Exxon Valdez Oil Spill
Restoration Project Annual Report

Sound Ecosystem Analysis: Phytoplankton and Nutrients
Restoration Project 96320G

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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April 1997

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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 and 1996 under the title "SOUND ECOSYSTEM ANALYSIS: Phytoplankton and Nutrients" and continues under the present grant number. Papers were presented at the AGU/ASLO Ocean Sciences meeting and The Oceanography Society meeting.

Abstract: In 1996 we collected 1110 samples from several platforms including 3 cruises (April, May and June) on chartered vessels and daily collections (April through June) from a station in Elrington Passage near AFK Hatchery. Measurements included chlorophyll, nutrients, particulate carbon and nitrogen, species composition, CTD, and dissolved oxygen from 6 depths in the upper water column. This is the second 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 biomass is a result of nutrient depletion and grazing. The spring phytoplankton cycle begins with a bloom dominated by diatoms, particularly *Skeletonema costatum*, followed by a low biomass of flagellates and succeeded by another low biomass of diatoms. The timing of the spring bloom is a signal to zooplankton. In the 4 years that we have data, the peak of zooplankton biomass occurs 3 weeks after the bloom. The data indicate a robust, healthy foundation for the pelagic ecosystem in Prince William Sound where variability is determined by weather, mixing processes and basin structure.

Key Words: Exxon Valdez, phytoplankton, nutrients, primary productivity, algae

Citation: McRoy, C.P., A. Ward, E.P. Simpson, D. Clayton, J. Cameron, S. McCullough and E. Suring. 1997. Sound Ecosystem Analysis: Phytoplankton and Nutrients, *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project 95320G), Institute of Marine Science, University of Alaska, Fairbanks, Alaska

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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.

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 Prince William Sound.
2. Determination of basin-wide patterns of temperature, salinity nutrients and chlorophyll from ship-board observations.
3. Determination of temporal patterns of temperature, salinity, nutrients and chlorophyll in western Prince William Sound from a station near AFK Hatchery.
4. 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. 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 Continuous Flow Analysis methods with an Alpkem Auto-Analyzer in our laboratory in Fairbanks.

Personnel

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

P. Simpson	Graduate Student
A. Ward	Graduate Student
D. Clayton	Technician
J. Cameron	Technician
S. McCullough	Technician
E. Suring	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 in Prince William Sound. These data are collected in conjunction with other SEA projects and are supplied to the SEA data base after appropriate analysis and verification.

Sample Collection

We collected water samples for analysis from two types of platforms in Prince William Sound. Short, monthly SEA cruises on board chartered vessels from March to June permitted regional sampling from the standard SEA ocean stations. The second sample site is a station in Elrington Passage near 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. These data provide temporal continuity to the ship-board sampling.

The field season began in March and ended in June. In 1996 we collected 1110 samples from 3 cruises and a time series station. An decrease of 14% over 1995 (Tables 1 and 2). The chartered vessels provided areal coverage of the sound for oceanographic and biological parameters (Figure 1).

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 identification and enumeration were processed.

Time Series Measurements

The best time series data in 1995 were collected from a station in Elrington Passage (60°01'N, 148°00'W) the southwest sound near the AFK Hatchery. The station was visited daily by skiff and all samples were collected from a 5 liter Niskin bottle lowered repeatedly to each sample depth with a hand winch. The data series begins on 06 April 96 and ends on 16 June 96. The phytoplankton bloom was already underway when sampling began (Day 97) and terminated by Day 126. The pattern is similar to that in 1995.

Hydrography

One CTD cast to 80 m was lowered daily to determine salinity, temperature and density of the sea water over the duration of the study. From a contour plot of σ_t vs. depth and time we were able to determine mixing events and the stability of the water column throughout the season.

The waters were cold and well mixed throughout the water column during the spring bloom in 1995 and 1996 (Figure 2). In 1995, from April through early May temperatures remained between 4 - 5 °C. Surface warming wasn't apparent until Day 121. Weak

stratification occurred earlier around Day 112 due to freshening at the surface from precipitation. However this weak stability was disrupted two days later as waters continued to mix within the upper 75 m. That year the salinity averaged 31.17 (psu) at 5 m and density profiles mirrored salinity (Figure 2). The density remained between 24.2 - 25.2 σ_t. In 1996, temperatures were the same as 1995 and mixing extended down to 80 m prior to Day 113. Fresh water input was reduced in 1996 and salinity averaged 31.55 psu at 5 m. Stratification didn't occur as the density of the water remained between 24. 8 -25.2 σ_t.

During the post bloom, stronger stratification was achieved as solar gain and fresh water runoff increased (Figure 2). In 1995, the surface waters warmed to 6.75°C by Day 143. A strong pycnocline was formed in the upper water column due to heavy fresh water input. Below 30 m mixing occurred daily. Salinity fell to 29 psu at surface. In 1996, clear sunny skies enable water temperatures to warm to 7 °C by Day 144. Salinity ranged from 31.2 - 31.8. Salinity remained higher in 1996 due to reduced precipitation and increased evaporation. Due to decreased freshwater input, densities remained much higher than 1995. Frequent deep mixing to 80 m (Days 135-140) continued to occur throughout this period. A salty intrusion was detected on Day 138 between 20 and 60 meters and lasted for several days.

