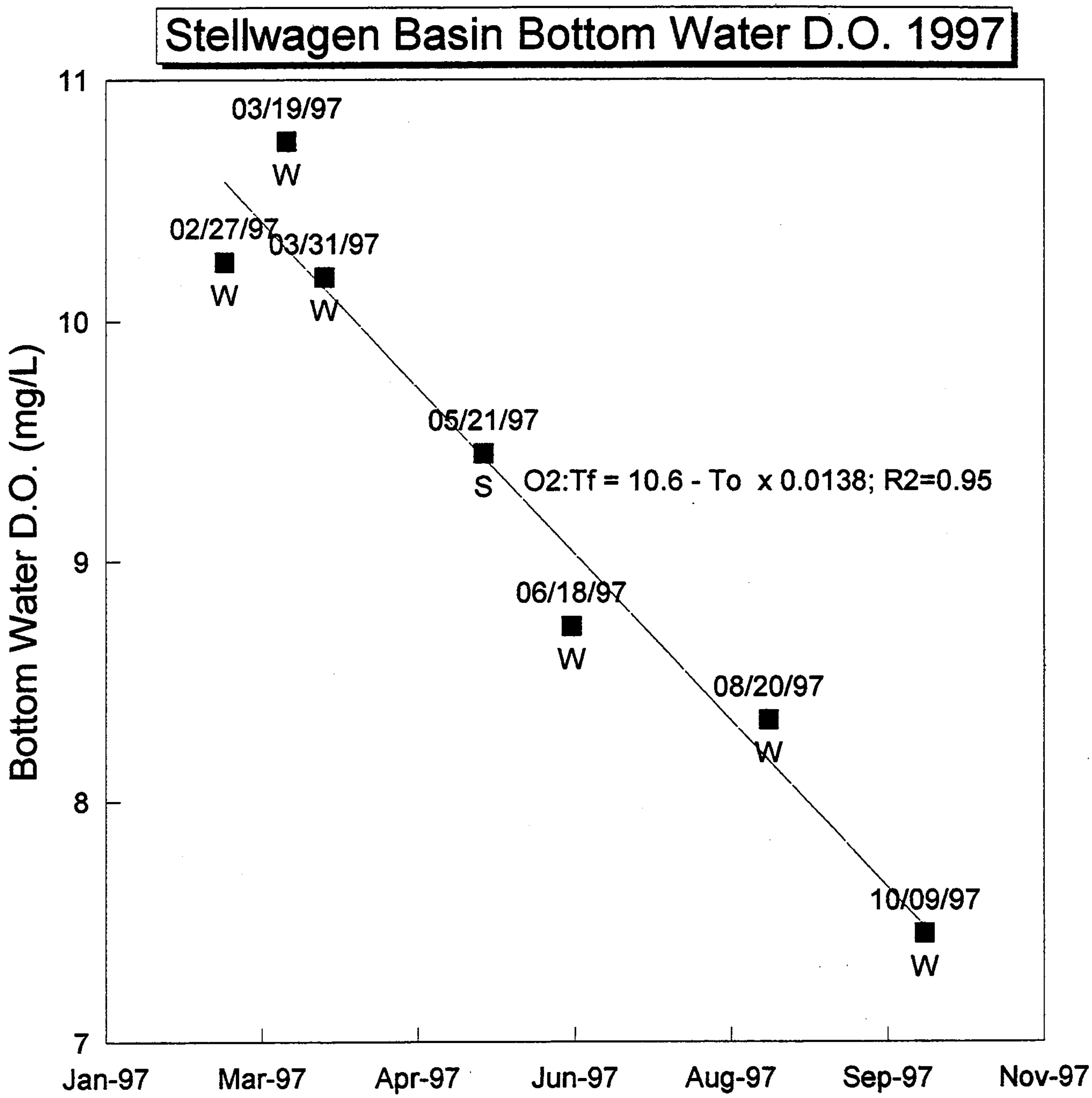
Do97pred
2/16/98

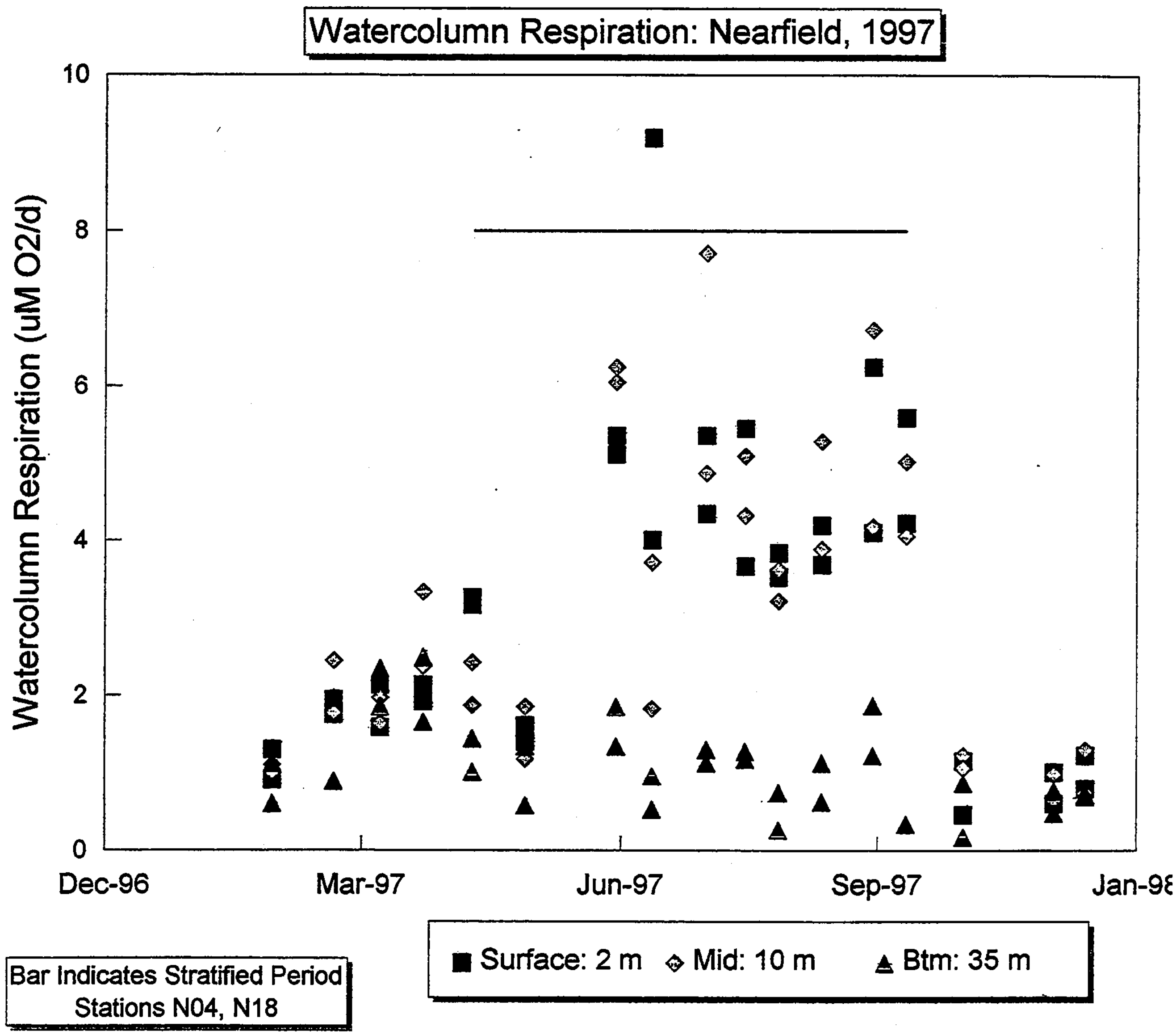


Stellwagen Basin Bottom Water D.O. 1995
Bottom Water D.O. (mg/L)
11
10
9
8
7
6
Feb-95
Apr-95
May-95
Jul-95
Sep-95
Oct-95
04-Mar-95
W
04/01/95
S
08-Apr-95
W
06/01/95
S
O2:Tf = 10.3 - To x 0.0151; R2=0.94
23-Jun-95
W
07/19/95
S
08/14/95
S
24-Aug-95
W
10/03/95
S
11-Oct-95
W

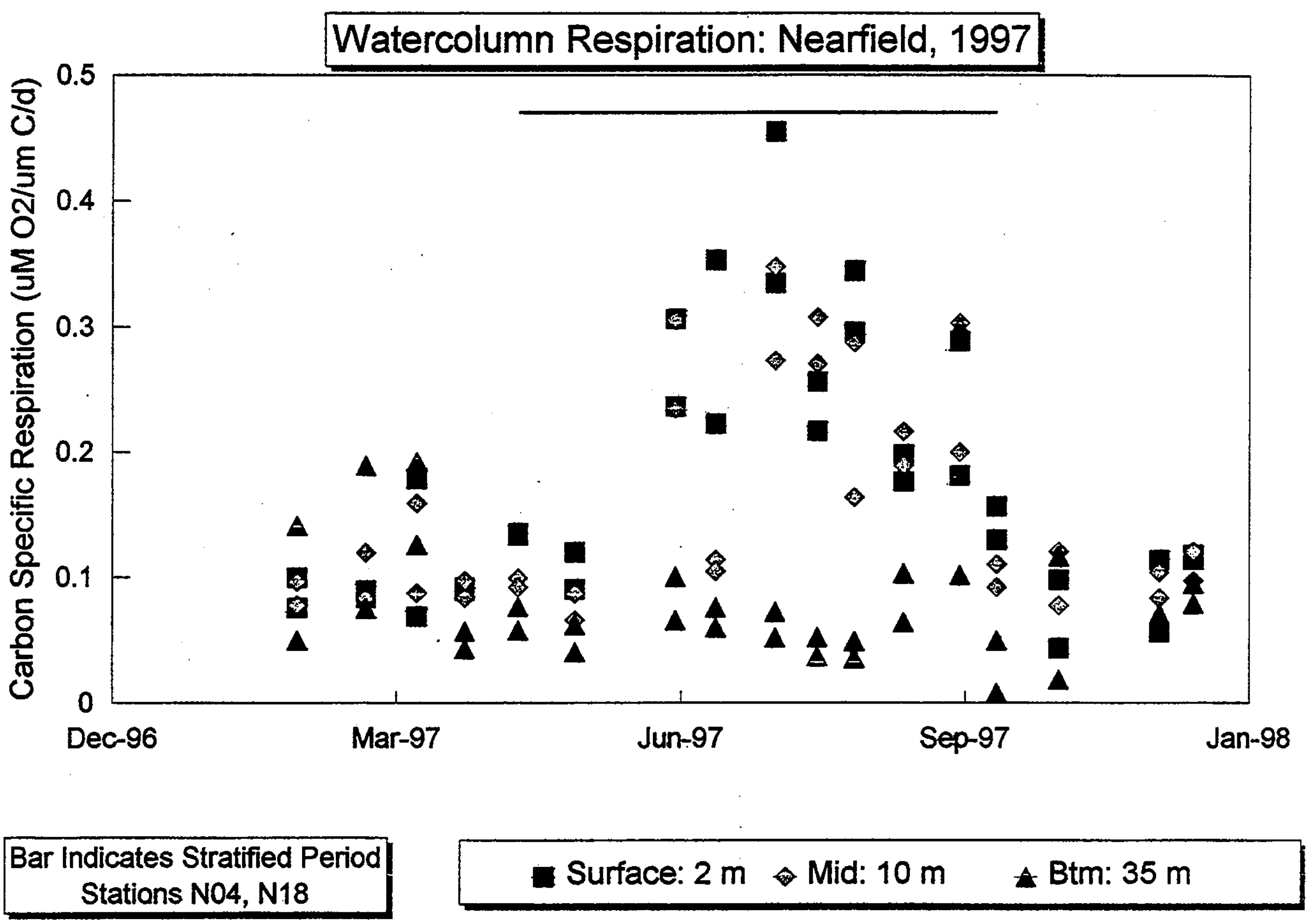


Stellwagen Basin Bottom Water D.O. 1996
Bottom Water D.O. (mg/L)
11
10
9
8
7
6
Oct-95
Feb-96
May-96
Aug-96
Dec-96
03/22/96
02/26/96
02/08/96
04/04/96
O2:Tf = 10.4 - To x 0.0118; R2=0.95
05/28/96
06/20/96
07/22/96
08/22/96
08/21/96
10/11/96
10/17/96
W
S

