

Chapter 4

95320G Phytoplankton and Nutrients

Exxon Valdez Oil Spill
Restoration Project Annual Report

Sound Ecosystem Analysis: Phytoplankton and Nutrients
Restoration Project 95320G

This annual report has been prepared for peer review as part of the Exxon Valdez Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Study History: The project was initiated as Restoration Project 94320G. A "Draft Final Report" was produced as an annual report in 1995 under the title "SOUND ECOSYSTEM ANALYSIS: Plankton Dynamics: Phytoplankton and Nutrients" and continues under the present grant number. Papers were presented at the AAAS Arctic Division Science Conference and the AGU/ASLO Ocean Sciences meeting.

Abstract: In 1995 we collected 1400 samples from several platforms including 5 cruises on chartered vessels and daily sampling at two locations at the AFK Hatchery. The observations (chlorophyll, nutrients, particulate carbon and nitrogen, species composition, CTD, and dissolved oxygen) were supplemented with a moored instrument array (CLAB Buoy) that recorded temperature and chlorophyll (by fluorometry). The geographical coverage of observations was expanded and integrated using satellite images. Field work began in March and was completed in September. This is the first data set for phytoplankton and nutrients that fully includes the spring bloom. The spring phytoplankton increase is strongly influenced by light and mixing. The decline of phytoplankton is a result of nutrient depletion and grazing. In 1995 the limiting nutrient was silicate, in 1994 it was nitrate. In 1995 and 1994 the peak biomass was weeks later than 1993. The timing of the spring bloom is a signal to zooplankton. In all 3 years, the peak of zooplankton biomass occurs 3 weeks after the bloom. Regional coverage confirms the model results showing "river" conditions in the south and "lake" conditions in the north and central sound.

Key Words: Exxon Valdez, phytoplankton, nutrient cycles, primary productivity, algae

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Introduction

The project seeks to determine the driving force and variability of ecosystem production from a bottom-up point of view. It is our hypothesis in this component that the timing, quantity and species composition of the plant community, that is, the phytoplankton, is the major determinant of annual cycles. Ultimately, physical forces in the ocean play a major role in the dynamics of the phytoplankton community.

The Sound Ecosystem Assessment program (SEA) aims to understand and predict restoration of populations of pink salmon and herring in Prince William Sound. Fundamental to this goal is the understanding of controls of ecosystem processes that nourish the food web at its primary level. This is the goal of this component of SEA. Restoration of marine populations that have been damaged by human activity is usually limited to a few options that focus on controlling loss rate processes, i.e. harvest level, predator control, etc., or minor habitat modification. Pink salmon and herring offer a spectrum of strategies since a large portion of salmon are protected in hatcheries in their early life and herring are completely wild subject to the variance of nature. What then is the role of the annual cycle of primary production in the success of these upper trophic level species? Does the magnitude of the phytoplankton production determine the strength of a year class? Is the phytoplankton species composition an important determinant of the grazing zooplankton community? Does any of this matter or is there always enough food at the right time of the year so that predator populations are determined by the uppermost consumer on the food web? All are questions that are being examined in this study.

One central SEA hypothesis concerns the impact of circulation and physical conditions on the restoration of fish stocks (the Lake-River Hypothesis). This proposes that the circulation of Prince William Sound alternates irregularly between years of strong through-flow, river-like conditions, and relatively stagnant, lake-like conditions. The consequence is a high biomass of large zooplankton (copepods) in 'lake' years that are the major food for target fish (salmon, herring) and their predators (termed 'middle-out' food web control by Cooney and associates). In alternate 'river' years, the large zooplankton are sparse and predation on the target fish species predominates ("top-down" control).

While middle-out or top-down are principal hypotheses being tested by SEA research, the possibility of 'bottom-up' control, where the production of upper trophic level species is modulated by variations in light- and nutrient-driven phytoplankton production. In this hypothesis, the structure and composition of the zooplankton community are determined by variations in phytoplankton primary production and by the species composition of the phytoplankton community. For example, a phytoplankton community dominated by large diatoms can support a high biomass of large oceanic copepods, whereas a phytoplankton population dominated by smaller flagellates results in a reduced number of larger copepods, or in a shift to a zooplankton community dominated by smaller neritic copepod species. Variations in the timing of phytoplankton populations have been previously suggested to be a control of ecosystem events in Prince William Sound (McRoy 1988). A further complication in the interrelationship is that the large zooplankton are one year old when they become major prey for fishes (Cooney, personal communication) so their abundance must be determined by the events of the previous year and their specific biomass by the production cycle of the present year.

In this component, we provide the nutrient and phytoplankton data that are essential to evaluate the influence of phytoplankton dynamics on the food web and to test the bottom-up hypothesis. We will characterize the interannual spatial and temporal variation in nutrient and phytoplankton fields. We will evaluate the role of phytoplankton production in zooplankton recruitment and growth (especially for *Neocalanus* and *Pseudocalanus*). In a general sense we will provide an answer to the question "Is it food?"

A central tenet of the Lake/River Hypothesis is the variable advection of Gulf of Alaska waters into Prince William Sound. This advection affects not only zooplankton populations, but also the Prince William Sound phytoplankton populations and production.

Strong advection may confound the effects of in situ primary production in the Sound. To test the hypotheses further, we use satellite-derived sea-surface temperatures to examine the movement of Gulf of Alaska surface waters into Prince William Sound. In 1995 we assumed the responsibility for maintenance and data collection for the moored instrument array (CLAB) that has been gathering continuous oceanographic data in Prince William Sound since 1992. This platform has provided a valuable data set.

Objectives

This study is designed to investigate the distribution, amount, and type of phytoplankton growth and the major inorganic nutrient fields associated with the growth processes. Our hypothesis is that variations in the phytoplankton production and populations are transferred to the zooplankton and that such variations are a function of oceanographic conditions that control the supply of inorganic nutrients and light. The objectives for 1995 were:

1. Analysis of phytoplankton community ecology in PWS.
2. Determination of basin-wide patterns of temperature, salinity, and chlorophyll from ship-board observations. nutrients and
3. Determination of temporal patterns of temperature, salinity, and chlorophyll from AFK Hatchery. nutrients and
4. Provide data for interpretation of CLAB data and integrated modeling.
5. Determination of the linking between phytoplankton and upper trophic levels.

Methods

Phytoplankton Biomass, Spatial and Temporal Patterns:

Phytoplankton biomass is measured using the standard chlorophyll techniques (Parsons et al., 1984) on a Turner Designs Fluorometer. Samples were collected at specific 309 time/space locations on cruises and at a shore-based station. Data allow mapping the areal pattern and description of the water column profile.

Phytoplankton Primary Production

The biomass pattern provides a picture of what is present, but it does not provide information on the phytoplankton dynamics. In 1995 we were unable to make any direct measurements of primary productivity by using isotopes due to the limitations, because of regulatory prohibitions of using radio-isotopes on the available platforms. We can estimate production using dissolved oxygen and nutrient data. Productivity data are also available in our historical database (McRoy, unpublished data). Methods used involved uptake of ^{14}C by phytoplankton in containers under neutral density filters (Strickland and Parsons, 1972; Parsons et al., 1984).

Phytoplankton Community Composition:

The composition of the phytoplankton community can be as important as the total primary production in determining zooplankton species and abundance. We collected 50 ml aliquots from water samples and preserved them in Lugol's solution for species identification. Identifications and cell counts were done using an inverted microscopy method (Sournia 1978). On low (20x) magnification, all visible cells in two transects are counted. On high (40x) magnification, fields are counted until a total of 300 cells is reached. For cell volume calculations and calculation of carbon content, cells identified to genus were grouped according to the maximum cell dimension. At least 20 cells of each species for size class were measured. The procedure is labor intensive and only a portion of the samples collected can be counted.

Nutrient Fields:

Phytoplankton require the major inorganic nutrients (nitrogen, phosphorus and silica) for growth. General oceanographic circulation and land run-off supply nutrients. Since phytoplankton also require light, the problem is understanding how the nutrients are supplied to the illuminated zone of the sea. We routinely collected water samples for quantitative nutrient analysis

In the field, water samples were collected with Niskin Bottles at standard depths over the upper 100 m (deeper if necessary). A small aliquot (250 ml) was filtered and frozen for later chemical analysis. Chemical determination of the quantity of dissolved nitrogen (as nitrate, nitrite and ammonium), phosphate and silicate were measured using prescribed methods with an Alpkem Auto-Analyzer in our laboratory in Fairbanks.

Moored Instrument Array: The CLAB Buoy

We assumed the responsibility for deployment and recovery of the CLAB moored instrument program in 1995 and are working with R.T. Cooney to insure the quality of the data. This mooring consists of a thermistor chain, which measures temperatures at 10 depths from 0 m down to 100 m; an in situ fluorometer at 10 m; and a meteorological package, which measures wind velocity, air temperature, and buoy hull temperature. The buoy continuously acquires wind speed and direction, barometric pressure, air temperature, sea surface temperature, chlorophyll fluorescence, and ocean temperature at 10 depths. Data are relayed via the ARGOS satellite system in near real time. Data from the CLAB buoy are also passed to other groups for use in modeling. The moored instruments provide a mechanism to integrate other discrete observations collected from ships.