Following Day 145, waters gained their greatest stability and temperatures (Figure 2). In 1995, surface temperatures reached a maximum of 9 °C as the surface salinity dropped to 26.7 psu. Strong stratification and pycnocline caused by heating and fresh water remained throughout the month of June. Mixing was restricted to depths below 50 m. In 1996, surface temperatures rose to 10 °C by Day 163 and warm waters penetrated to 80 m. Freshening occurred in the surface waters after Day 150 but the minimum salinity in June reached only 30 psu. Due to the large number of clear days, insolation warmed the waters increasing stability but, at the same time, increasing evaporation and therefore salinity which overall controlled the waters stability. In June waters were less stable in 1996 than 1995 and weak stratification in the upper 25 m was interspersed with deep mixing events. Another high salinity intrusion at mid depths was seen on Day 158 and lasted two days.

Nutrients

Daily water samples were collected and later analyzed for inorganic nutrient concentrations. Concentrations of nitrate+nitrite (μM), silicate (μM) and phosphate (μM) were determined. Phosphate and nitrate were chosen because the assimilation of these two nutrients in the Redfield-Richards Ratio of 1:16 (Libes 1992) is required for photosynthesis and phytoplankton growth. Silicate was chosen because it is required for the formation of diatom tests and it can affect phytoplankton community structure in its presence and absence.

Nutrient concentrations were high preceding the spring bloom; then they decreased in surface waters as production increased (Figure 3). In 1995, concentrations of all nutrients were highest around Day 107 and a nutricline was apparent throughout the bloom. In the upper 75 m concentrations of N+N, SiO_4 and PO_4 ranged from 10 - 15 μM, 15 - 25 μM, and 1.0 - 1.5 μM, respectively. As the bloom progressed nutrients were depleted in the surface waters but remained high below 50 m. By Day 120 concentrations of N+N, SiO_4 and PO_4 had dropped to levels between 1.7 - 2.5 μM, 3 - 4.5 μM and 0.3 - 0.7 μM in the upper 10 m. Following Day 120 nutrient concentrations remained low but detectable in the surface waters. In 1996, a similar pattern emerged but nutrient levels were lower throughout the bloom especially at depth. At Day 97, N+N, SiO_4 and PO_4 in the upper 75 m ranged from 10.9 - 11.3 μM, 16 - 17 μM and 1.2 - 1.5 μM, respectively. As the month of April passed, all the nutrients deceased at the surface around Days 104 and 117. No nutrients were completely assimilated by plankton but ratios of N+N:SiO_4 were very low. Nutrients were replenished in-between the periods of low concentrations.

During the post bloom nutrients were replenished from depth and low nutrient concentrations did not exist below 25 m (Figure 3). In 1995, high concentrations of all nutrients were present. Only around Days 138 - 143 did all the nutrients show a decline in the upper 10 m. Nutrients remained highest below 50 m with maximum N+N, SiO_4 and PO_4 concentrations of 16 μM, 25 μM and 2 μM, respectively. In 1996, all nutrients were also replenished in the upper layers. Only two periods around Days 131 and 141 had decreased concentrations. Maximum values at depth, as well as surface, were much lower in 1996. Below 50 m maximum N+N, SiO_4 and PO_4 concentrations only reached 14 μM, 19 μM and 1.8 μM, respectively. Higher concentrations of phosphate existed at depths in 1996.

During the resurgence period, nutrients in the surface waters deceased again and concentrations at depth remained high. In 1995, nutrient concentrations remained low in surface waters and high below 25 m. The highest concentrations throughout the entire spring bloom of nitrate appeared in June at 75 m. In 1996, all surface nutrients were reduced in the upper 25 m throughout the recovery period. Concentrations were highest at depth but considerable lower than 1995.

Phytoplankton Biomass

Water samples were collected daily from the upper 75 m of the water column to determine the vertical distribution of phytoplankton from chlorophyll *a* (mg/m^3) fluorescence over three months. The bloom in 1996 was bimodal with peaks around Days 104 and 118. The timing of the bloom is an important signal to the zooplankton community which in previous years seem to follow the bloom by about 3 weeks. The 1996 bloom spans most of the range observed from all sources since 1993 (Figure 4).

During the spring bloom chlorophyll extended as far down as 75 m and the highest concentrations of chlorophyll were present at this time (Figure 4). In 1995, the highest chlorophyll levels were between 4 - 36 mg/m^3 in the upper 25 m dropping to 2 - 25 mg/m^3 at 50 m and 75 m. The peak biomass occurred in a short pulse between Days 111-114 in the upper 25 m. In 1996 chlorophyll levels were lower, variations with depth were less and the length of the bloom increased. High levels of chlorophyll were present between Days 97 - 121. In the upper 25 m the chlorophyll ranged from 2 -20 mg/m^3. At 50 m and below the levels decreased to 0.5 - 16 mg/m^3. There were two distinct periods of high biomass between Days 100 - 105 and 114 - 116. Both periods had high levels of chlorophyll at depth.

During the post bloom chlorophyll was at its' lowest concentrations and it was distributed uniformly throughout the water column (Figure 4). In 1995, chlorophyll ranged from 0.5 - 7 mg/m^3 throughout the water column. Small ephemeral blooms occurred in the upper 10 m on Days 125 - 127 and 138. Chlorophyll levels at 50 m and below remained ≤ 3 mg/m^3. In 1996, chlorophyll ranged from 0.2 - 3 mg/m^3. Unlike 1995, no small blooms occurred at this time.

Following Day 145, chlorophyll levels increased but almost all of the biomass remained above 25 m (Figure 4). The greatest resurgence was seen in 1995. Chlorophyll levels returned to as high as 12 mg/m^3 as stratification strengthened. Concentrations between 5 - 10 mg/m^3 remained until Day 170 in the upper 25 m. Small transitory increases in chlorophyll occurred in 1996 above 25 m. Chlorophyll biomass only increased to highs of approximately 5 mg/m^3 on Days 153 - 154, 160 - 163, 165 and 169. Levels remained low below 25 m except on Day 154 where 6.3 mg/m^3 was measured at 50 m. This anomaly may be due to downwelling of surface waters.