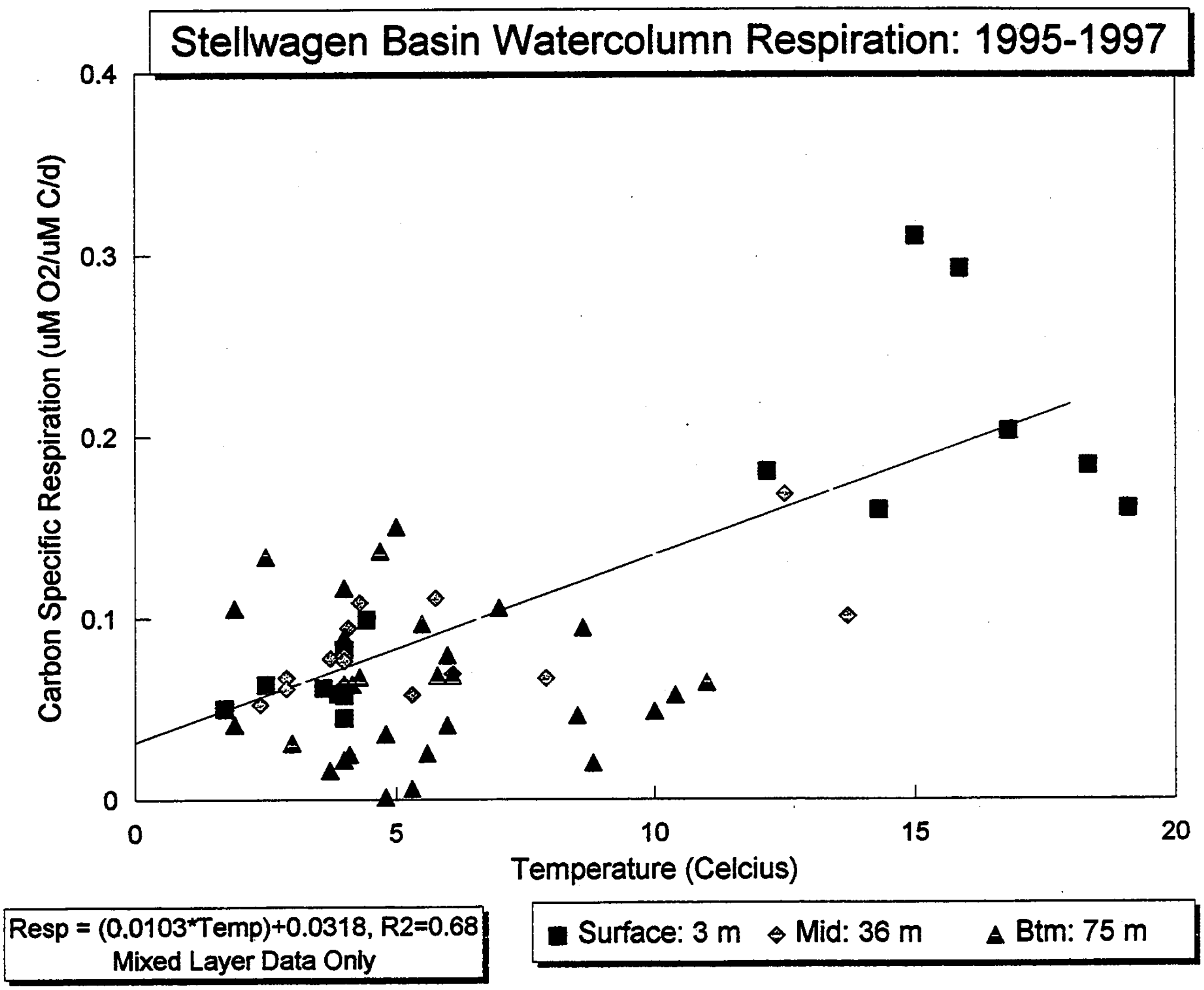

Stellwagen Basin Bottom Water D.O. 1997
Bottom Water D.O. (mg/L)
11
10
9
8
7
03/19/97
W
02/27/97
W
03/31/97
W
05/21/97
S
O2:Tf = 10.6 - To x 0.0138; R2=0.95
06/18/97
W
08/20/97
W
10/09/97
W
Jan-97
Mar-97
Apr-97
Jun-97
Aug-97
Sep-97
Nov-97

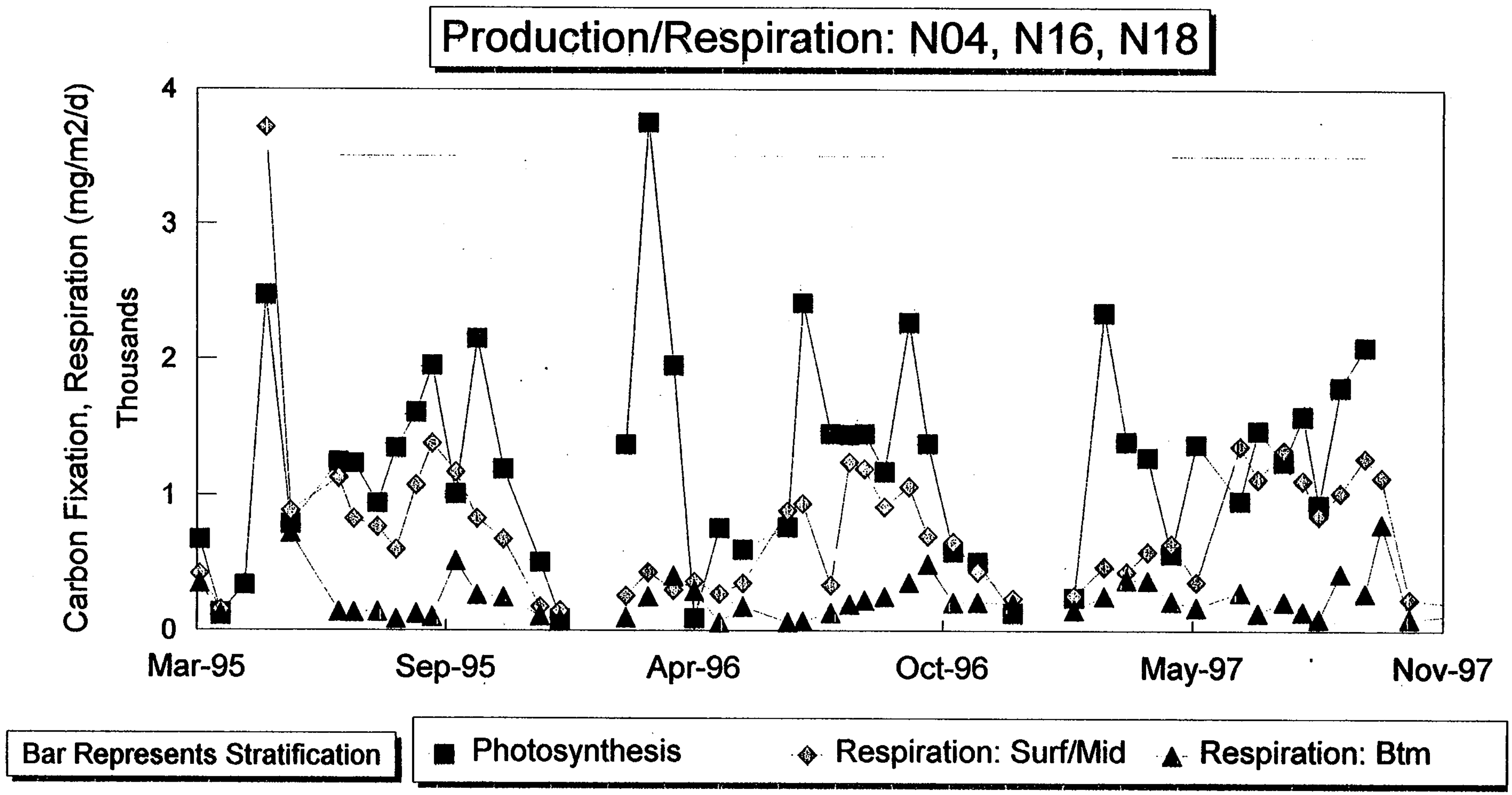


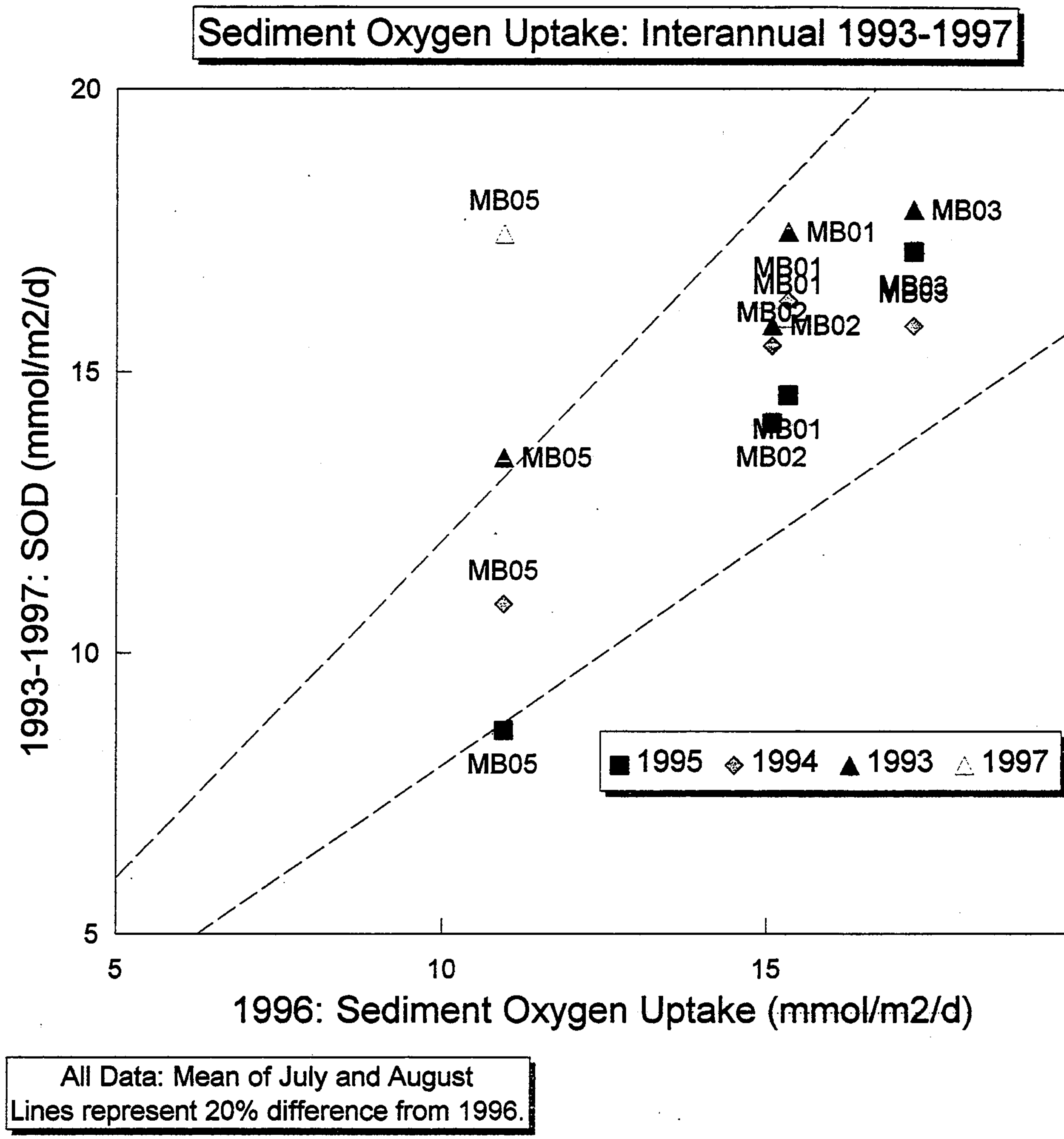
Watercolumn Respiration: Nearfield, 1997
Watercolumn Respiration (uM O2/d)
10
8
6
4
2
0
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
Bar Indicates Stratified Period
Stations N04, N18
Surface: 2 m
Mid: 10 m
Btm: 35 m