Satellite Image Analysis:

Satellite images are a powerful integrative tool. While field samples provide ground truth data, satellite images are valuable sampling mechanisms to examine the pelagic ecosystem on a broad geographic scale and over the entire year. We are currently scanning NOAA Advanced Very High Resolution Radiometer (AVHRR) imagery from the University of Alaska Fairbanks High-Resolution Picture Transmission (HRPT) ground station. The AVHRR data produce sea-surface temperature images of the sound and adjacent regions. We use these images to monitor the inflow of water to Prince William Sound and to determine the spatial extent of water masses identified by the field program.

Personnel

The following people have contributed to sample and data collection and analysis:

B. Bergeron	Technician
D. Clayton	Technician
J. Cameron	Technician
S. Danielson	Graduate Student
L.J. Miller	Graduate Student
N. Pintchouck	Graduate Student
P. Simpson	Graduate Student
S. Speckman	Graduate Student
A. Ward	Graduate Student
C. DeLaca	Student

Results

Samples were collected to document the time series of events in the annual phytoplankton/nutrient cycle as well as to examine spatial variations.

Sample Collection

We collected water samples for analysis from two platforms in Prince William Sound. Short, monthly SEA cruises from March to September (except for August) permitted

regional sampling from the standard SEA ocean stations. This work provides a data set, collected in conjunction with many other SEA components, that is crucial to modeling and synthesis. The second sample site is the AFK Hatchery on Evans Island in the southwestern corner of the sound. We used this shore facility to collect daily samples from mid-April until late June from two nearby locations. These data provide temporal continuity to the ship-board sampling. Additional time series data from the CLAB permanent ocean buoy permit comparison with previous years.

The field season began in March and extended until late September. Platforms for sample collection included ships and shore-based facilities. In 1995 we collected 1400 samples from 5 cruises and 2 shore-based stations from AFK Hatchery, an increase of more than 60% over 1994 (Figure 1). The chartered vessels provided areal coverage of the sound for oceanographic and biological parameters (see Appendices I and II for station locations).

The Phytoplankton-Nutrient Component database includes dissolved nutrients (nitrate+nitrite, ammonia, phosphate, and silicate), dissolved oxygen, CTD (salinity, temperature, depth), chlorophyll a, and particulate carbon (PC) and nitrogen (PN) from all sampling platforms. In addition selected representative samples for phytoplankton enumeration are being processed. We searched daily satellite images showing sea surface temperature from late March to present; of these, 20 are being interpreted for basin-wide patterns and integration with CLAB data. Finally, data from the CLAB buoy (temperature and chlorophyll) are being correlated to the time series data from AFK Hatchery and with satellite temperature images to elucidate basin-wide patterns and processes.

Time Series Measurements: CLAB Buoy

The continuously recorded data from the CLAB mooring presents a detailed time series of phytoplankton biomass (as measured by fluorometer) and associated oceanographic parameters for a central location in the sound. Unfortunately due to necessary maintenance the deployment of the buoy was delayed until May so the data series does not include the spring bloom but only post-bloom summer conditions (Figure 2). A good time series exists for 1994 and 1993. In 1994 the increase was interrupted by storm conditions in April which delayed the spring maximum until the third week of April, two weeks later than in compared to 1993. The fluorometer record is a relative scale so no statement can be made about the absolute level of biomass reached in a year from CLAB data. Such determinations require direct measurement of chlorophyll content in the field.

The phytoplankton biomass at the CLAB buoy (fluorometer) shows a close relationship to the variation in the wind speed as expected. Napp et al. (1996) show that the initiation of the bloom in Shelikov Strait is determined by cloud cover and mixing depth and this probably applies to the start of the bloom in Prince William Sound. The CLAB data missed the early spring increase due to the late date of deployment but the bloom is evident in the AFK data. There is no close correlation between the AFK chlorophyll data and the CLAB fluorometer data for the period they overlap indicating that local conditions dominate.

Time Series Measurements: AFK Hatchery

The best time series data in 1995 were collected from 2 stations in the southwest Sound near the AFK Hatchery (Figure 3). The data series begins on 18 April 95 and ends on 19 June. In both stations the bloom terminates by the end of April. The pattern is similar in both locations with the differences reflecting the effect of water depth. The deeper station (AFK95.2) more reflects the pattern of the open sound. A high biomass in April is followed in both locations by much lower levels in May and June, with occasional pulses of higher biomass stimulated by mixing events (see the Biological Modeling Component). At AFK95.2 during the bloom an increased biomass occurs down to 100 m, likely a result of the sinking of phytoplankton cells rather than growth in place, but both are possible. The appearance of algal cells at depth is a signal and food source to herbivores in deep water.

Phytoplankton Community

From April 17 - June 20, 1995, phytoplankton samples were collected daily at 0, 5, 10, 25 and 50 meters depths at station SB1 and SB2 at AFK Hatchery. A total of 640 phytoplankton samples were collected for analysis in Fairbanks.

Sixty five samples from the spring bloom (April 17- April 29) were enumerated, identified and measured for cell volume calculations using the Utermohl inverted microscope technique (Sournica 1978). Phytoplankton cells were identified to the lowest possible taxon, genus or species, depending on the condition and orientation of the cells. Small nanoplankton (2-20 μ m) were classified according to composition and cell size as unidentified flagellates or dinoflagellates. Cell volume calculations will be used to estimate individual diatom and flagellate carbon biomass contributions.

At Station AFK95.2 in Elrington Passage a time-series of physical and biological data were collected from April 18 -June 20. The phytoplankton spring bloom occurred between April 18-28. During this period, the average temperature and salinity were 4.3 °C and 31.45 psu, respectively. The lowest temperature and salinity were 4.1 °C and 30.98 psu recorded on April 19 and April 22. The highest temperature reading of 4.7 °C occurred late in the bloom on April 28. The highest salinity measurement peaked at 31.85 on April 26.

The chlorophyll biomass and phytoplankton cell abundance (cells/ml) at the chlorophyll maximum on the surface were examined between April 18-27. The average biomass was 27.30 (mg/m³) and the average cell number of flagellates and diatoms was 1287 cells/ml and 1410 cells/ml, respectively. The biomass peak occurred on April 21 followed by a peak in abundance on April 22. The fluctuations in the biomass and abundance observations followed a similar trend especially apparent at the onset of the bloom.

Total cells/ml of phytoplankton was tallied from 18-27 April at all depths to show where the maximum number of cells were found. Totals showed a peak of 25,323 cells/ml at 5 meters depth and a minimum of 15,500 at 50 m. Composition of phytoplankton was dominated by diatoms and flagellates. Phytoplankton counts by taxonomic grouping show a decrease in abundance with depth for all groups (Figure 4). Percentage of diatoms and flagellates didn't vary significantly over time and depth. The average composition from 18/4-27/4 was approximately 55% diatoms and 45% flagellates (standard deviation averaged 8%) for all depths . No significant variations were apparent at deeper depths.

Five genera of phytoplankton composed the majority of the diatom population at all depths (Figure 5). No significant variations in species composition occurred between surface and 50 m throughout the bloom. *Skeletonema costatum* comprised the largest component of the bloom averaging 38%-44% of the diatoms at all depths. *Thalassosira* spp. followed with an average of 30%-34% by depth. *Chaetoceros* spp. was the third largest constituent averaging 10%-12% of the diatom community. *Leptocylindrus* spp. averaged 2%-8% and the small pennate diatom *Nitzschia* spp. averaged 6%-7% of the population. Other diatoms, listed on the species list, averaged 1%-5% of the diatom bloom for all depths.

Nutrient Limitation (Figure 6)

The time series plot of nitrate vs. silicate for AFK 1995 and WNH 1994 indicate a significant shift in the nutrient limitation of phytoplankton growth between 1995 and 1994. In 1994 the system became depleted in nitrogen, but in 1995 silicate is the major limiting nutrient. This difference could result from a shift in circulation, in the herbivore community, in the herbivore predators, or in all of the above.

Phytoplankton-Zooplankton Linking (Figure 7)

A comparison of the seasonal time series of zooplankton and phytoplankton biomass for 1993, 1994, and 1995 is possible using data are from AFK Hatchery (zooplankton data from R.T. Cooney) and from the CLAB buoy (93 & 94 fluorometry) and AFK Hatchery. A key feature of these data is that the peak of the phytoplankton bloom occurs 15 to 20 days earlier in 1993 than in 1994 or 1995. The timing of the bloom in the latter 2 years is nearly

identical. The subsequent peak increase in zooplankton directly reflects the phytoplankton timing. The zooplankton peak is early in 1993 and later in the replicate '94 and '95 seasons. The unavoidable conclusion is that the ecosystem phenology is determined by the timing of the phytoplankton bloom which is itself driven by ocean conditions. While the exact mechanism linking the phytoplankton to zooplankton increase is unknown, we speculate that it is the rain of phytodetritus into the deeper waters that is the signal to the herbivore community to begin grazing and moving up into the surface layers.

Spatial Measurements: Ship-Board Results

Phytoplankton Community Size Fractionation (Figure 8)

For species identification, unfiltered water samples from 5 depths (0, 5, 10, 25, and 50 m) were collected at each phytoplankton station on all 1995 Bering Explorer cruises (see table below).