During the bloom phytoplankton growth strips the major nutrients from the water column and conditions of nutrient limitation develop. The close relationship of N+N to Silicate in the upper layers of the water column is a result of this activity (Figure 5). In 1996 the slope of the regression of silicate on N+N was 1.2 with a silicate intercept of 2.6. this relationship indicates that the bloom was terminated by nutrient limitation and that the concentration of silica was below that required by diatom cells. The species abundance reflect this fact (see Figure 8) since diatoms are absent from the water column for a time following the bloom. It is only after some additional nutrients are advected into the system

that the diatoms reappear. This condition existed in 1994 and 1995. The average intercept for all 3 years of N+N vs. silicate is 2.5, a value just at the limiting threshold for diatoms.

Distribution and Abundance of Phytoplankton

In 1995 and 1996 during the spring bloom diatoms and flagellates were present at all depths (Figure 7 & 8; Table 3). Their population remained high throughout the bloom and started to decline by the end of the period at all depths. The distribution of cells revealed highest abundance within the uppermost 10 m, slightly lower populations at 25 m and lowest but still significant abundance at 50 m. In 1995, the diatom abundance ranged from 813 - 3,110 cells/ml within the top 50 m. Flagellates appeared in high abundance and ranged from 525 cells/ml at 50 m to 1,900 cells /ml at the surface. Flagellates were the most numerous phytoplankton with as great as 61 % of the total abundance and a mean of 45 % for all depths. In 1996, diatom abundance was approximately three times as great as 1995. Diatom abundance ranged from 1,872 - 13,500 cells/ml in the upper 50 m. However, flagellate abundance remained about the same in 1996 as 1995. Flagellates peaked at 2,021 cells/ml on Day 110 at 10 m. During the bloom their lowest abundance of 481 cells/ml occurred at 50 m on Day 106. At this time, they only accounted for $\leq$ 25 % of the total phytoplankton abundance. In both years, dinoflagellates (from the class *Dinophyceae*) and silicoflagellates, mainly *Distephanus speculum*, were less than 1 % of the cell abundance.

During the post bloom and recovery periods flagellates were more abundant than diatoms at all depths, interannual differences were less and abundance was low (Figure 7 & 8). In 1995, flagellates composed >90 % of the phytoplankton abundance and ranged from 283 - 880 cells/ml throughout the upper 50 m during periods of lowest chlorophyll. Populations increased slightly (250 - 1,088 cells/ml) during the recovery period and flagellates composed about 60% of the community. In 1996, >80 % of the post bloom phytoplankton was composed of flagellates. At this time the lowest flagellate abundance at 50 m as 300 cells/ml and the highest abundance (1,014 cells/ml) was at the surface. Day to day variations at all depths were slight. In June of 1996, populations increased but flagellates only composed an average of 53 % of the phytoplankton over 50 m. Flagellate abundance over the upper 50 m ranged from 494 - 1,689 cells/ml.

In both years, centric diatoms were the most common phytoplankton during the bloom at all depths but interannual differences in abundance were immense. In 1995 and 1996, *Chaetoceros spp., Skeletonema costatum, Thalassiosira spp., Leptocylindrus spp.* were present in highest abundance throughout the upper 50 m (Figure 7 & 8). Species composition remained the same over depth but diatom abundance decreased with depth below 10 m. In 1995, total diatom abundance ranged from lows of 813 cells/ml at 50 m on Day 109 to a maximum of 3,110 cells/ml at 10 m on Day 113. *Skeletonema costatum* and *Thalassiosira spp* averaged over 37 % and 30 %, respectively, of the total diatom abundance during the bloom at all depths (Figure 9). *Chaetoceros spp.* was always present at all depths and constituted between 5 - 31 % of the total diatoms. *Leptocylindrus spp.* appeared inconsistently composing only a small portion of the bloom. In 1996, the same species and genera reappeared in the sea-water but the smaller diatoms tripled in abundance while the larger species declined in abundance (Figure 8). *Skeletonema costatum* had greater than 72 % of the diatom abundance throughout the water column (Figure 10). Vertically its' abundance ranged from 1,150 - 12,072 cells/ml. The population of *Chaetoceros spp.* increased at all depths and reached a maximum of 2,311 cells/ml at the surface on Day 102. The same year had a lower abundance of *Thalassiosira spp.* and *Leptocylindrus spp.* than was present in 1995. These genera composed < 9 % and < 2 % , respectively, of the diatom population. For both years, other diatoms, in order of abundance, that were $\leq$ 5 % of the total diatom abundance were *Fragilariopsis spp. , Asterionella glacialis, Navicula spp., Eucampia spp., Stephanopyxis nipponica* and *Rhizosolenia stolterforthii .*

During the post bloom the lowest diatom abundance was present and 1995 and 1996 showed less dissimilarities in terms of abundance (Figure 7 & 8). In 1995, less than 100 cells/ml existed at all depths in mid May. Only small variations in cell abundance occurred with depth. The small diatoms, *Pseudo -nitzschia spp.* and *Chaetoceros spp.*, dominated the

community and *Thalassiosira spp.* decreased in abundance (Figure 9). In 1996, at the same time, less than 150 cells/ml were observed and lowest abundance was at 50 m (Figure 8). *Chaetoceros spp.* dominated the abundance at all depths. *Pseudo -nitzschia spp.* and *Leptocylindus spp.*, present during the bloom in low abundance, were present still accounting for as high as 35 % of the diatom abundance (Figure 10). *Skeletonema costatum* abundance declined and was absent at several depths around Day 138. *Rhizosolenia fragilissima*, not present during the bloom, first appeared in low abundance at this time in 1996 but not 1995.