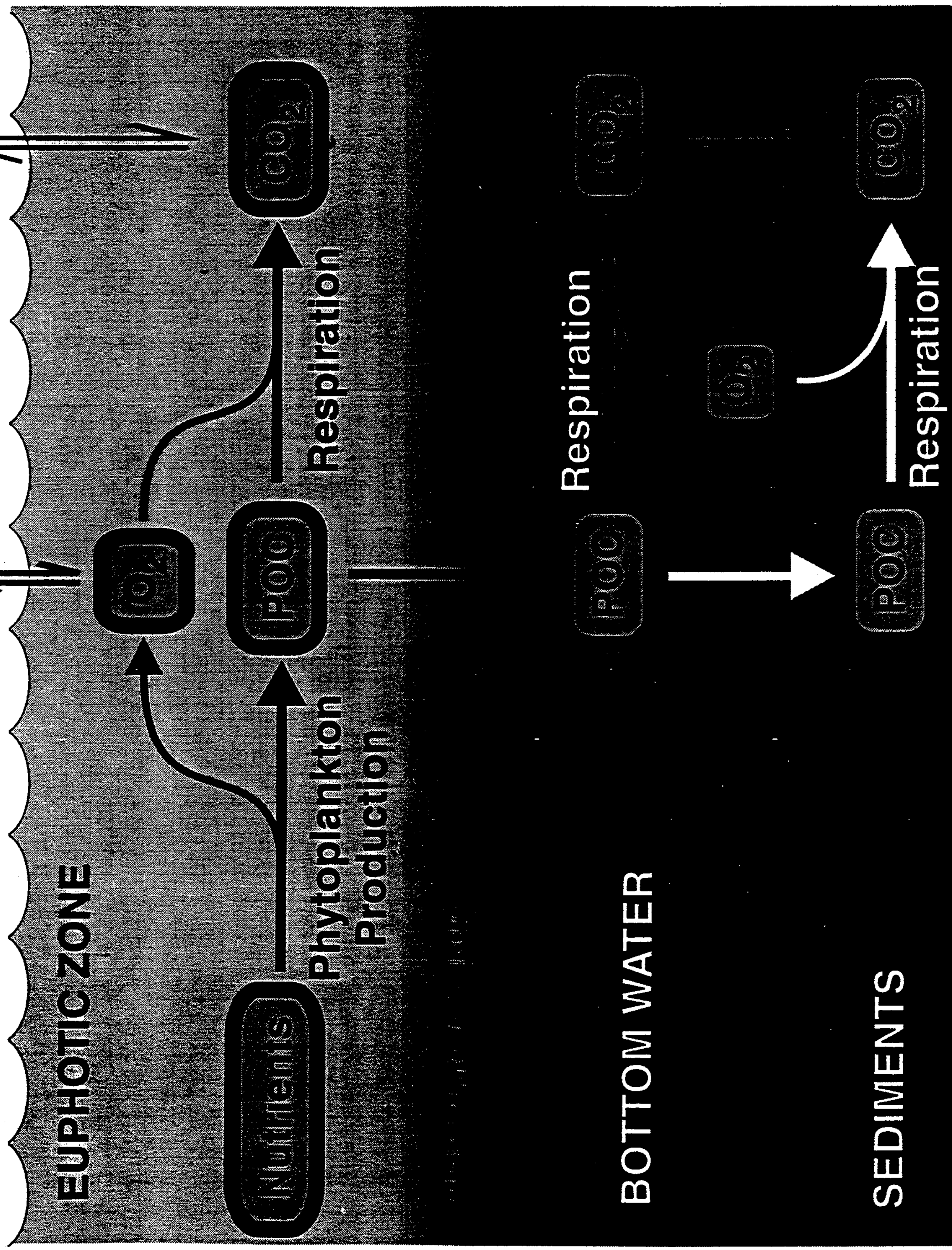


Watercolumn Respiration: Nearfield, 1997
Carbon Specific Respiration (uM O2/um C/d)
0.5
0.4
0.3
0.2
0.1
0
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
Bar Indicates Stratified Period
Stations N04, N18
Surface: 2 m
Mid: 10 m
Btm: 35 m

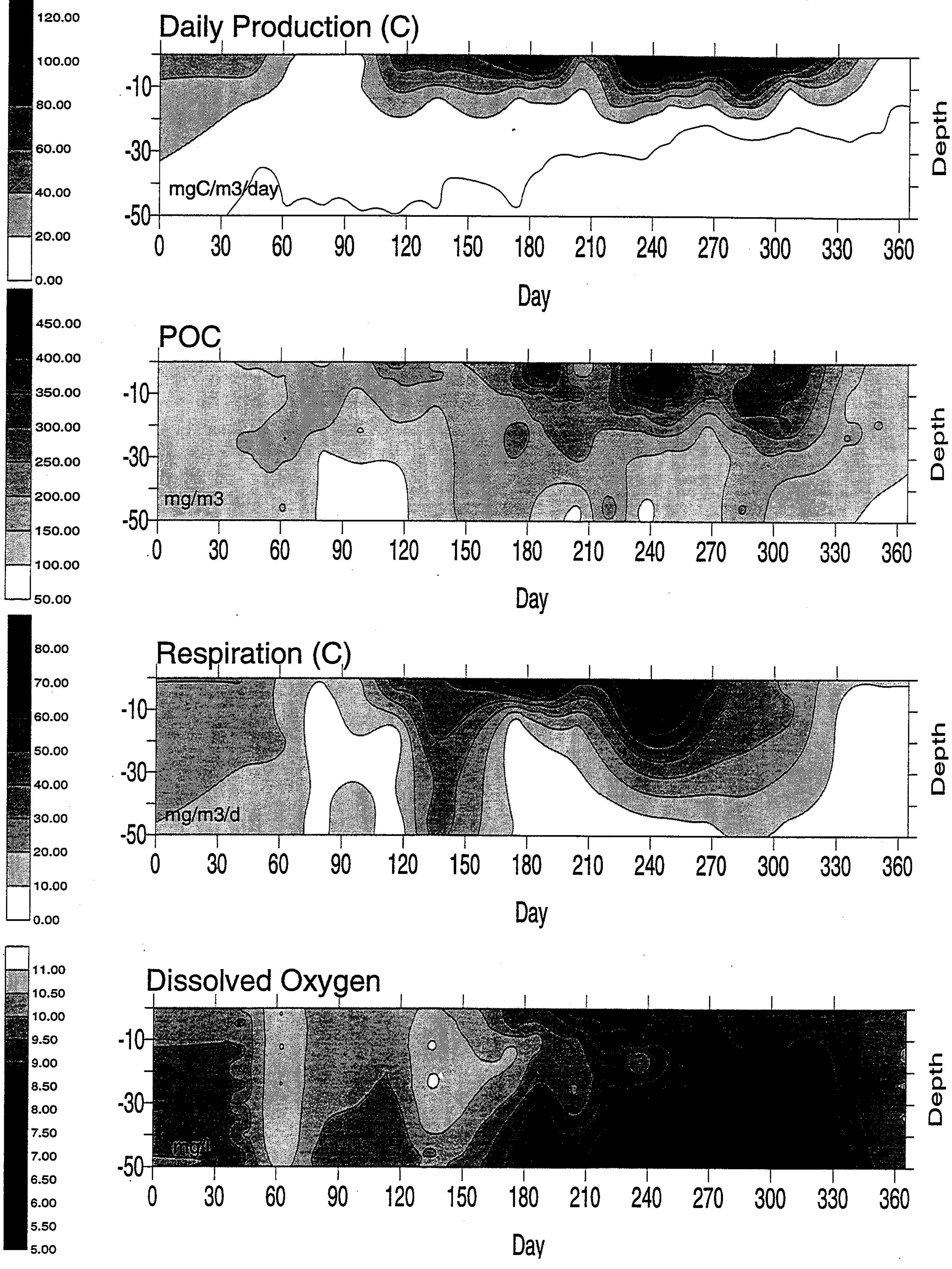

Stellwagen Basin Watercolumn Respiration: 1995-1997
Carbon Specific Respiration (uM O2/uM C/d)
0.4
0.3
0.2
0.1
0
0
5
10
15
20
Temperature (Celcius)
Resp = (0.0103*Temp)+0.0318, R2=0.68
Mixed Layer Data Only
Surface: 3 m
Mid: 36 m
Btm: 75 m


Production/Respiration: N04, N16, N18
Carbon Fixation, Respiration (mg/m2/d)
Thousands
4
3
2
1
0
Mar-95
Sep-95
Apr-96
Oct-96
May-97
Nov-97
Bar Represents Stratification
Photosynthesis
Respiration: Surf/Mid
Respiration: Btm

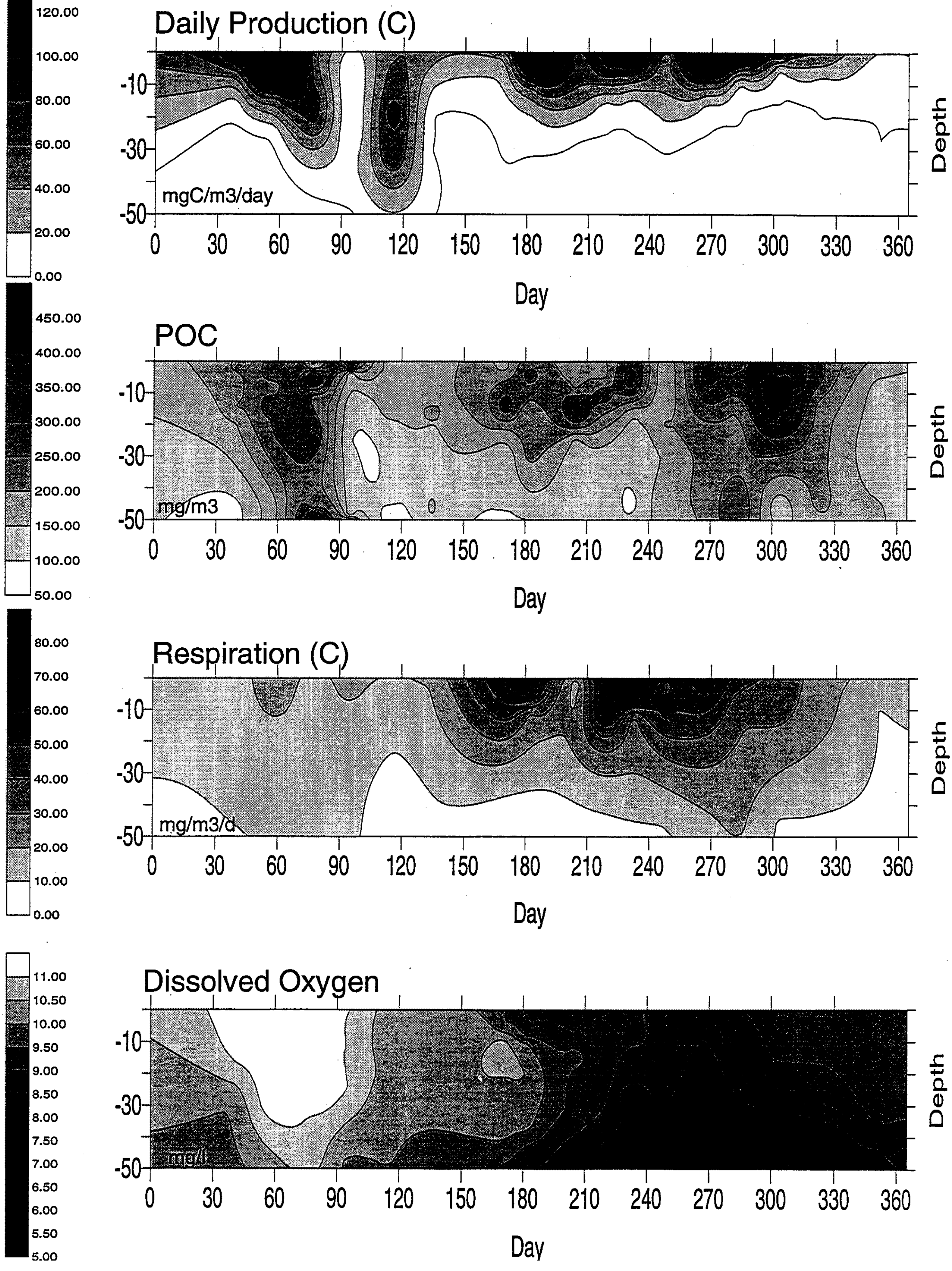

Sediment Oxygen Uptake: Interannual 1993-1997
1993-1997: SOD (mmol/m2/d)
1996: Sediment Oxygen Uptake (mmol/m2/d)
20
15
10
5
5
10
15
20
MB05
MB01
MB03
MB01
MB01
MB03
MB03
MB02
MB02
MB01
MB02
MB05
MB05
MB05
1995
1994
1993
1997
All Data: Mean of July and August
Lines represent 20% difference from 1996.