In addition to phytoplankton standing stock estimates from chlorophyll a fluorescence, additional size fractionation of chlorophyll a was also conducted on all cruises using three filter sizes, 5 μ m, 20 μ m and 100 μ m Nitex netting at the maximum chlorophyll depth. Size fractionation experiments were conducted to roughly determine the composition of the bloom based only on cell size and fluorescence. All fractionation work directly followed the fluorometric studies that determined the depth of the maximum chlorophyll biomass.

Table 1. List of phytoplankton samples collected for size fractionation measurements.

Cruise	Dates	Phytoplankton Samples Collected	Size fractionation
BE503	3/15-3/23	150	50
BE504	4/10-4/16	195	18
BE505	5/4-5/11	150	102
BE506	6/15-6/20	155	93
BE509	9/28-10/3	110	66

Between April 10-16, size fractionation of chlorophyll a was conducted at five stations to determine the dominant phytoplankton biomass based only on cell size. Four stations showed the majority of cell size was between 20 μ m and 100 μ m with values ranging from 51% to 92% of the chlorophyll biomass. Stations MS6, SEA27 and SEA11 had between 30-33% of the chlorophyll from cells greater than 100 μ m. Only Station HE12 deviated from the others, showing 53% of the biomass from cells <5 μ m and 11% from cells between 20 and 5 μ m. All the other stations had an average of 7.5% of chlorophyll from cells < 5 μ m during the month of April.

Phytoplankton Nutrient and Zooplankton Interactions (Figure 9)

In March high nitrate (15-20 μ M) concentrations occur throughout the sound along with low biomass of both phytoplankton and zooplankton. In the northern and western sound, in April, the phytoplankton bloom occurs, nitrate declines, and zooplankton begin to increase. In May nitrate is depleted (<2 μ M) in the surface waters except the south "river" region, phytoplankton declines, and zooplankton are high. The data show closely coupled spatial and temporal connections for nutrients phytoplankton and zooplankton. The progression is essentially from inorganic nutrients in March to organic biomass (as zooplankton) in May. The spatial pattern is a separation of "lake" type conditions in the northern and western sound and "river" conditions in the south. Nutrient isoclines are

parallel to the flow trajectories described by the SEA physical model (see the modeling component). The high biomass of both plant and animal plankton is confined to 'Cooney's Lake'. These data support the results of the SEA ocean model (Figure 10).

Spatial Measurements: Satellite Images

Eslinger is collecting contemporaneous AVHRR SST data. As part of our 1995 work, we helped in the analysis of remotely sensed sea surface temperature data which was collected prior to the SEA project. We have performed an empirical orthogonal function (EOF) analysis on the SST data covering the spring period for three years. An EOF analysis of satellite images allows one to represent the total spatial and temporal variability in the data set by a temporal mean, a time series of spatial means, and a series of independent (orthogonal) modes or patterns (images), which are sorted from those explaining the most amount of variance down to those explaining the least amount of variance. With each EOF mode, there is an associated time series of unitless eigenvectors, which indicate the relative importance of the associated mode at a particular time. The spatial and temporal variation explained by a particular pattern can be reconstructed by multiplying the spatial pattern by the eigenvector at a particular time; this gives the variation about the mean due to the particular mode at that particular time. The EOF analysis reveals that 40.5% of the variation in the springtime sea surface temperatures, after spatial and temporal means have been removed, is explained by the pattern and time series seen in Figure 11. We maintain that this pattern discriminates the high-flow (river) region from the low-flow (lake) region. The figure shows that temperatures in the early spring are warmer in the Gulf-dominated high flow region, i.e., negative SST variance values (blue) in the southern Sound are multiplied by the negative eigenvectors, which occur prior to day 120, to give a positive overall effect. The SST difference between the two regions decreases through time and, near day 120, changes sign. After day 120, the northern Sound waters are warmer than the southern Sound "river" waters. Interannual variation in the extent and strength of this "lake/river" EOF mode can be seen in by comparing the eigenvectors for the three different years. The largest eigenvectors occurred in 1991, indicating that was the year with the strongest cross-Sound temperature difference and, we maintain, the strongest "river" year. In contrast, 1992 eigenvectors are all very small and the first mode was therefore relatively weak in 1992, i.e., 1992 should have been more of a river year. In 1990, eigenvalues were intermediate, and we maintain it was a mixed year, with more high flow "river" conditions than in 1992, but less than in 1991.

The patterns revealed in this analysis are very similar to the patterns found in our 1995 field data (Fig. 9) and to the dominant circulation patterns observed in the physical modeling work of the SEADATA subprogram. We are greatly encouraged by these findings and since the SEA project as a whole has succeeded in 1) identifying the "river" and the "lake" portions of the sound from physical characteristics, 2) observing the biological effects of the different regions, and 3) implementing a model which contains the necessary physics to reproduce these different regions.

Modeling

As part of our coordination with other SEA groups, we supplied the phytoplankton modeling portion of the SEADATA project with chlorophyll data, for both cruises and hatchery time-series stations, from 1994 and 1995. These data will be important for examining the River/Lake hypothesis and for developing the spatial aspects of the plankton model. In addition, we supplied meteorological and physical oceanographic (water-column temperature) data from the CLAB buoy system to the modeling components. The buoy data is used to force the biological model, and to provide validation data for comparison of the model temperature structure with the actual temperature structure.

Discussion

The general pattern of the time course of phytoplankton biomass is a rapid spring increase followed by an equally sharp decline after about a month. The increase begins in early April unless storm conditions are present, and the decline occurs in May. Summer increases occur if oceanographic mixing events provide new nutrients to the surface euphotic zone. We observed such small scale events both in the buoy data and in the time series from Lake Bay. In 1994 the phytoplankton biomass reached maximum in the last week of April (in 1993 it was early April) and the following minimum occurred in the third week of May (first week in 93). In both years these events in the annual cycle occurred more than a month before those in the phytoplankton cycle reported for Port Valdez in 1987 (Alexander and Chapman, 1980; McRoy, 1988).

The timing of the spring bloom is apparently determined by the interaction of light and mixing in the classic relationship (Sverdrup, 1953). The interruption of the cycle by storms indicates the fragility of the relationship at this time of year and how the ocean conditions can impart an event signal to the food web. The zooplankton data that have been included here show that the delay in the phytoplankton bloom is translated to zooplankton and hence to upper trophic levels.

The pattern of the phytoplankton cycle indicates the classic response of increasing light and stratification in spring followed by nutrient limitation. Such a pattern has been reported for previous studies of Prince William Sound (Goering et al., 1973a, 1973b). The nutrient data we collected generally confirm this as well. It is possible that the end of the bloom period is also influenced by zooplankton grazing since the increase in zooplankton directly follows the decrease in phytoplankton. It is likely that both nutrient limitation and grazing lead to the decrease in phytoplankton biomass. These forces can also have a major impact on the composition of the phytoplankton community.

Alexander and Chapman (1980) report that the phytoplankton community consisted of 97% diatoms in April but by July it was 95 % microflagellates. We found that the diatom fraction in April, 1995 was 55%, with remainder consisting of flagellates. The presence of abundant flagellates is indicative of a mechanism for channeling dissolved organic matter (DOM) that is excreted by phytoplankton through a microbial loop. Such a mechanism retains energy in the food web that might otherwise be lost through excreted DOM. The process is relatively inefficient since at least 3 trophic levels are probably involved (Azam et al., 1983).

Horner et al. (1973) report a detailed list of phytoplankton species for Port Valdez that can also be used for comparison. The shift from nitrate limitation in 1994 to silica limitation in 1995 can have profound impact on the species composition of the phytoplankton community later in the season. Furthermore, such a shift must be the result of changes in ocean conditions that, we hope, can be modeled.

The diatoms present in April and May are expected to be prime food for the large zooplankton, and hence a major energy source for upper trophic level species. On the other hand the picoplankton are a poor food source for these zooplankton but contribute to a microbial food web that can eventually provide energy to the larger consumers.

Particulate nitrogen and carbon are closely correlated with each other and with the chlorophyll values. This is reassuring since it indicates that our chlorophyll techniques are not missing a significant component of the community biomass. Furthermore, nutrient vs. nutrient regressions show a close relationship of nitrogen to silicate, a confirmation of the dominance of diatoms in the system as reported by direct counts.

The close correlation of the phytoplankton and zooplankton increase in biomass in 1993, 1994, and 1995 (Figure 9) indicates more bottom-up forcing than has generally been assumed in this system (refer to the SEA general overview documents).

Do phytoplankton drive the food web? Yes, but. Based on our evidence and that of past studies, the timing of the bloom is a critical event that sends a signal to all trophic levels. Actually, it is an oceanographic event that initiates the signal. The manifestation of such an event in the phytoplankton community could take several forms. It could lead to a different suite of species that may or may not be acceptable zooplankton food. It may simply be a

quantitative event and the early zooplankton could be food limited. The translation of this could then be fewer progeny in the following year.