In June the diatom abundance recovered slightly and a shift in species composition occurred (Figure 7 & 8). In 1995, total diatom cells/ml increased to 1/3 of previous bloom abundance. This phytoplankton community was composed almost entirely of *Rhizosolenia fragilissima* at all depths (Figure 9). *Chaetoceros spp.* was the second most abundant diatom with < 10 % of the abundance. *Skeletonema costatum* was absent at this time. In June of 1996, diatoms resurged and ranged from 560 cells/ml at 50 m to 1,088 cells/ml at 5 m (Figure 8). *Rhizosolenia fragilissima* returned in 1996 but only accounted for 25 - 48 % of the diatom community and shared dominance with *Chaetoceros spp* (Figure 10). *Pseudo-nitzschia spp.* and *Leptocylindrus spp.* were the third most abundant diatoms. *Skeletonema costatum* was present but averaged only 6 % of the abundance in the upper 50 m.

Spatial Measurements:

The results from the April, May, and June cruises provided perspective of the areal patterns of phytoplankton and nutrients (Figures 9, 10, and 11). In April the integrated chlorophyll values are high everywhere except the along the northern-most coast and inlets including Port Valdez. A maximum value occurs around Green Island and this feature recurs annually. At this time the nutrient stocks are still high in most areas but large areas of low nitrate and silicate appear in the central sound. By June the transition from a spring to a summer sound is complete. Chlorophyll values are now 10% of the April quantities and nitrate and phosphate are 20 to 30 % of the earlier values. There is some evidence for a small addition of nutrients from the Gulf of Alaska through Hinchinbrook entrance.

Discussion

The general pattern of the time course of phytoplankton biomass is a rapid spring increase followed by an equally sharp decline after about 3 weeks. The increase begins in early April unless storm conditions are present, and the decline occurs by the beginning of May. Summer increases in phytoplankton biomass occur if oceanographic mixing events provide new nutrients to the surface euphotic zone. In both 1995 and 1996 the bloom occurred more than a month before that in the phytoplankton cycle reported for Port Valdez in 1987 (Alexander and Chapman, 1980; McRoy, 1988) indicating the effect of local control on the processes.

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. This pattern has been reported for previous studies of Prince William Sound (Goering et al., 1973a, 1973b). The time series data indicate that nutrient limitation is a significant factor in terminating the bloom. The nutrient-nutrient plot of silicate vs. nitrate shows that the diatoms are able to utilize silicate below the threshold level required for growth (Paasche 1980). The condition must also be a powerful force in species succession. 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. Horner et al. (1973) report a detailed list of phytoplankton species for Port Valdez that can also be used for comparison

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 abundance in April 1995 and 1996 was over 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).

The nutrient inventory presented by the sound-wide distributions for April, May and June (Figures 9, 10 and 11) permit an analysis of overall integrated production for the spring. The difference in the nitrate+nitrite inventory between April and June indicates a utilization of about 8.3 mmol $m^{-2}d^{-1}$ for nitrogen which based on a Redfield ratio of C/N of 6.6 converts to a carbon rate of 0.7 $gCm^{-2}d^{-1}$. This is a conservative estimate of new production. The total production is probably twice this value if the *f* ratio is less than 0.5 as would be expected for the region.

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. The close correlation of the phytoplankton and zooplankton increase in biomass in 1993, 1994, 1995 and 1996 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.

Finally, the picture that we now have is a robust foundation for the pelagic ecosystem that shows no continuing effects of the contamination from the 1989 oil spill. The species composition and primary production vary due to the vagaries of weather and mixing processes as further influenced by the characteristics of the basin.

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. In 1996 the bloom began about Day 98 (7 Apr) and ended by Day 124 (1 May).
2. Phytoplankton bloom community consists of at least 55% diatoms in both '95 and '96, followed by a post-bloom period of 3 weeks consisting of more than 80% flagellates. A resurgence of diatoms occurred after the post-bloom period but attained only 33% of their former abundance.
3. Productivity in 1995 and 1996 was ultimately silica limited. New production (nitrate based) in spring is estimated to be about 0.7 $gCm^{-2}d^{-1}$ which is likely to be half the total productivity rate for the period.
4. 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.
5. The foundation of the pelagic ecosystem in Prince William Sound is robust and healthy.

Papers Presented

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Table 1. Summary of data collection, including number of samples collected, and sampling days for 1995 and 1996 at AFK Station SB2.

Data Collection	1995	1996
Sampling Dates (Julian)	107 - 170	97 - 169
Sampling Depths	0, 5, 10, 25, 50, 75	0, 5, 10, 25,50, 75
No. Sampling Days	64	73
CTD Casts	63	73
Secchi Depth Measurements	63	73
Chlorophyll a Concentration Measurements	372	437
Size Fractionation Measurements	0	68
Nitrate + Nitrite Concentration Measurements	372	438
Silicate Concentration Measurements	369	438
Phosphate Concentration Measurements	372	438
Species Composition and Abundance Measurements	73	80
Autotrophic Carbon Biomass Measurements	68	80

Table 2. Summary of data collection, including number of samples, for 1995 and 1996 from oceanographic cruises.

Data Collection	1995	1996
No. Cruises	5	3
No. Stations	153	112
Chlorophyll a Concentration Measurements	918	672
Size Fractionation Samples	329	0
Nitrate + Nitrite Concentration Measurements	918	672
Silicate Concentration Measurements	918	672
Phosphate Concentration Measurements	918	672
Species Composition and Abundance Samples	760	672

Table 3. Species list of diatoms and flagellates and their size ranges (μm) found in the upper 50 m during 1995 and1996 at AFK Station SB2.