EUPHOTIC ZONE
Nutrients
Phytoplankton Production
O_2
POC
Respiration
CO_2
BOTTOM WATER
POC
Respiration
CO_2
O_2
SEDIMENTS
POC
Respiration
CO_2

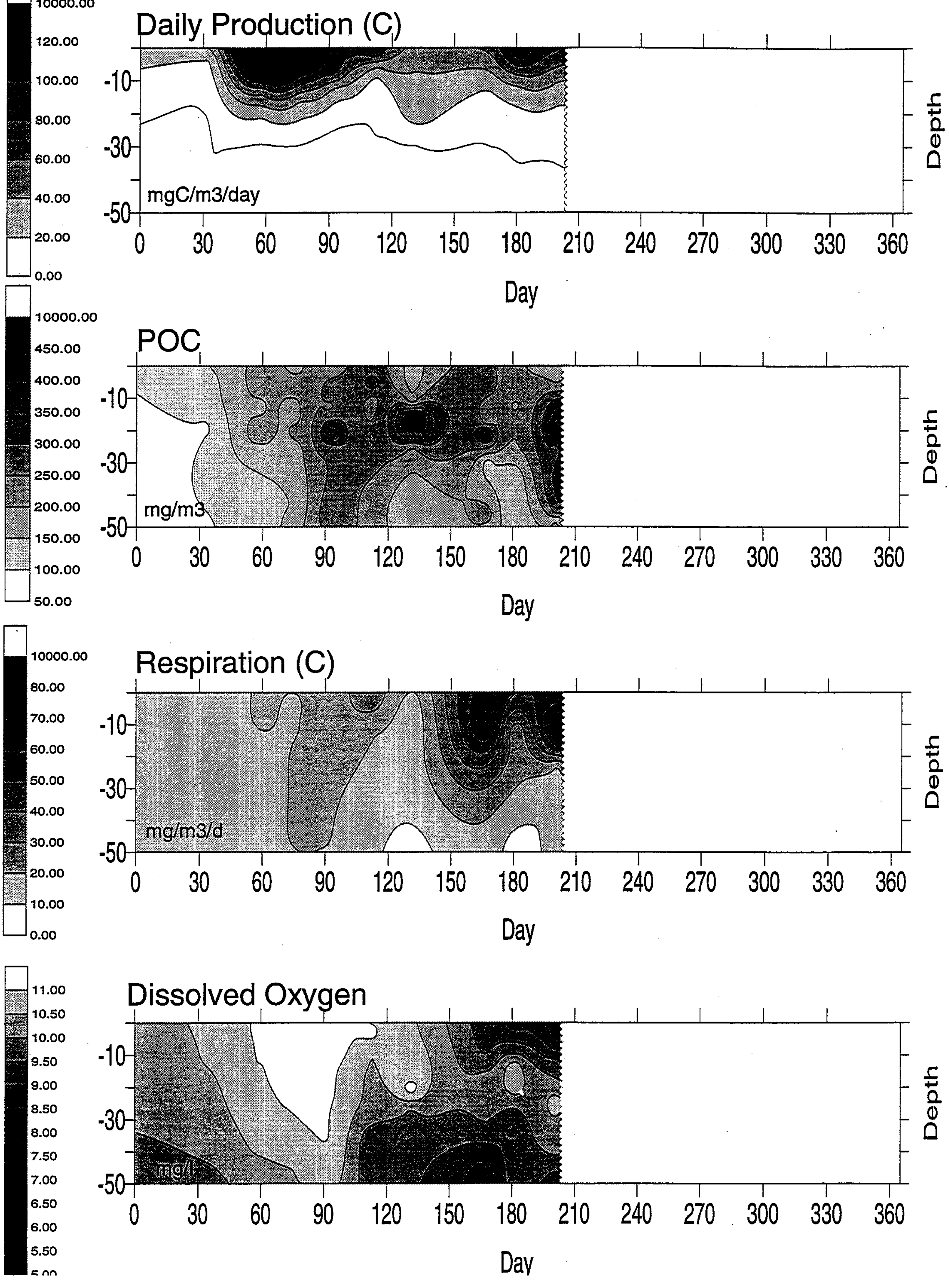
1995 Water Column Carbon Parameters

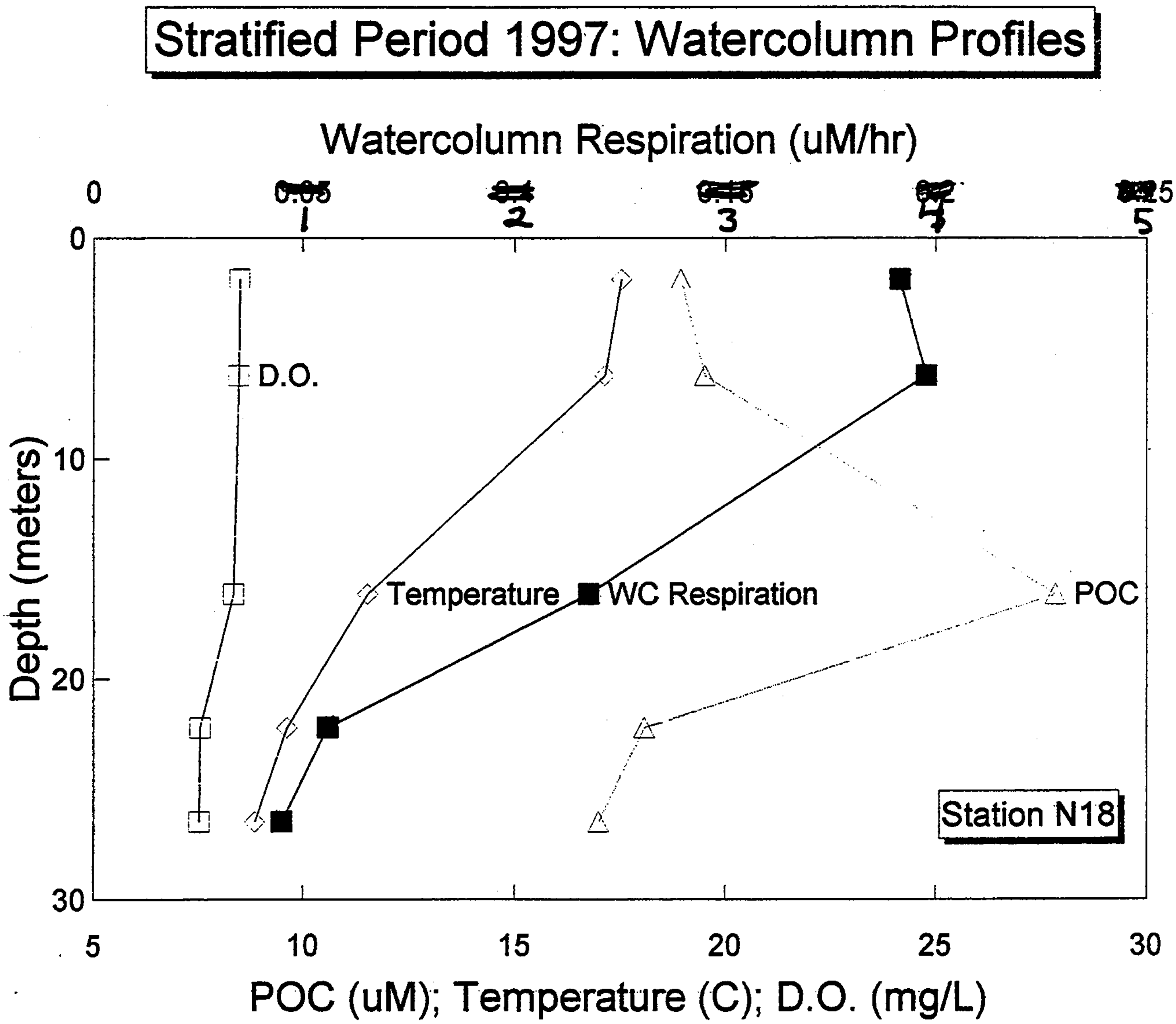


1996 Water Column Carbon Parameters



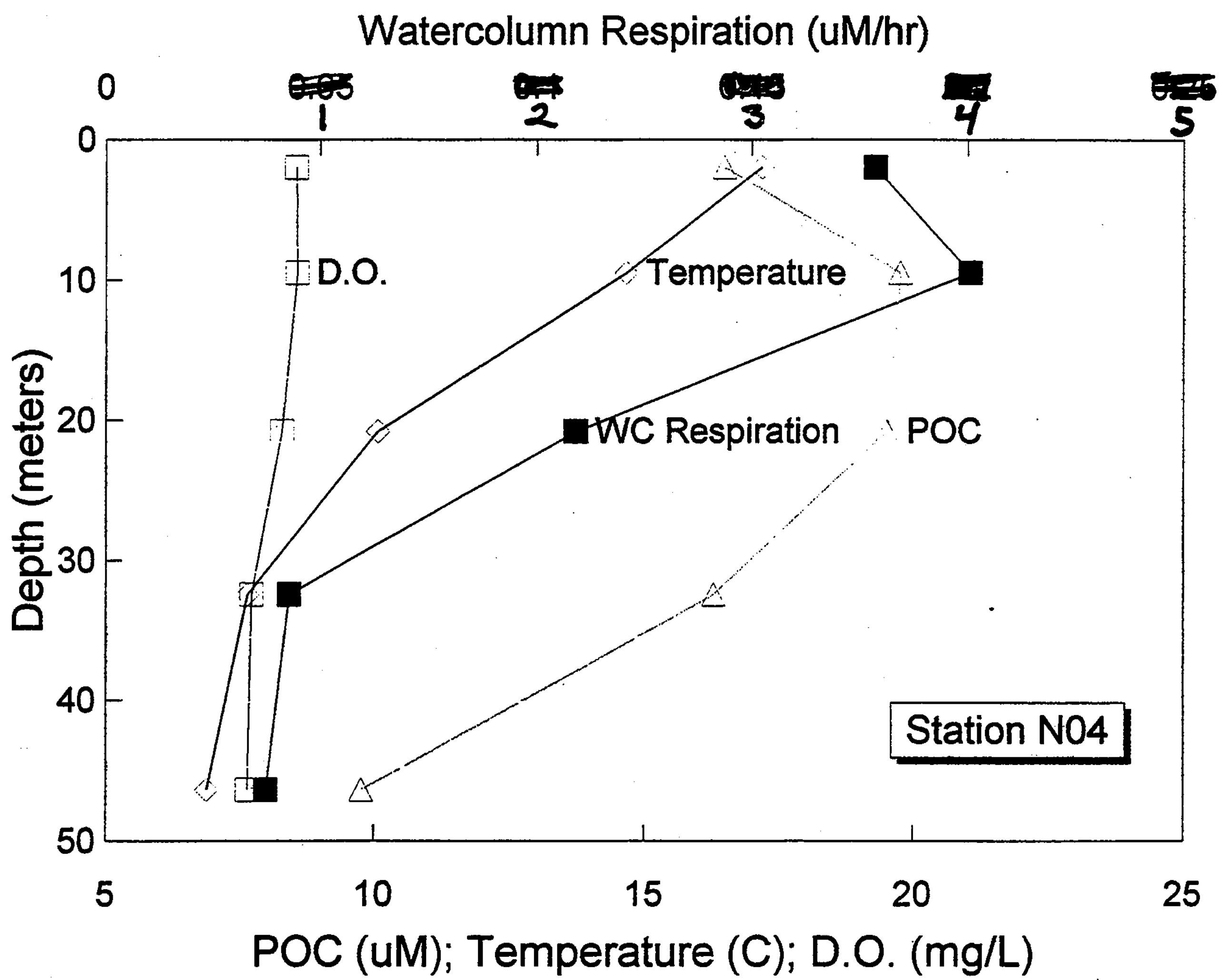
1997 Water Column Carbon Parameters



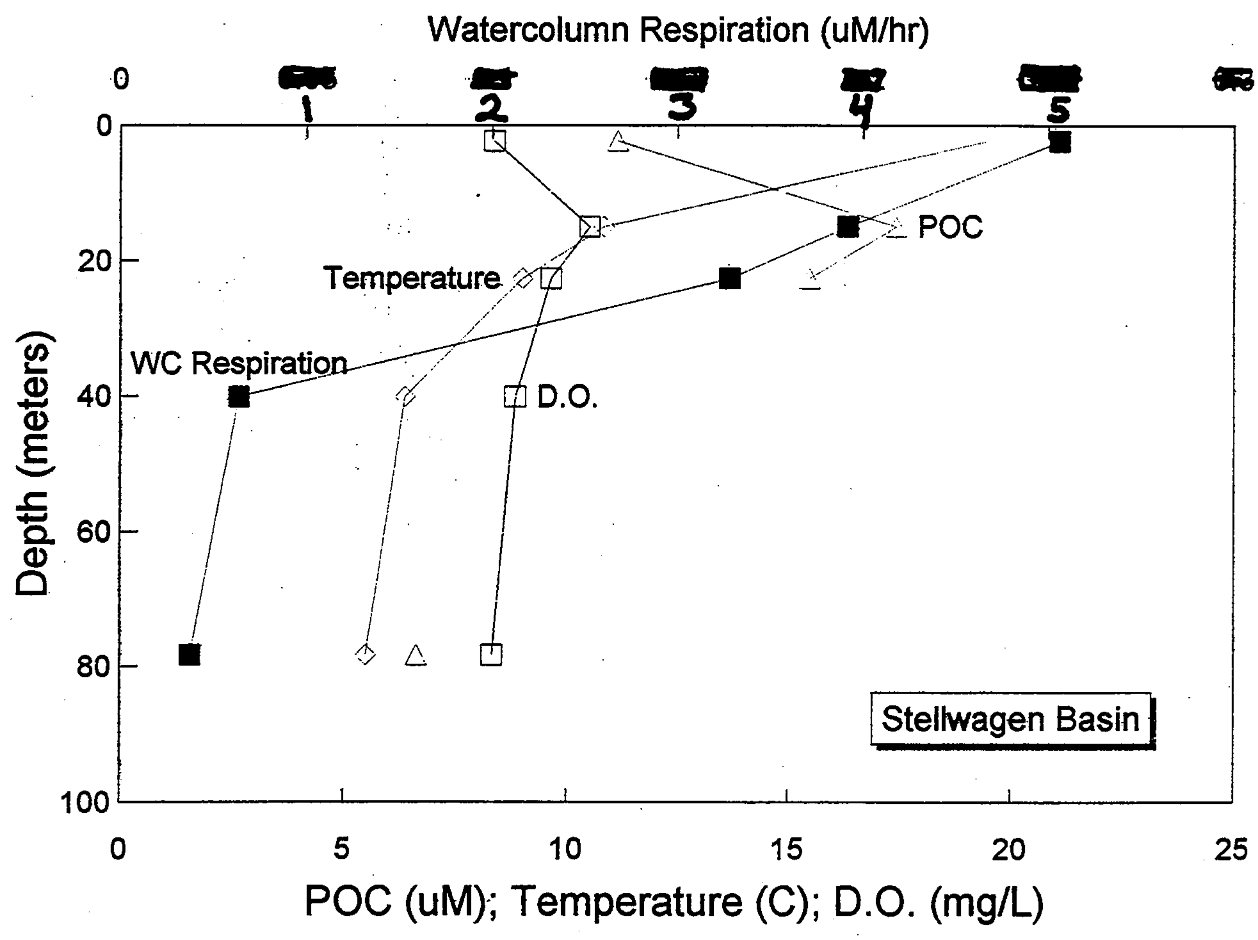


Stratified Period 1997: Watercolumn Profiles
Watercolumn Respiration (uM/hr)
0
1
2
3
4
5
0
10
20
30
Depth (meters)
D.O.
Temperature
WC Respiration
POC
Station N18
5
10