Conclusions

1. A well-defined spring bloom of phytoplankton occurs In Prince William Sound. The timing of the bloom depends on light and mixing conditions in a given year. Local conditions are important in determining the phytoplankton biomass.
2. Phytoplankton bloom community consists of at least 55% diatoms in the size range of 20 to 100 μ m, suggesting a direct herbivore link to the food web. An active microbial loop that retains energy in the main food web is proposed for the system.
3. Productivity in 1995 is ultimately silica depleted but in 1994 it was nitrogen limited. This suggests a shift in ocean conditions and ecosystem processes.
4. Spatial patterns indicate that the northern sound has 'lake' conditions and the southern portion is a 'river' of Gulf of Alaska water. The high biomass of phytoplankton and zooplankton occurred only in 'lake' waters in 1995.
5. Phytoplankton and zooplankton are closely coupled in space and time. The timing of the spring phytoplankton bloom sets the timing of the appearance of the zooplankton.
6. The field data support the SEA ocean model, confirming a biological reality of 'lake' and 'river' conditions.

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D.L. Eslinger, R.T. Cooney and C.P. McRoy. Physical forcing of interannual variability in plankton populations in Prince William Sound, Alaska: results of a biophysical model. AGU/ASLO Ocean Sciences meeting, San Diego CA, February 1996.

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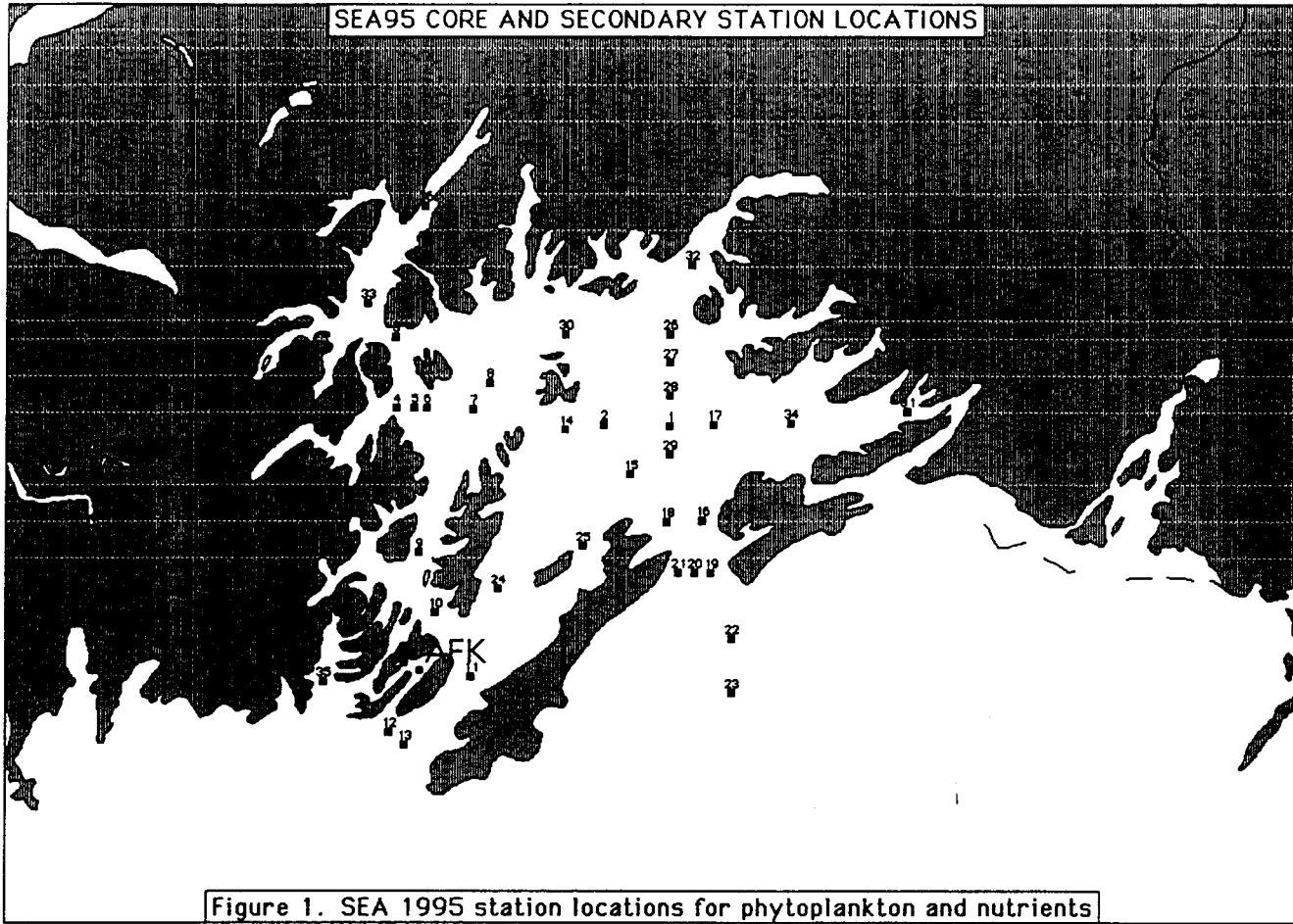
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Strickland, J.D.H. and T.R. Parsons. 1972. A Practical Handbook of Seawater Analysis. Bulletin 167, Fisheries Research Board of Canada, Ottawa, 310 pp.

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Table 2. Phytoplankton community composition during the bloom (April 18-27, 1995, Station AFK 95.2).

<u>DIATOMS</u>	<u>Size Range</u> (l x w) μm	<u>FLAGELLATES</u>	<u>Size Range</u> (l x w) μm
<i>Asterionella sp.</i>	12x3 - 15x4	<i>Oxytoxum sp.</i>	25x8 - 40x15
<i>Chaetoceros sp.</i>	2.5x2.5 - 40x30	<i>Peridinium sp.</i>	20x15 - 65x50
<i>Coscinodiscus sp.</i>	135 - 190	Unidentified flagellate	5x2.5 - 7.5x5.0
<i>Eucampia sp.</i>	35x20 - 60x15	Unidentified silicoflagellate	
<i>Grammatophora sp.</i>		Unidentified dinoflagellate	10x10 - 80x55
<i>Leptocylindrus danicus</i>	20x7 - 40x10		
<i>Leptocylindrus minimus</i>	35x5 - 40x5		
<i>Leptocylindrus sp.</i>	35x5 - 40x7		
<i>Navicula sp.</i>	40x15 - 60x10		
<i>Nitzschia sp.</i>	35x2 - 100x5		
<i>Rhizosolenia sp.</i>	25x14 - 500x15		
<i>Skeletonema costatum</i>	5x2.5 - 15x2.5		
<i>Stephanopyxis nipponica</i>	40x20 - 60x30		
<i>Thalassiosira sp.</i>	10 - 65		
<i>Thalassionema sp.</i>	30x5 - 45x5		
Unidentified centric diatom			
Unidentified diatom	15x10 - 130x15		
Unidentified pennate diatom	20x5 - 45x7		