DIATOMS	SIZE RANGE (lxw) μm	FLAGELLATES	SIZE RANGE (lxw) μm
Asterionella glacialis	10x5 -20x5	*Ceratium furca*	80x75
Biddulphia spp.	15x15	*Ceratium spp.*	20x12-90x90
Chaetoceros spp.	2.5x2.5 - 40x30	*Dinophysis spp.*	50x45
Chaetoceros deciprens	25x15 - 25x20	*Distephanus speculum*	20x20 - 25x25
Cocconeis spp.	40x20	*Ebria tripartita*	15x15-30x30
Coscinodiscus spp.	135 -190	*Oxytoxum sp.*	20x10 -40x15
Eucampia spp.	30x25 - 55x25	*Peridinium sp.*	20x15 - 65x50
Fragilariopsis sp.	10x2-15x2.5		
Grammatophora spp.	40x2.5-35x20	Unidentified flagellate	5 - 17.5
Leptocylindrus danicus	20x10- 85x10	Unidentified silicoflagellate	
Leptocylindrus minimus	20x2.5 - 35x2	Unidentified dinoflagellate	15x10- 60x20
Leptocylindrus spp.	35x5 - 40x7		
Licmophora glacialis			
Navicula spp.	20x5 - 80x5		
Pseudo-nitzschia spp.	30x2 -65x2		
Rhizosolenia fragilissima	15x5 - 35x5		
Rhizosolenia stolterforthii	45x8 - 60x10		
Rhizosolenia spp.	25x14 -500x15		
Skeletonema costatum	7.5x5 -17.5x5		
Stephanopyxis nipponica	30x20 - 60x20		
Thalassiosira spp.	10x7 - 55x15		
Thalassionema nitzschioides	25x5 -45x5		
Unidentified centric diatom	10x15-45x35		
Unidentified diatom	15x10 -130x15		
Unidentified pennate diatom	20x5 - 45x7		

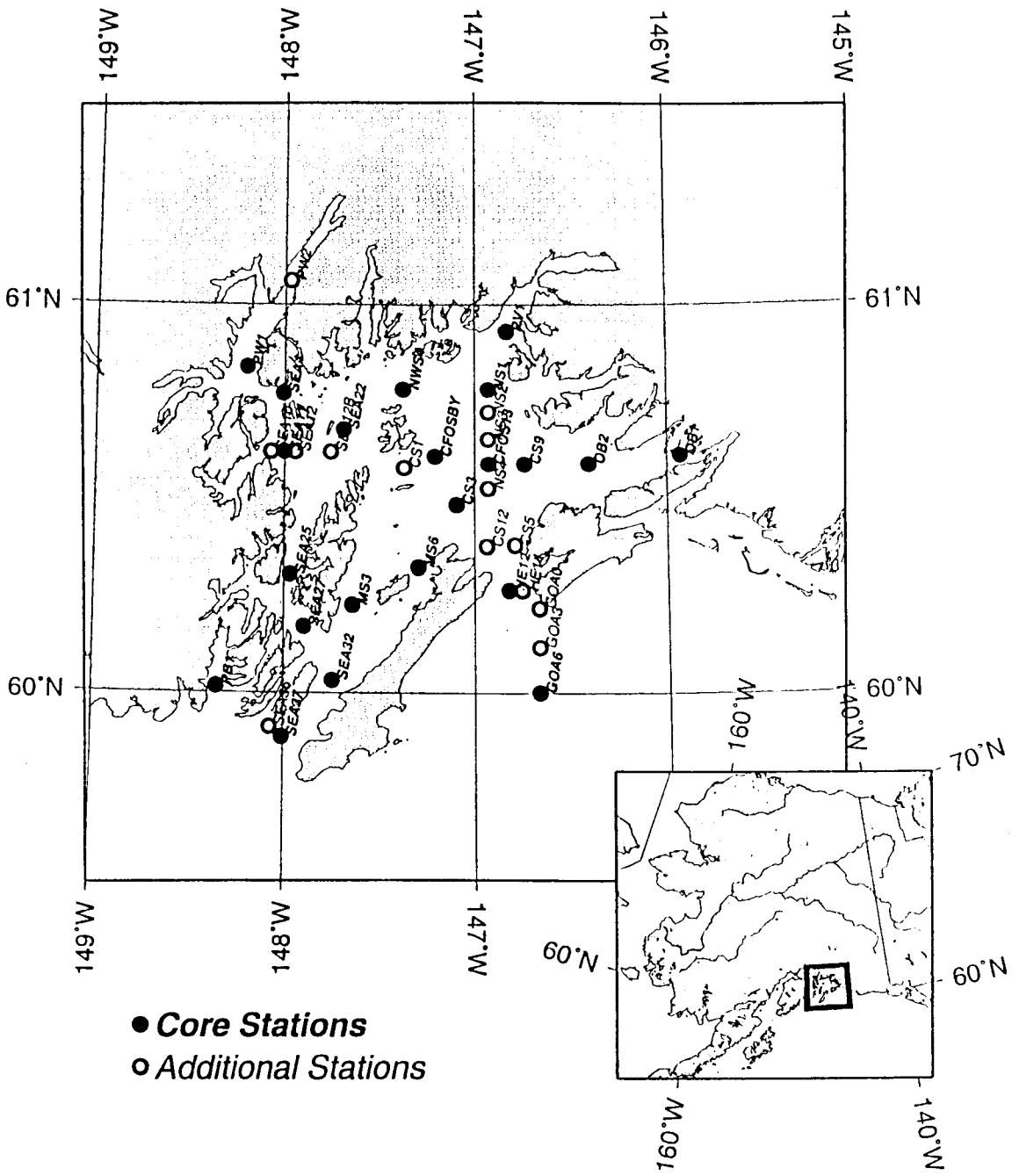

Figure 1. SEA 1996 station locations for phytoplankton and nutrient sample collection.