15
20
25
30
POC (uM); Temperature (C); D.O. (mg/L)

Stratified Period 1997: Watercolumn Profiles



Stratified Period 1997: Watercolumn Profiles



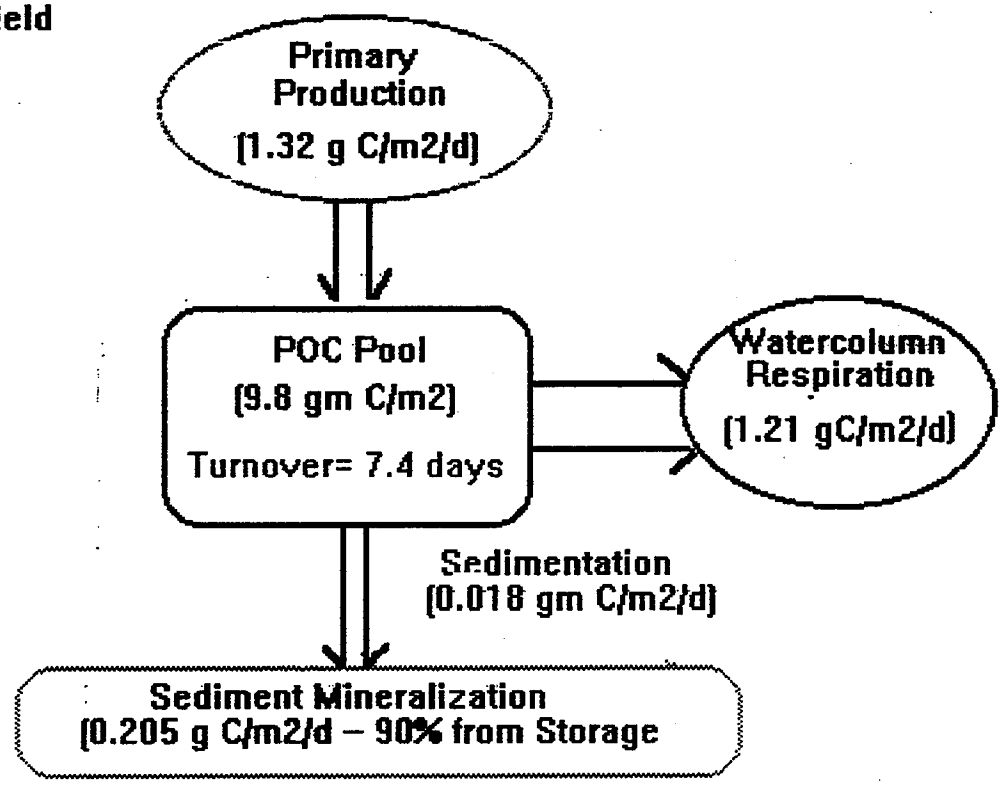
MASSACHUSETTS BAY OXYGEN DYNAMICS : STRATIFIED INTERVAL

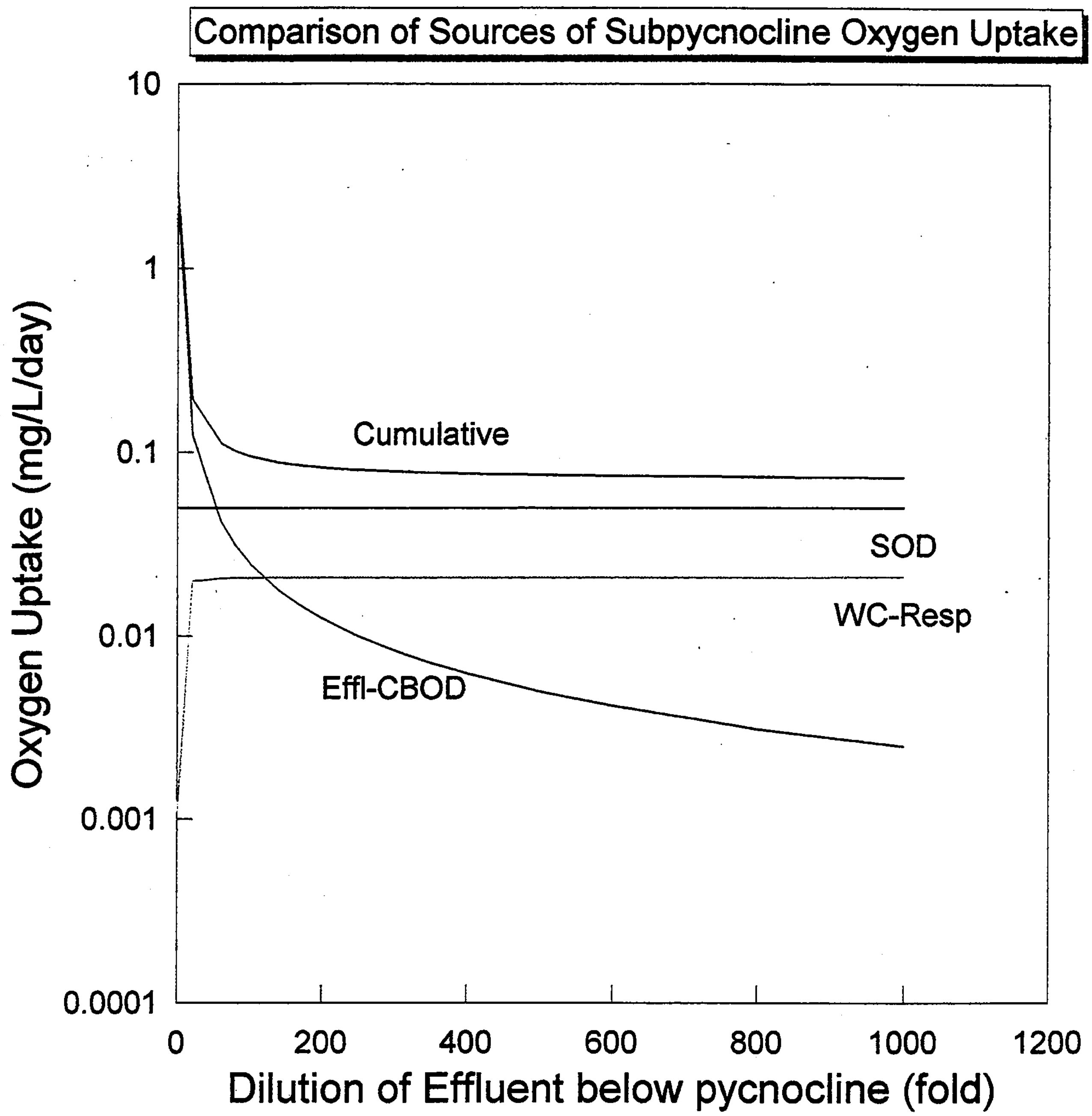
Year	Observed Btm Water D.O. Decline (mg/L/d)	Watercolum Respiration Potential Decline (mg/L/d)	Sediment Respiration Potential Decline (mg/L/d)	Ratio Pot/Obs
1992	0.024			
1993	0.025			
1994	0.031			
1995	0.027	0.0168	0.0161	1.22
1996	0.025	0.0182	0.0213	1.58
1997	0.020 ***	0.0226	0.0262	2.44 (1.952) **