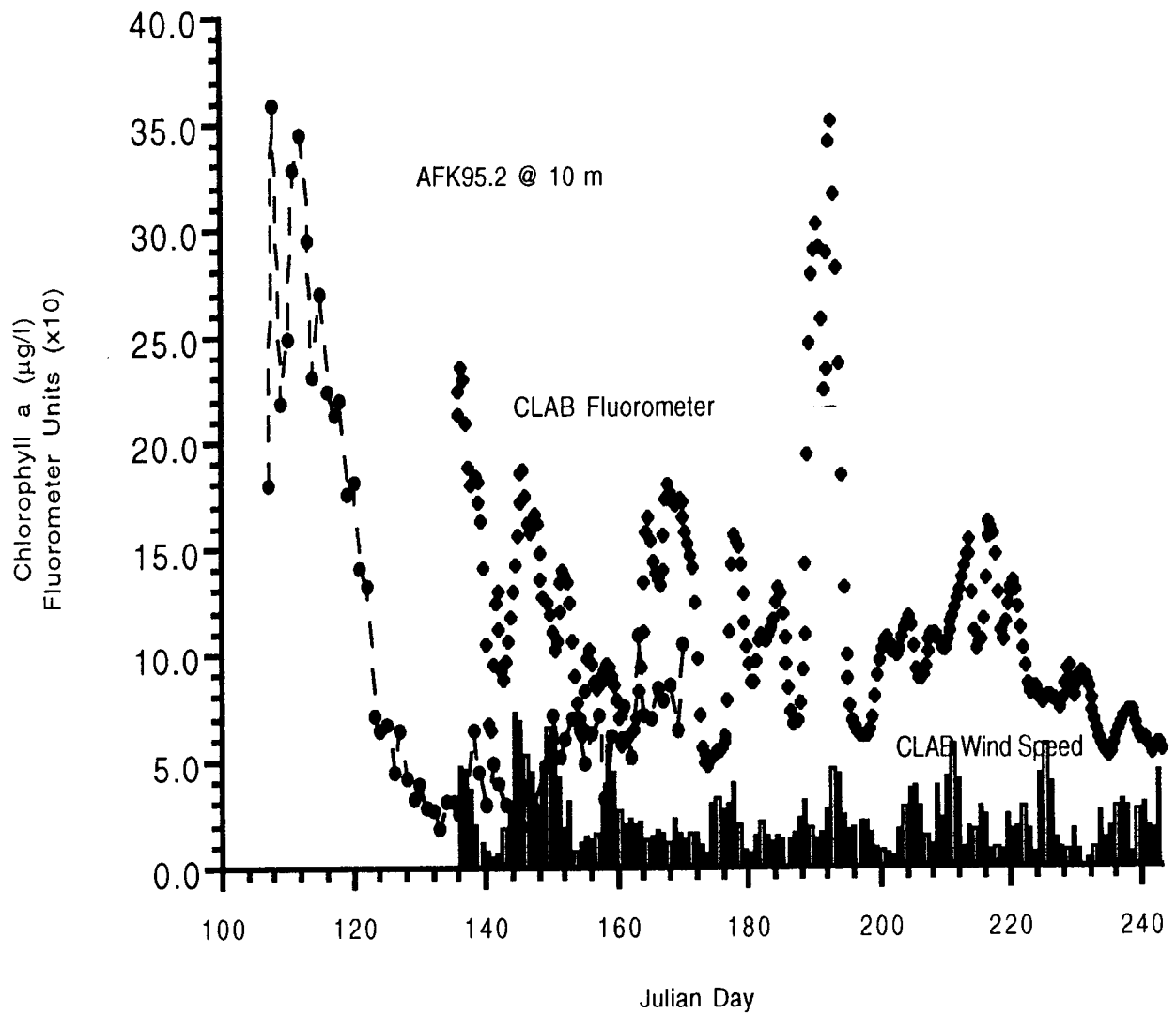
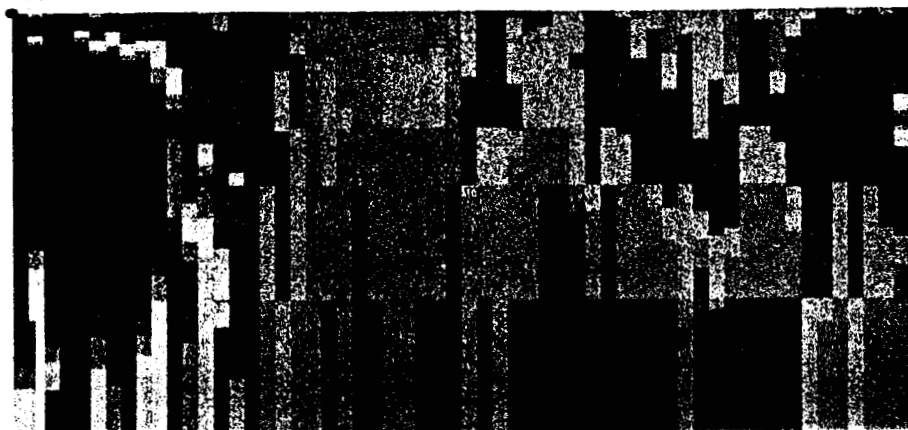
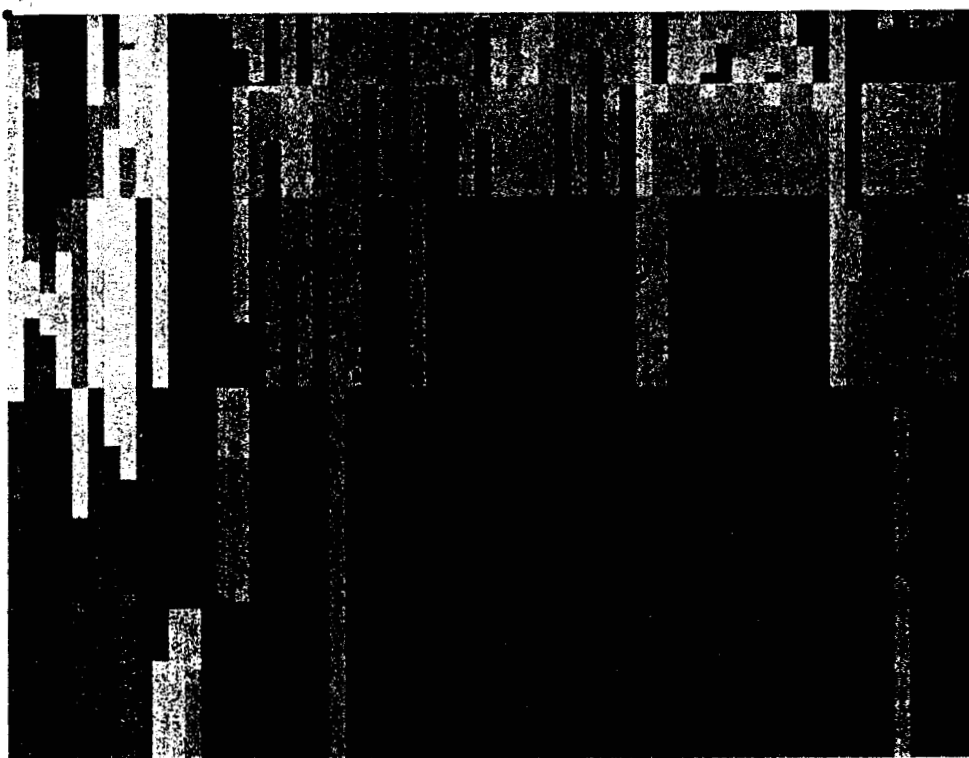


Figure 2. Time series of chlorophyll a at AFK95.2 (10 m) in relation to the 10 m fluorometer signal (x10) and surface wind speed (m/sec) at the CLAB moored instrument buoy.

AFK Station 1 1995



AFK Station 2 1995



18 April

19 June

Figure 3. Time series of phytoplankton biomass as measured by chlorophyll a for two locations in Prince William Sound in the vicinity of AFK Hatchery.

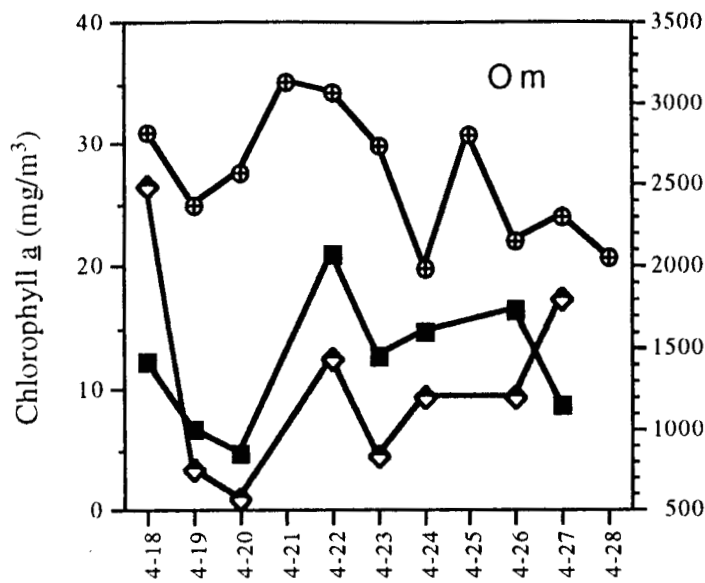


Figure 4. Phytoplankton biomass (chlorophyll a , mg/m³) and abundance (cells/ml) at 5 depths during the spring bloom in Prince William Sound (Sta AFK95.2).

- CHLOROPHYLL (mg/m³)
- ◇ FLAGELLATES (cells/ml)
- DIATOMS (cells/ml)