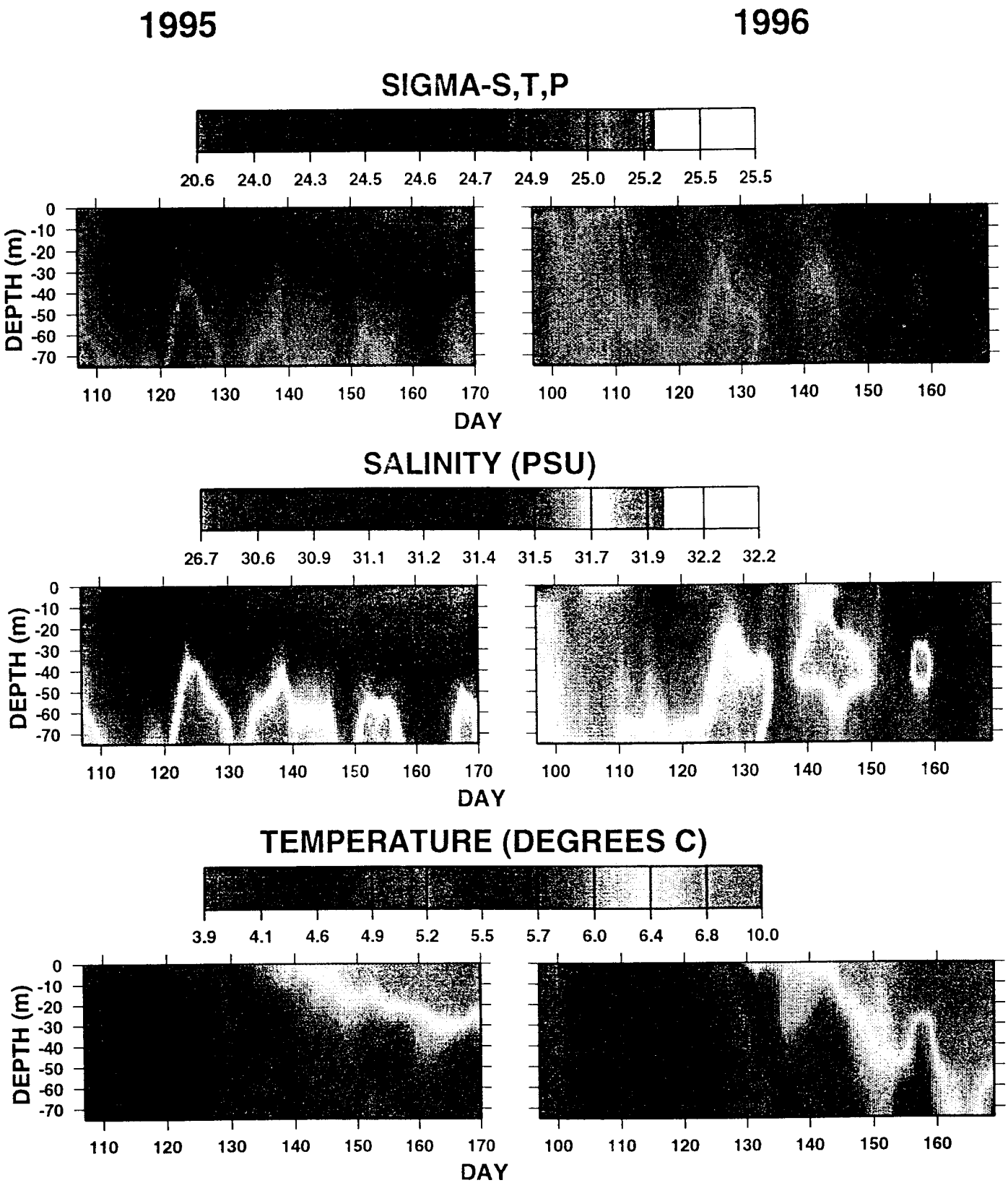

Figure 2. Time series of density (sigma-S,T,P), salinity (psu), and temperature (°C) for 07 Apr - 19 Jun 1995 (Days 97-170) and 06 Apr -17 Jun 1996 (Days 97-169) at Station AFK 96.2.