*** D.O. "intrusion" year.

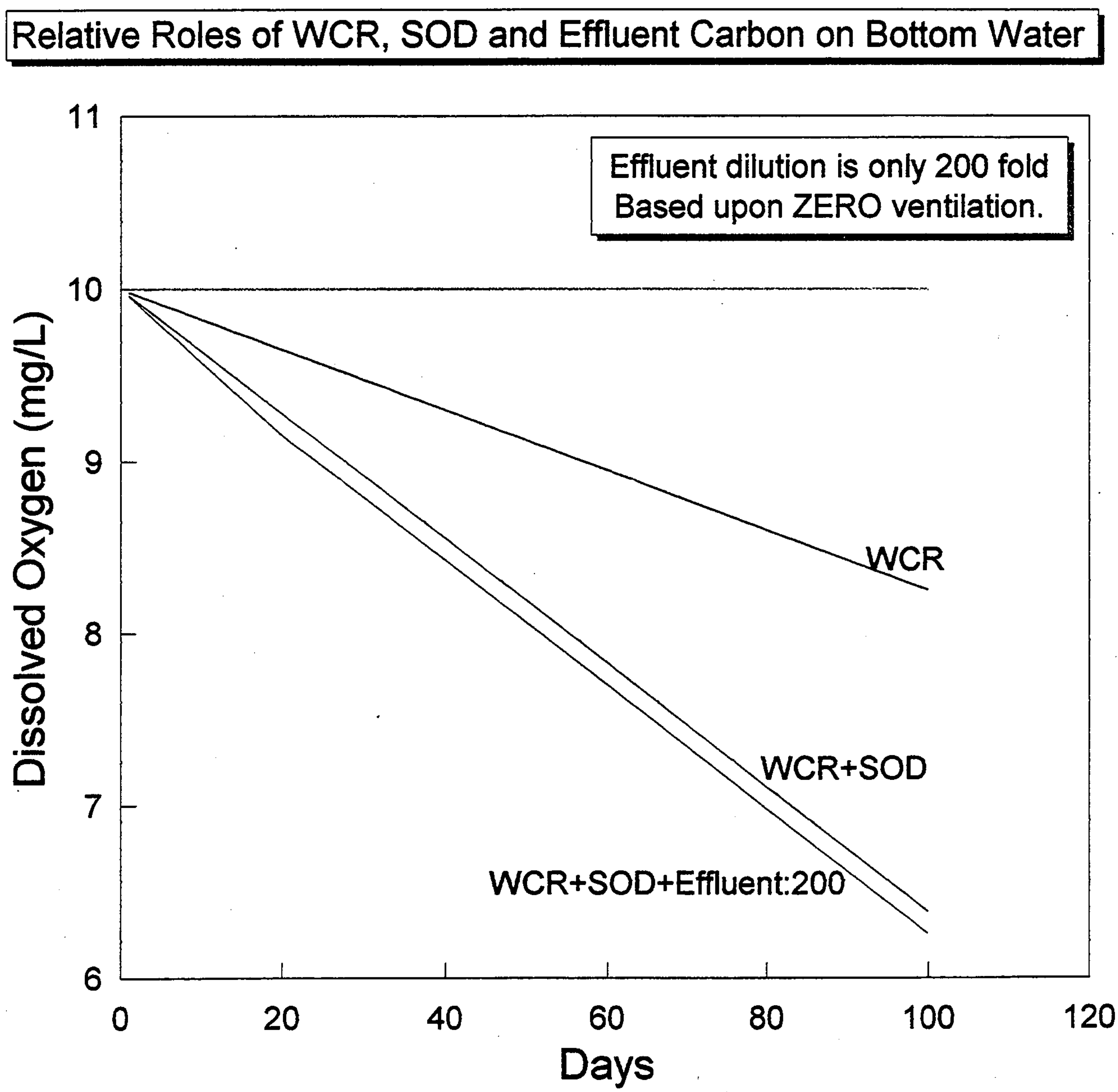
** using mean obs.

Mass Bay Nearfield
Carbon Balance:
Stratified Period

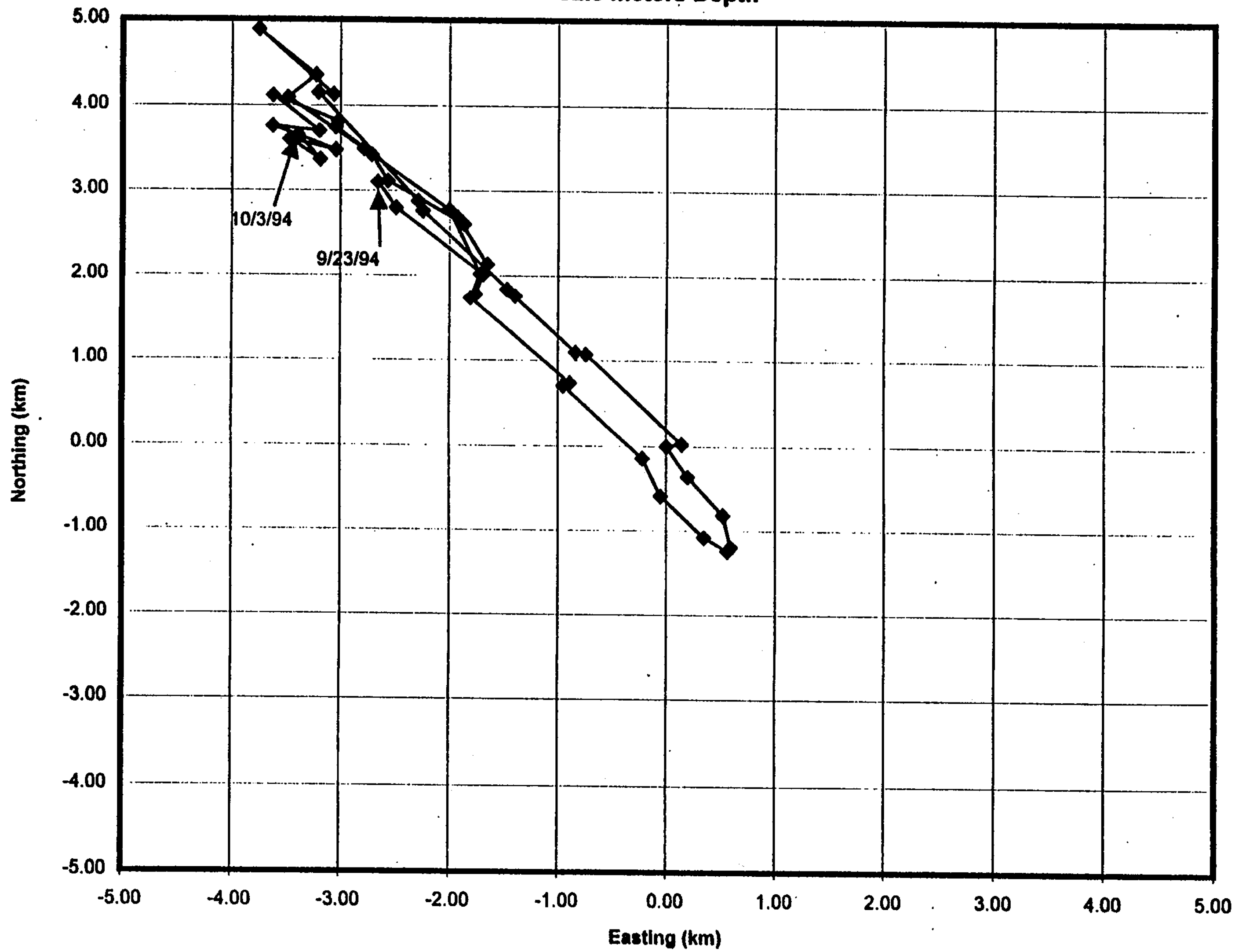




40 meter watercolumn, 20 m pycnocline, Q10=2, Temp=10C.
Stratified Interval Only.


Relative Roles of WCR, SOD and Effluent Carbon on Bottom Water
Effluent dilution is only 200 fold
Based upon ZERO ventilation.
Dissolved Oxygen (mg/L)
11
10
9
8
7
6
0
20
40
60
80
100
120
Days
WCR
WCR+SOD
WCR+SOD+Effluent:200

W9413 (September 23-October 3, 1994) Progressive Vector Plot
(Origin (0,0) located at 42° 22.6'N, 70° 47.0W)
32.5 meters Depth



APPENDIX B-8
Plankton Issues: Steve Cibik, Kristyn Lemieux, and Jack Kelly

Nuisance Algae
Steve Cibik

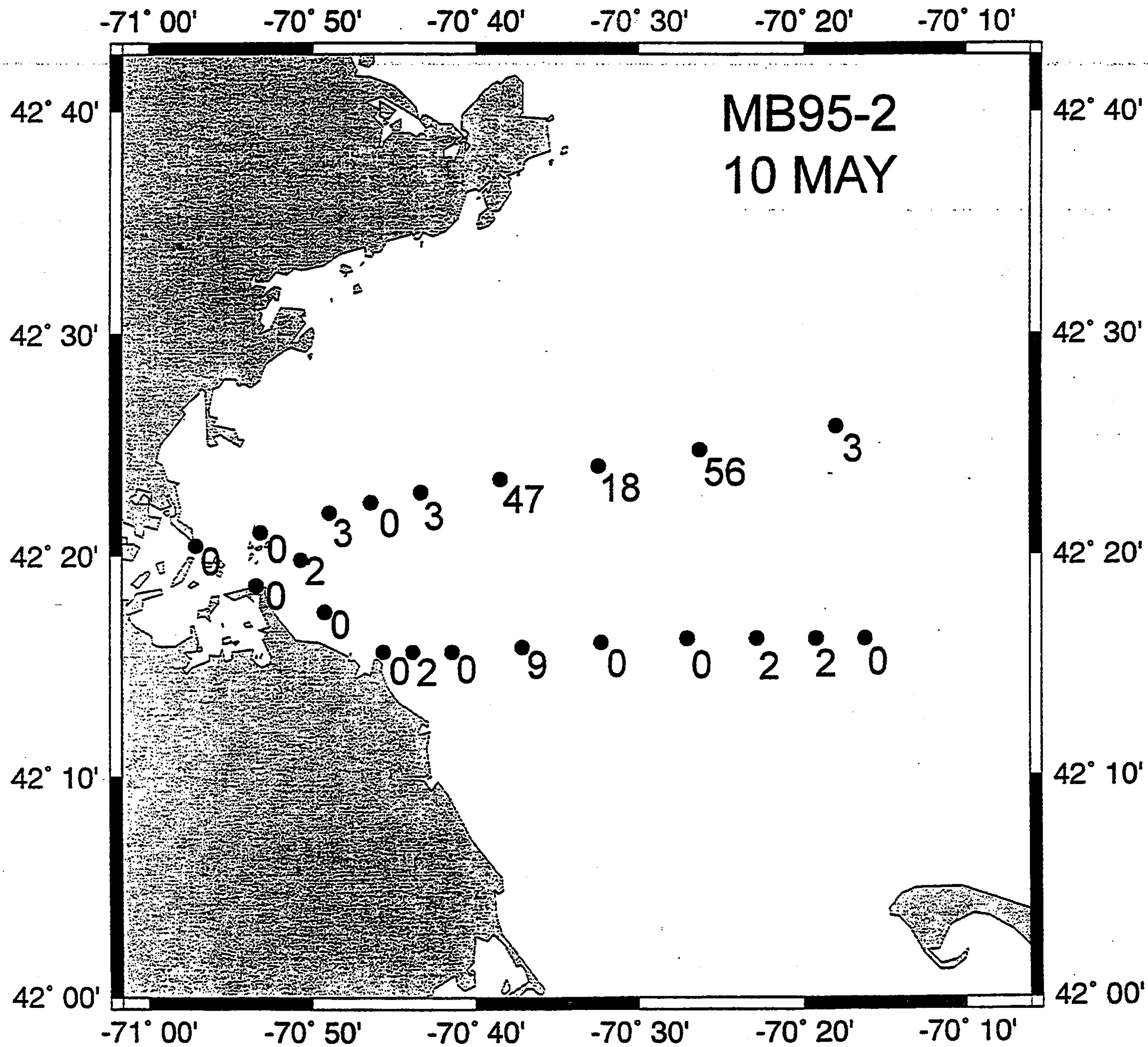
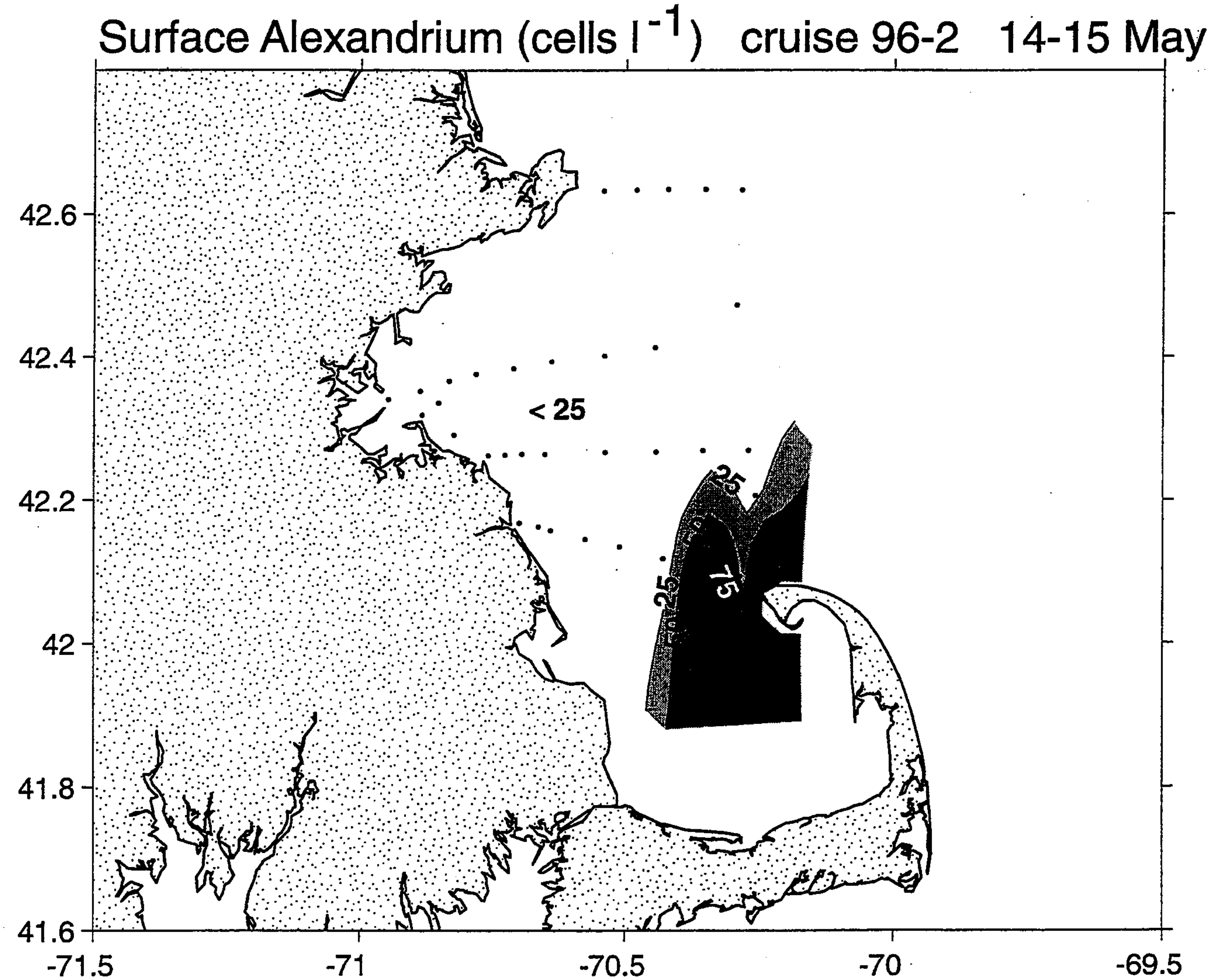