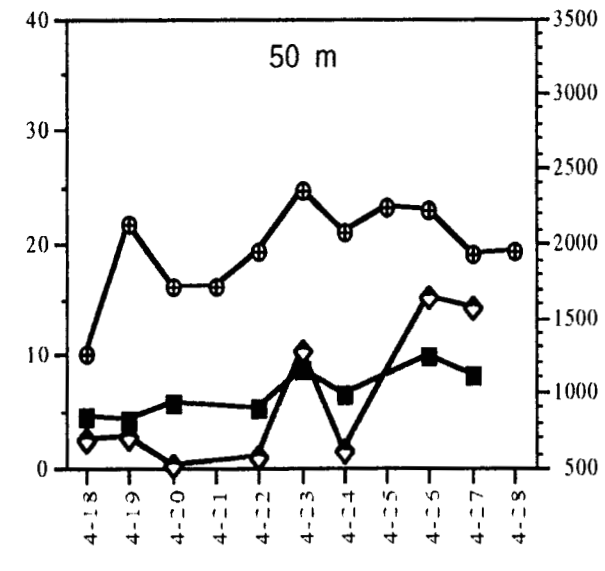
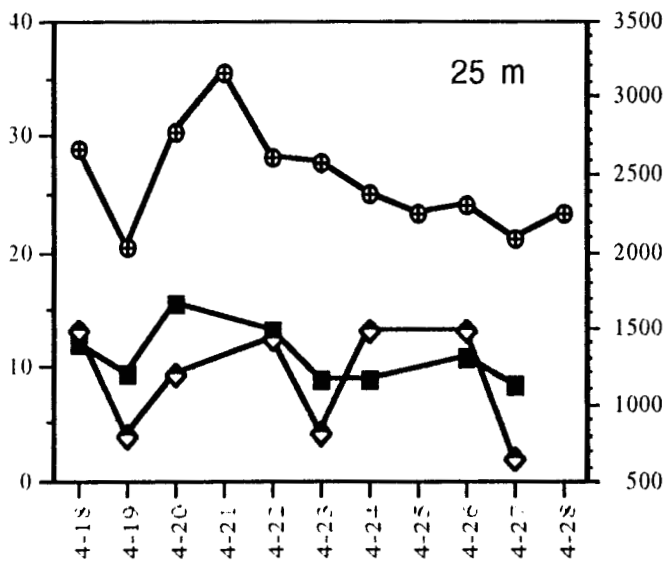
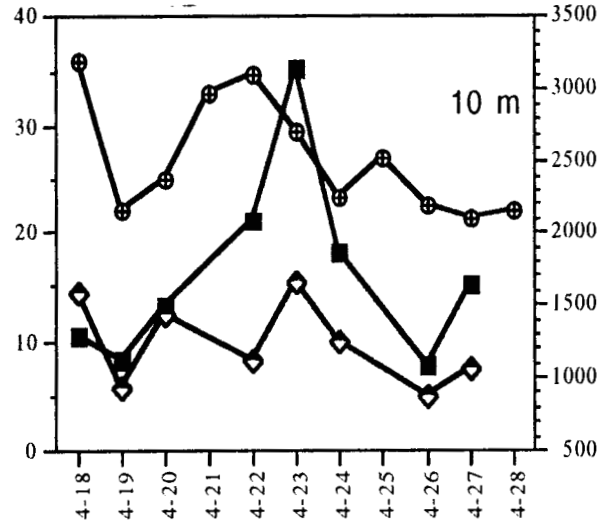
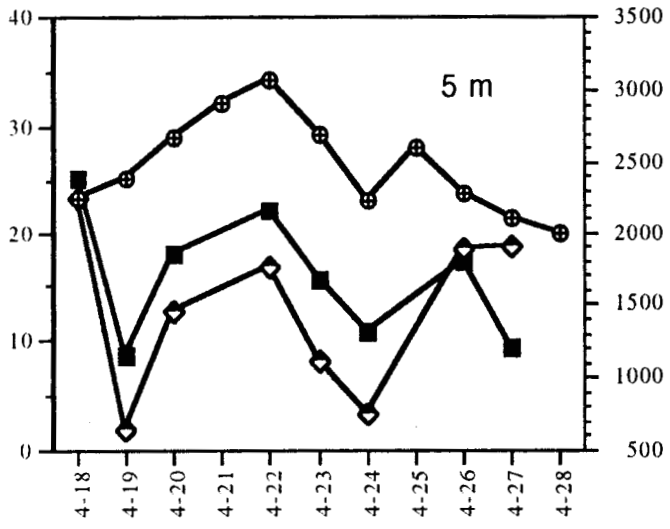
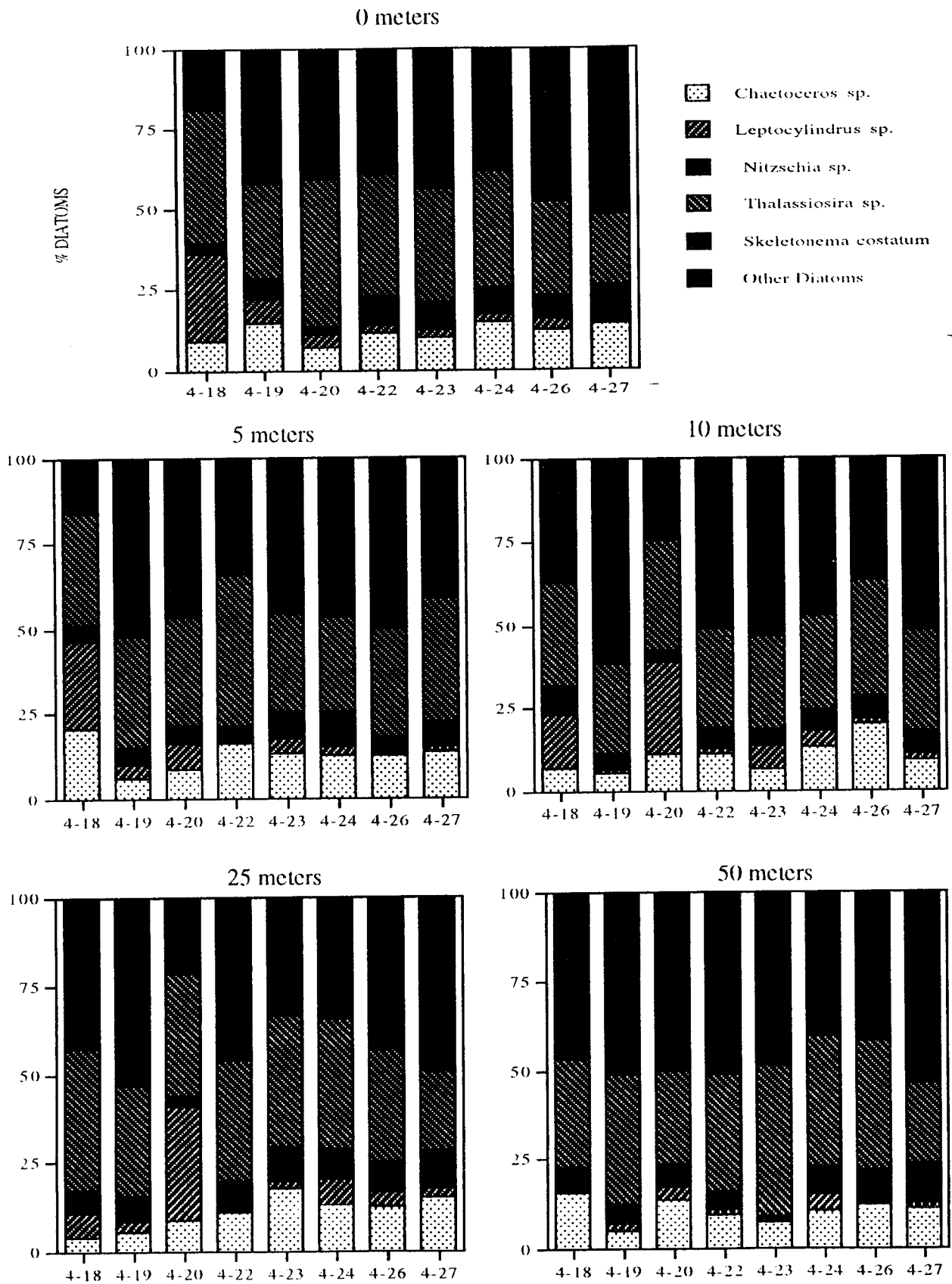


Figure 5. Major taxa of the diatom community during the spring bloom(18-27 April 1995) in Prince William Sound (Station AFK95.2).



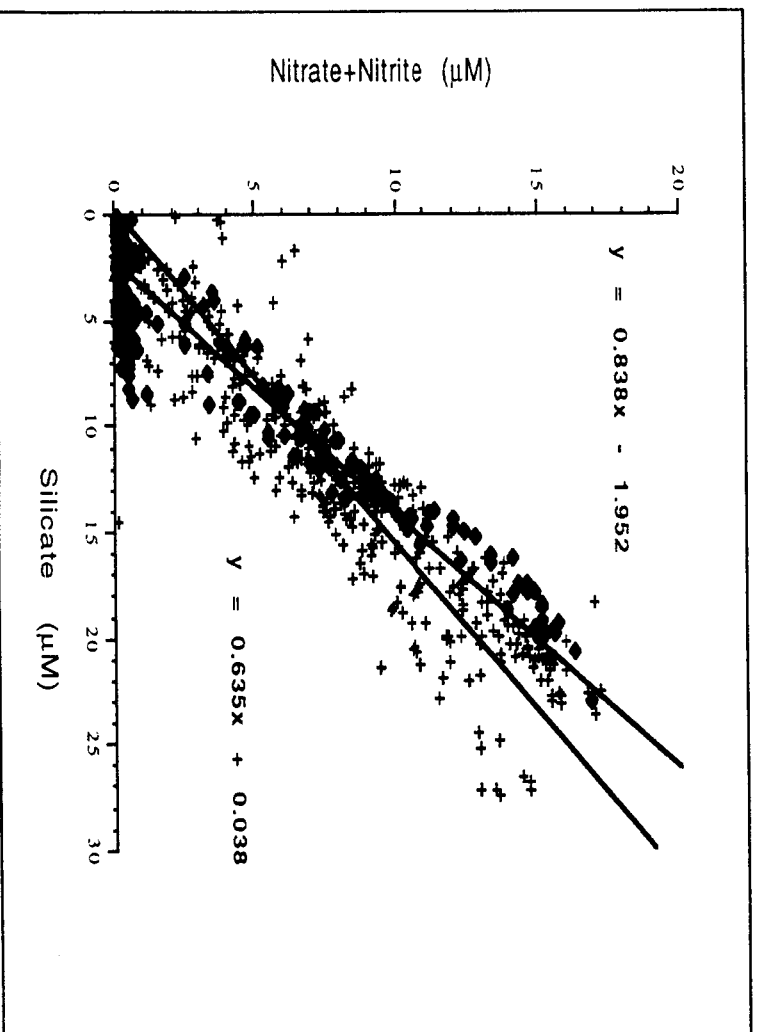
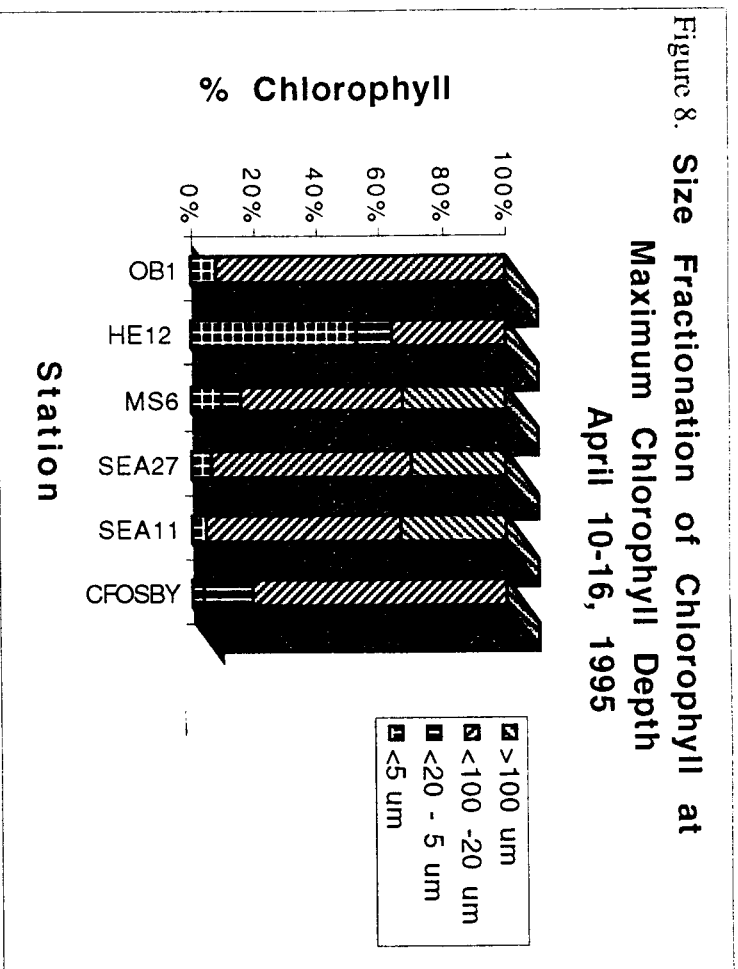