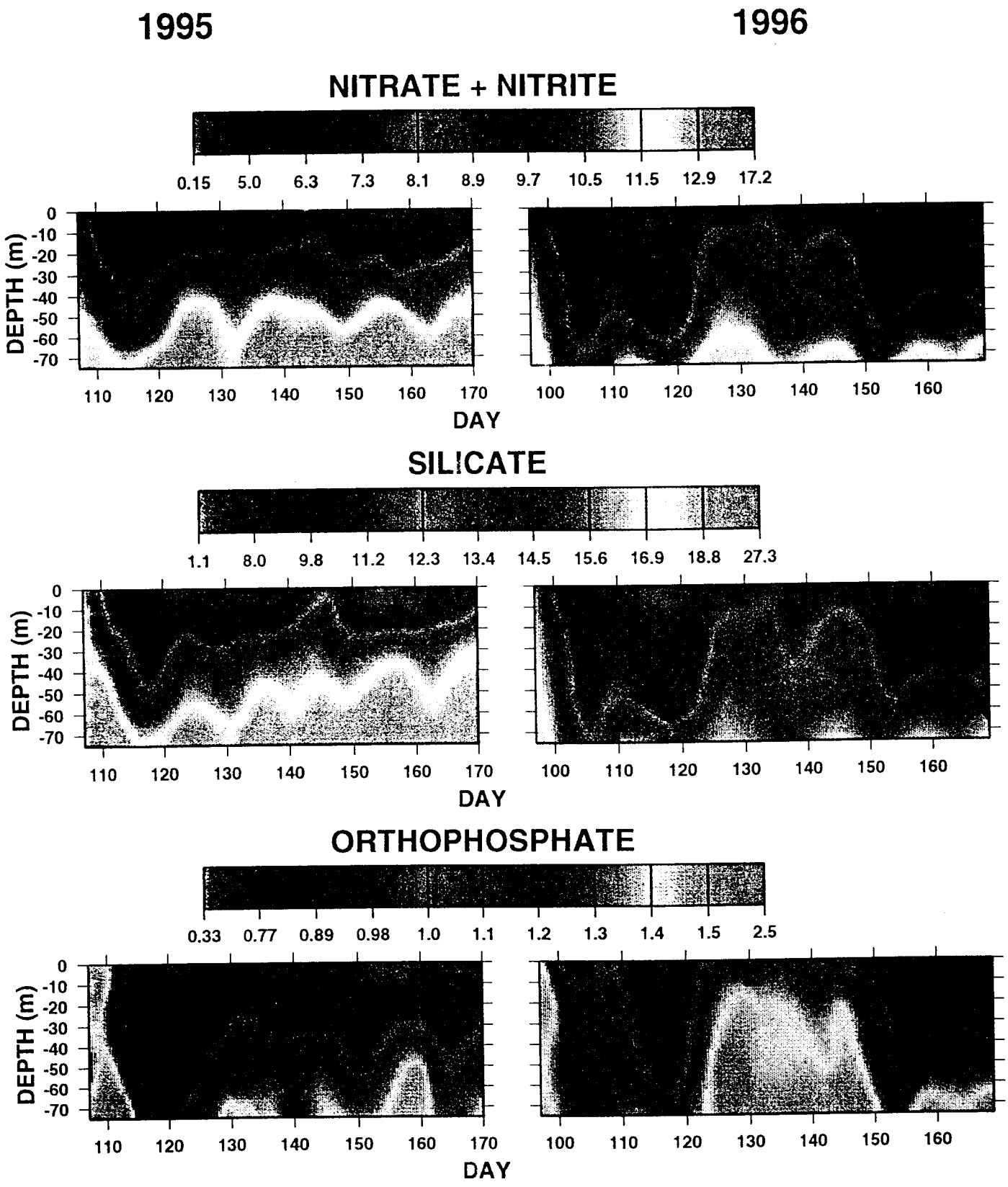

Figure 3. Time series of nutrients, Nitrate+Nitrite, Silicate and Orthophosphate (mmol m^{-2}) for 07 Apr - 19 Jun 1995 (Days 97-170) and 06 Apr -17 Jun 96 (Days 97-169) at Station AFK 96.2.