Figure 8-11. Surface cell concentration (cells liter^{-1}) of the toxic dinoflagellate *Alexandrium* sp. along two transects in Massachusetts Bay on May 10, 1995. An antibody-based detection method with a fluorescent microscope was used for the observations where the estimates ranged from non-detectable to about 50 cells per liter^{-1}. These relatively low abundances were the highest recorded in 1995 and were not enough to cause outbreaks in shellfish toxicity along the shore.



Surface Alexandrium (cells l⁻¹) cruise 96-2 14-15 May
< 25
25
75
42.6
42.4
42.2
42
41.8
41.6
-71.5
-71
-70.5
-70
-69.5

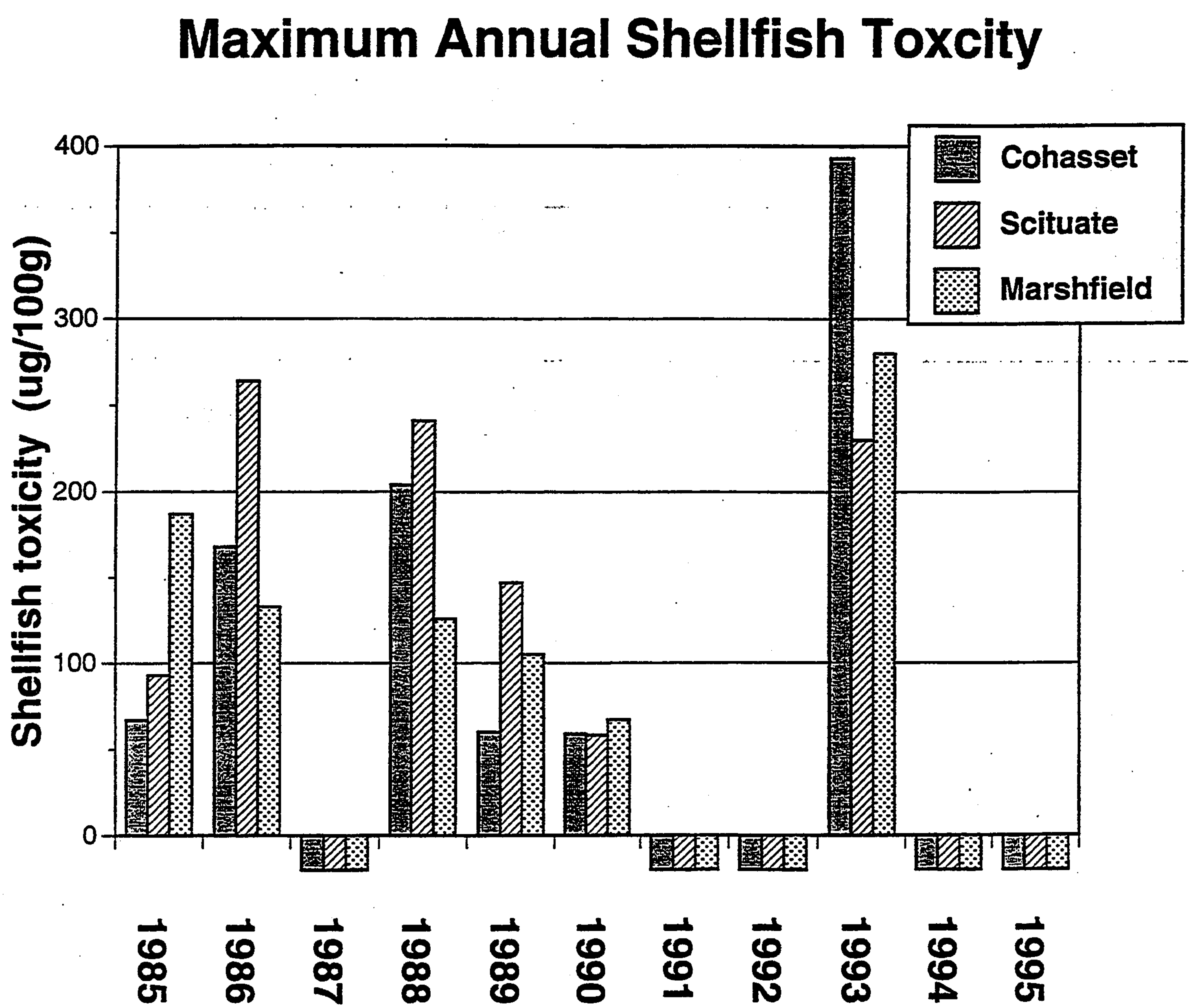


Figure 8-12. Bar graph of the maximum recorded shellfish toxicity at three primary shellfish monitoring stations along the "South Shore" in Massachusetts Bay for the years 1985-1995. The mouse bioassay measurements from the indicator species, mussels (*Mytilus edulis*), range from non-detectable in some years (i.e. bars shown below zero) to greater than several hundred µg toxin/100g of the shellfish tissue. Data supplied by David Whitaker of the Massachusetts Division of Marine Fisheries.

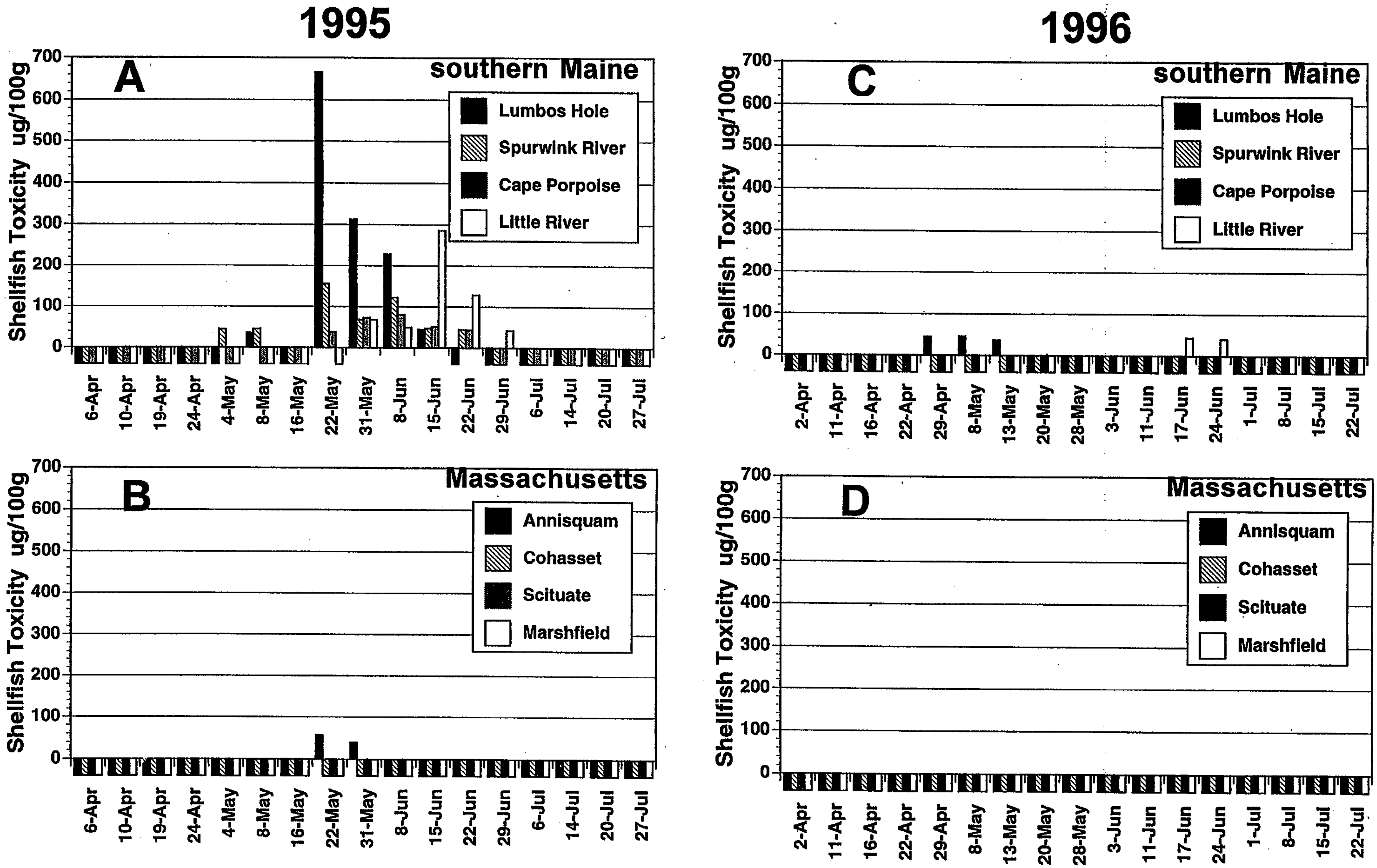


Figure XX. Shellfish toxicity recorded in mussels along the southern Maine and Massachusetts coastlines in 1995 (A and B) and 1996 (C and D). In 1995, toxicity was first detected in southern Maine waters (A) and reached as far south as Cape Ann, Massachusetts (Annisquam), but was not recorded in Massachusetts Bay (B). In 1996, very little toxicity occurred in southern Maine (C) and no toxicity was recorded in Massachusetts waters (D). Bars below zero represent samples that were below detection limits (<40µg/100g).