Figure 6. Plot of nitrate vs. silicate for time series data from 1995 (AI:K95.2) and 1994 (WN Hatchery, Ester Island).

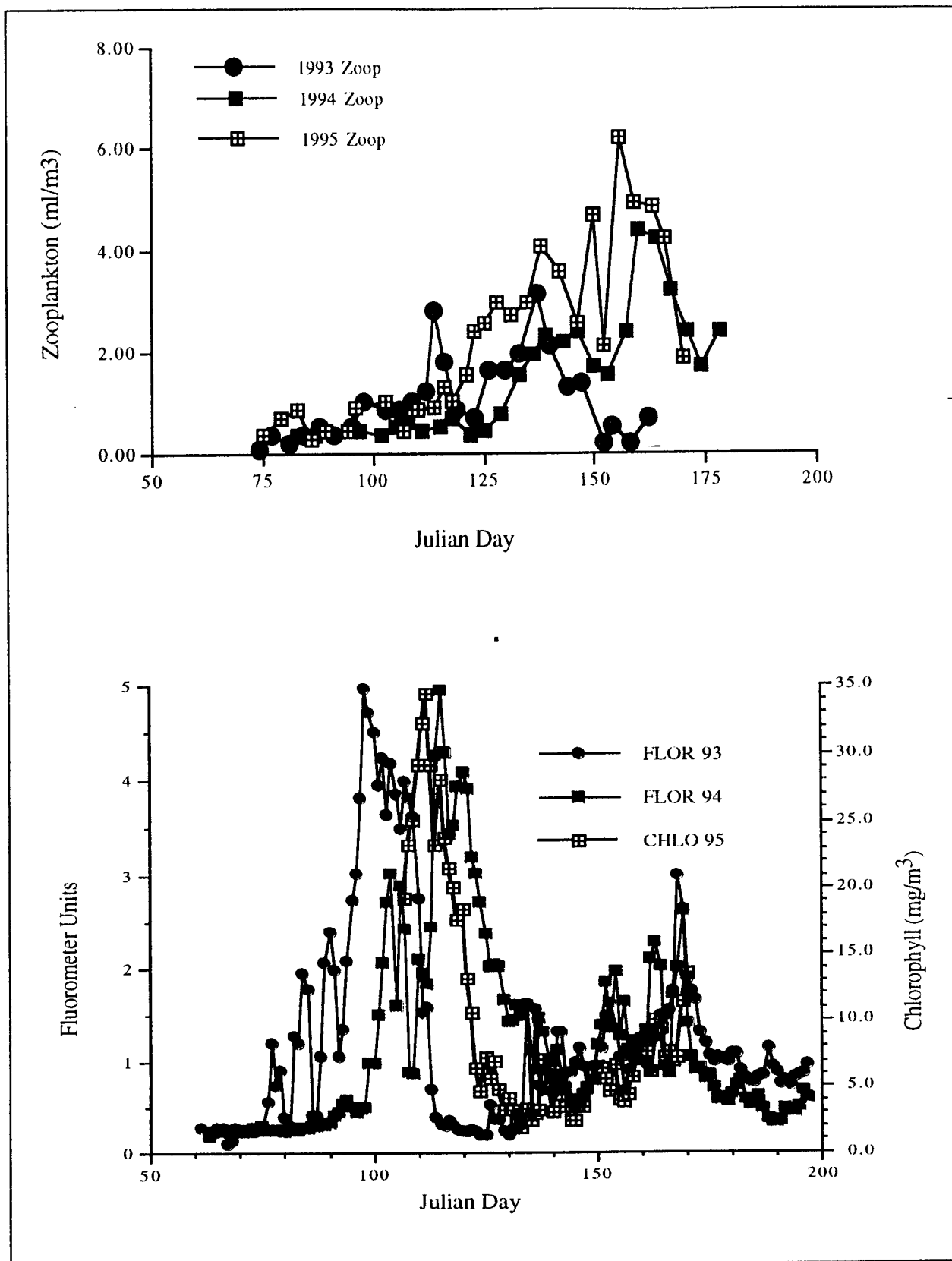
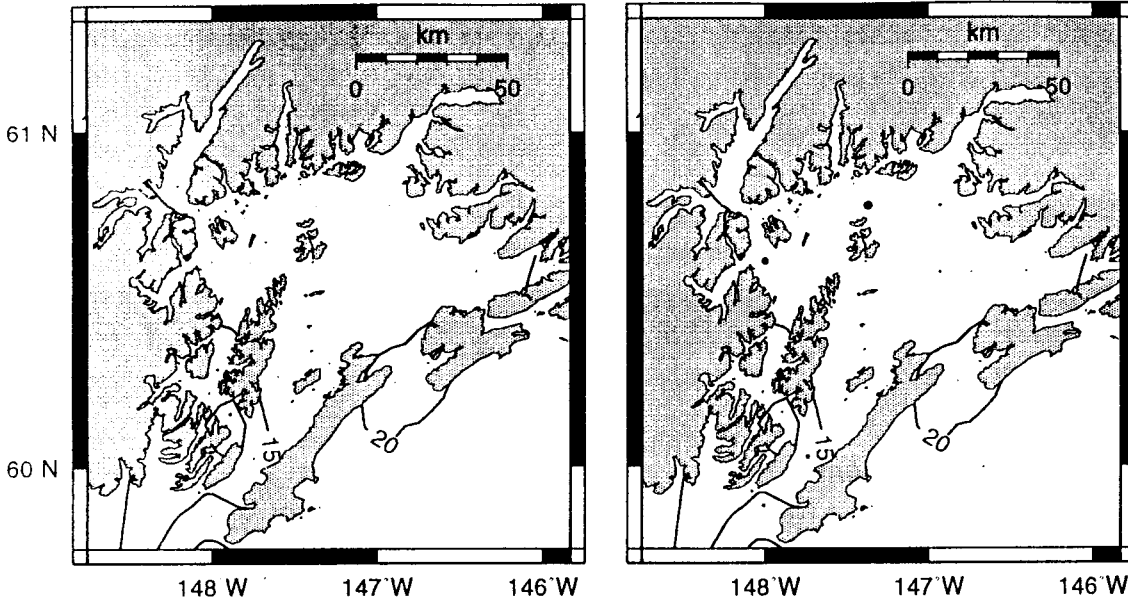


Figure 7. Time series of phytoplankton and zooplankton biomass from AFK95.2 and fluorometer data from CLAB buoy for 1993, 1994, and 1995. In all years the zooplankton peak lags that of phytoplankton by 17 to 21 days, indicating a close food web link.

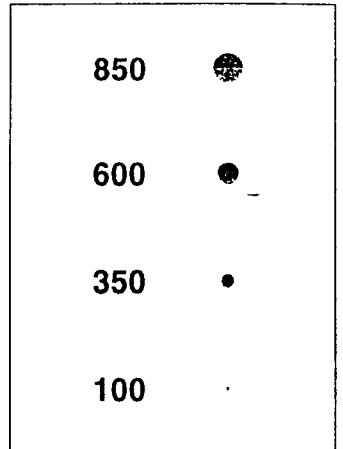
Figure 9. Spatial fields of nutrients, phytoplankton, and zooplankton for March, April and May 1995 in Prince William Sound.

Figure 9.