Zooplankton Retrospective
Kristyn Lemieux

ENSR

Scope of Zooplankton Retrospective

- "Identify all relevant zooplankton data from region"
- "Use all comparable data to distinguish Cape Cod Bay from other areas, if possible" (and identify any regional differences)
- "Establish a longer and broader baseline data set for Cape Cod Bay (CCB) than is presently available from only the MWRA monitoring"

CCS Dataset Rationale and Approach

- Investigate natural variability in the zooplankton community as well as zooplankton patches formed in the Bay
- To extent possible, document the spatial distribution of patch occurrences
- Assess whether CCB exhibits unique qualities

MARMAP and MWRA Datasets Rationale and Approach

- Define whether CCB and Massachusetts Bay (MB) assemblages are different
- Identify whether Cape Cod Bay exhibits unique qualities (or follows regional patterns)
- MARMAP provides data from an earlier decade

Results (CCS No Whale vs Feeding-Whale)

- Significant differences found between feeding-whale populations ("patches") vs no whale present populations
- Two exceptions were cyprids and nauplii in March

Results (MARMAP - MB to CCB)

- No significant differences were found between MB and CCB MARMAP samples
- While not significant, CCB had a higher abundance of *Acartia* sp. relative to MB

Results (MWRA - MB to CCB)

Within Region

- All CCB stations were similar
- MB stations were similar for most taxa, but showed nearshore/offshore differences for:
  - *Acartia*
  - *Oithona*
  - *Centropages hamatus*

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Results (MWRA - MB to CCB)

Regional Comparison

- No significant differences between MB and CCB except for *Calanus finmarchicus* (higher abundances in MB)
- No significant differences between Nearshore MB and CCB
- Significant differences were found between Offshore MB and CCB

Conclusions

- CCB appears to have characteristics which favor patch formation
- There is evidence that patches also form in areas of MB and adjacent Gulf of Maine (GOM), however there are comparably few studies to document the extent
- Patches and ambient samples appear to be similar in composition, but patches are significantly more dense

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Conclusions (Continued)

- Given all statistical evidence it appears as if MB and CCB are similar
- CCB is more similar to nearshore MB assemblages than offshore assemblages of MB
- The presence of nearshore/offshore gradients supports the MWRA zooplankton hypothesis

Food Web Conceptual Model
Jack Kelly

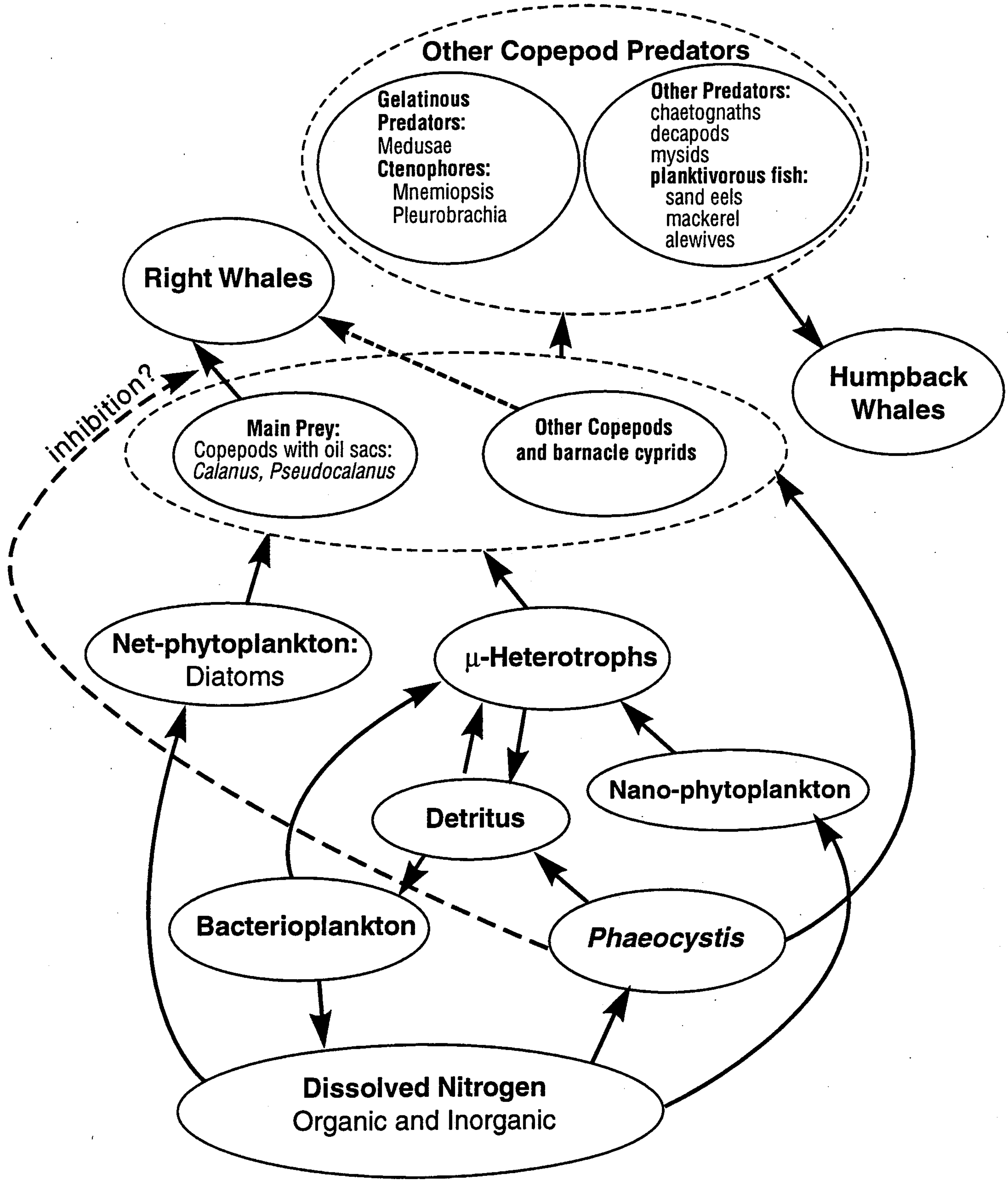

FIGURE 1
Conceptual schematic of right whale/
plankton food web in Cape Cod Bay

M980121bw

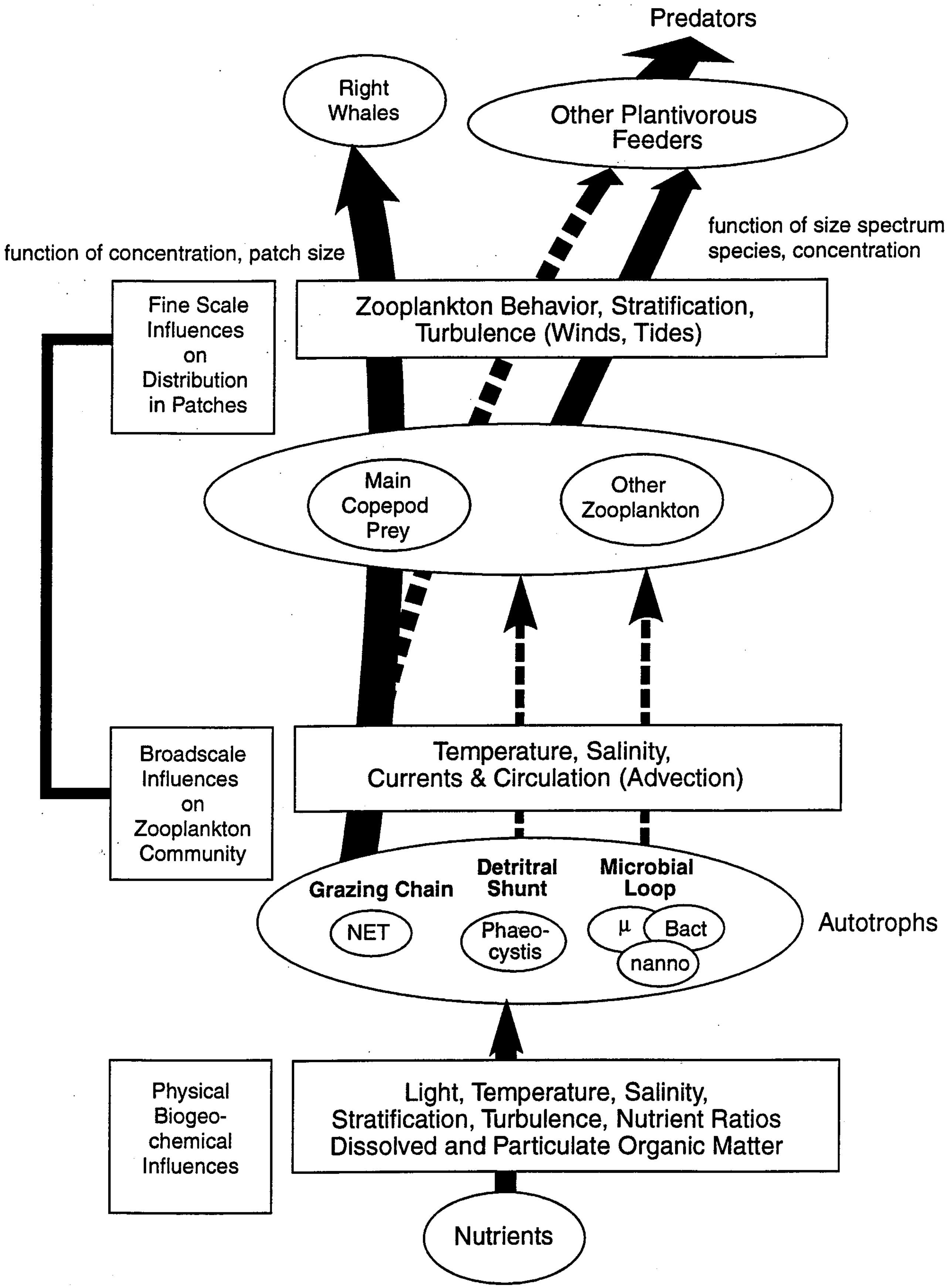

FIGURE 2
Factors at Different Scales and Levels Influence the Food Web

M980122bw

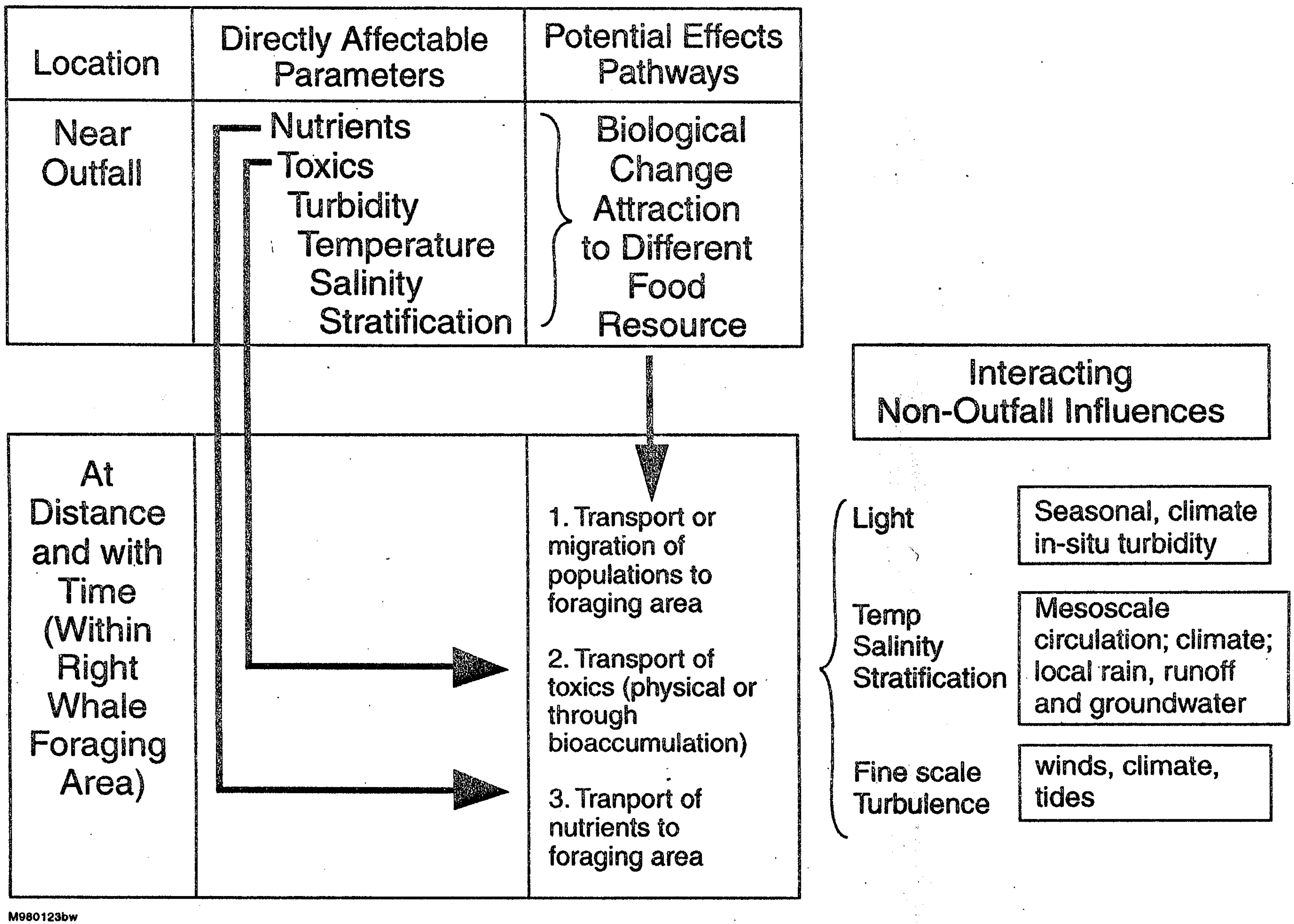

FIGURE 3
General Paths to Influence Cape Cod Bay Food Web.