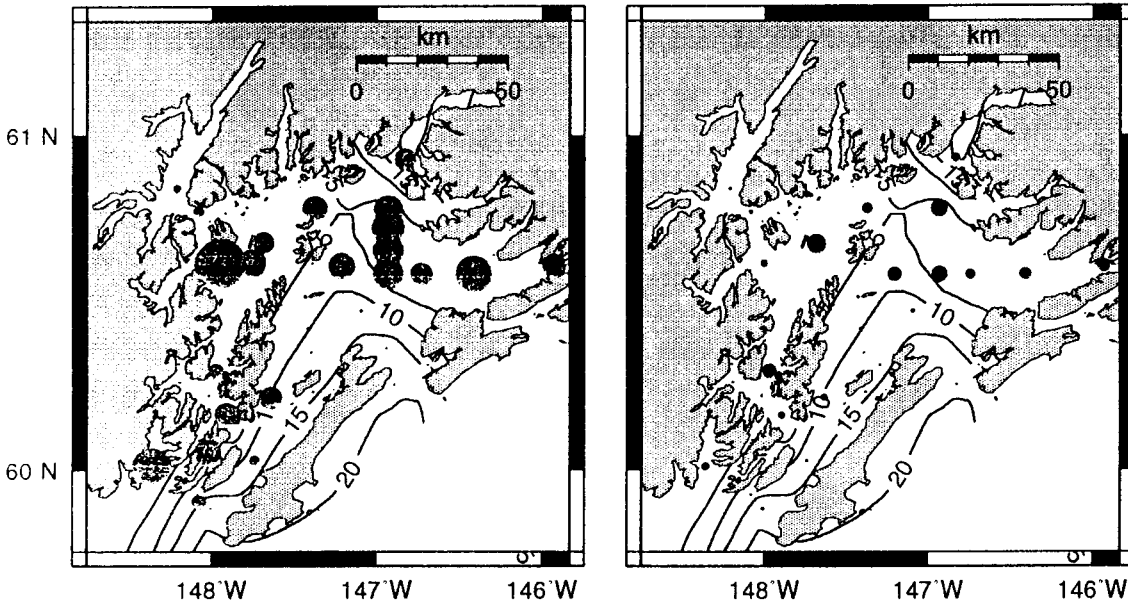
MARCH



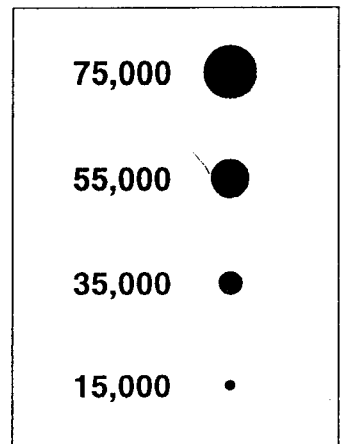
CHLOROPHYLL (mg/m²)



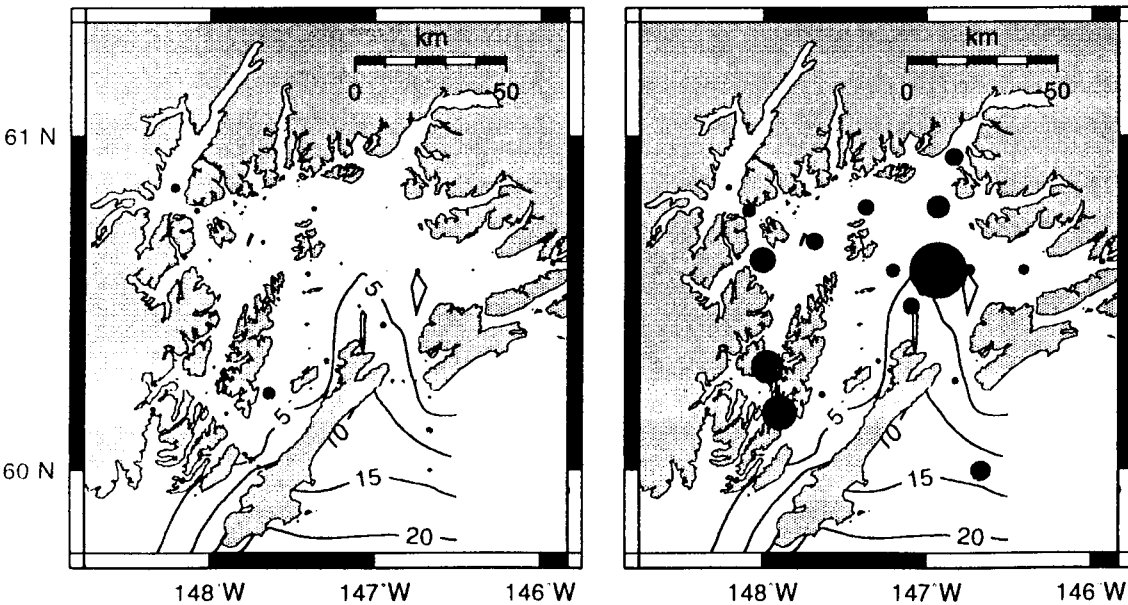
APRIL



ZOOPLANKTON (mg/m²)



MAY



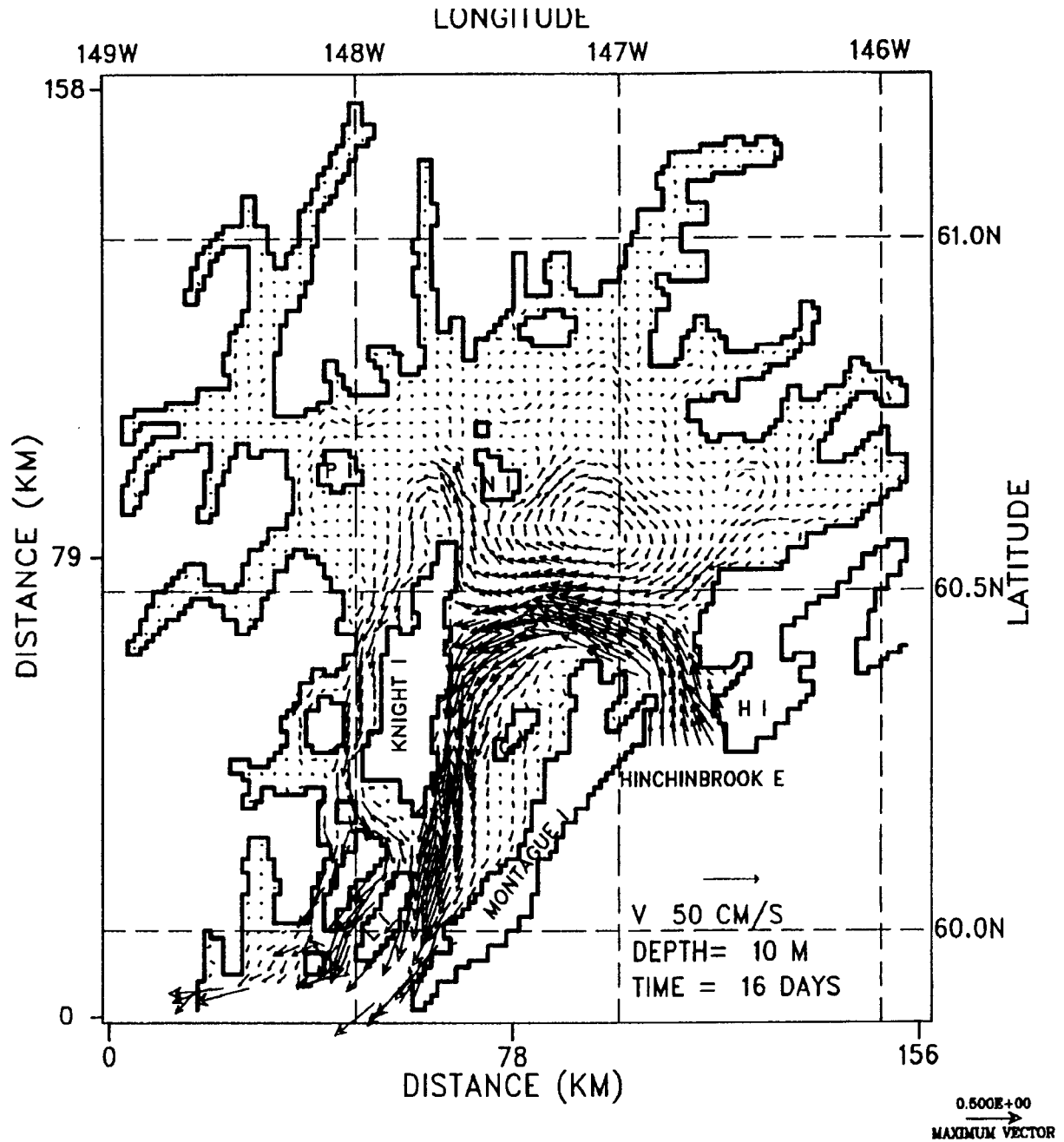


Figure 10. Ocean forcing model showing the "lake" and "river" (strong flow in southern part of Prince William Sound); compare these results to the phytoplankton and nutrient fields in Figure 9. This figure is by V. Patrick and J. Wang, Component 95320J.

Figure 11. First mode of EOF analysis of sea surface temperature patterns. This mode is the empirically derived spatial pattern and its associated time series of eigenvectors, which together explain more of the variance in SST images than any other possible patterns. In this case the first mode explains over 40 % of the variability in SST data from over three years. Eigenvectors are color coded according to year.

Mode 1

Figure 11:

40.5% variance