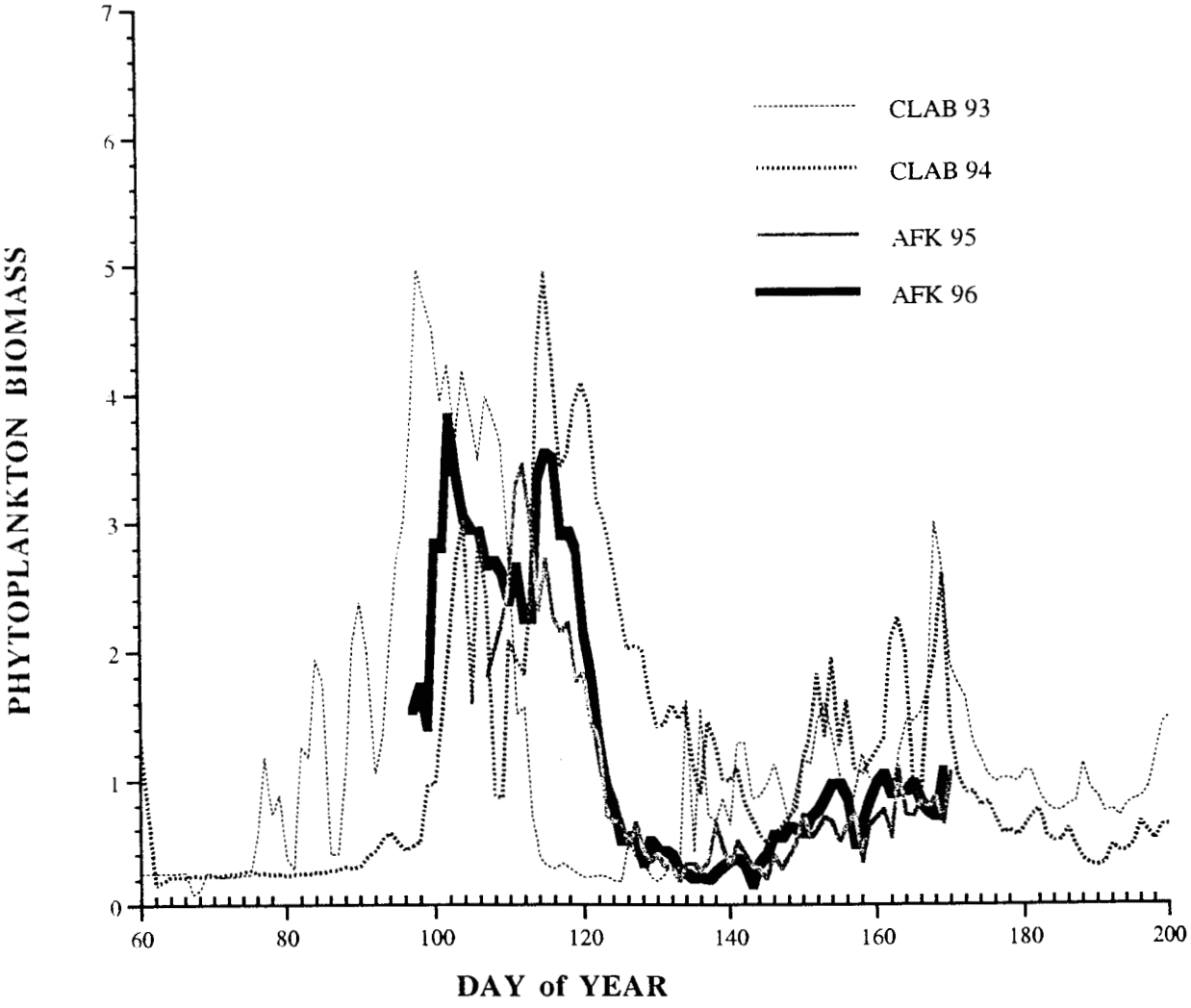

Figure 4. Comparison of phytoplankton time series for 1993 to 1996 in Prince William Sound (93 & 94 from CLAB buoy fluorometer; 95 & 96 from Station AFK96.2).

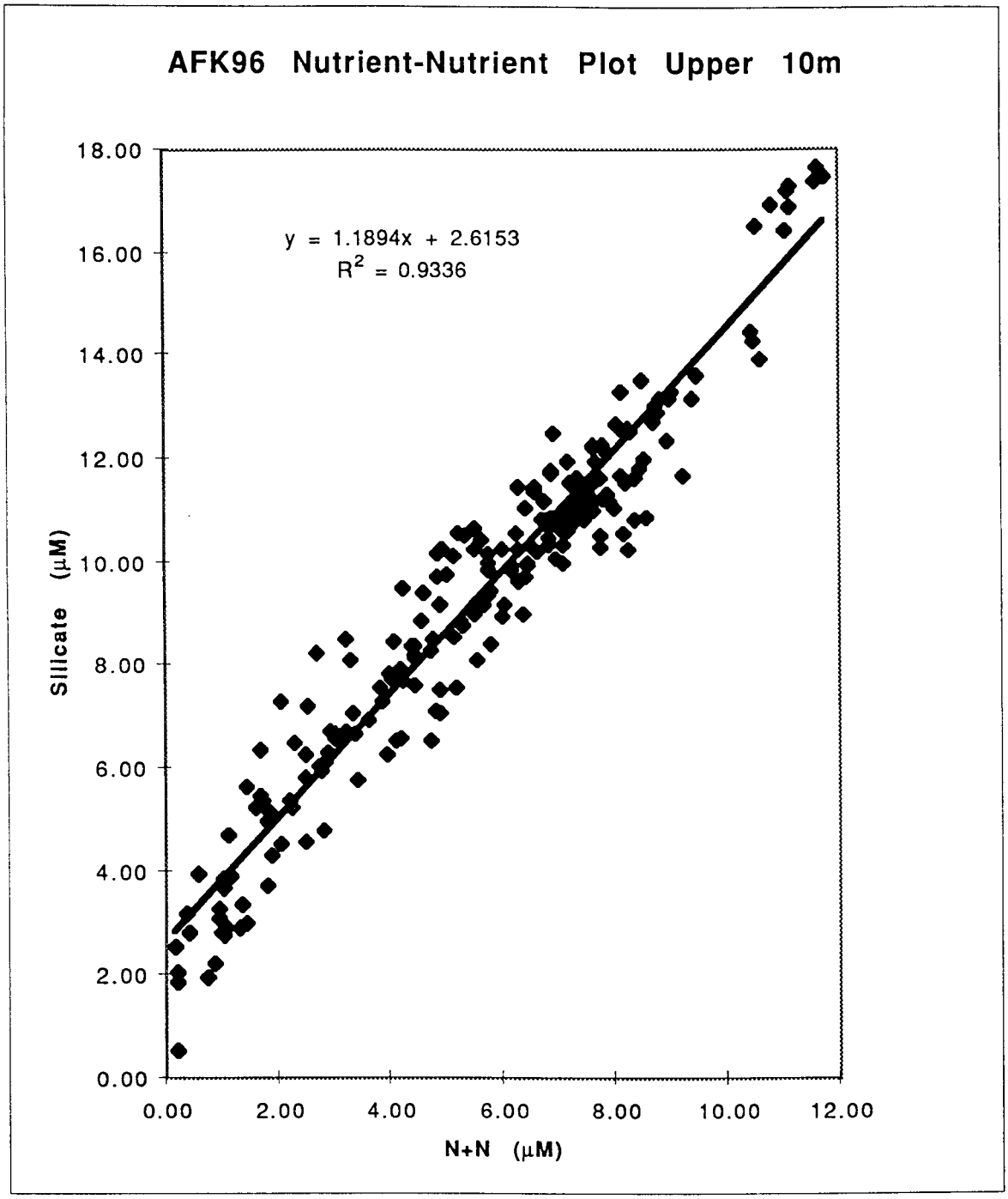

Figure 5. Nutrient-nutrient plot of N+N vs Silicate for the upper 10 m at Station AFK 96.2, 06 Apr -17 Jun 96 (Days 97-169).

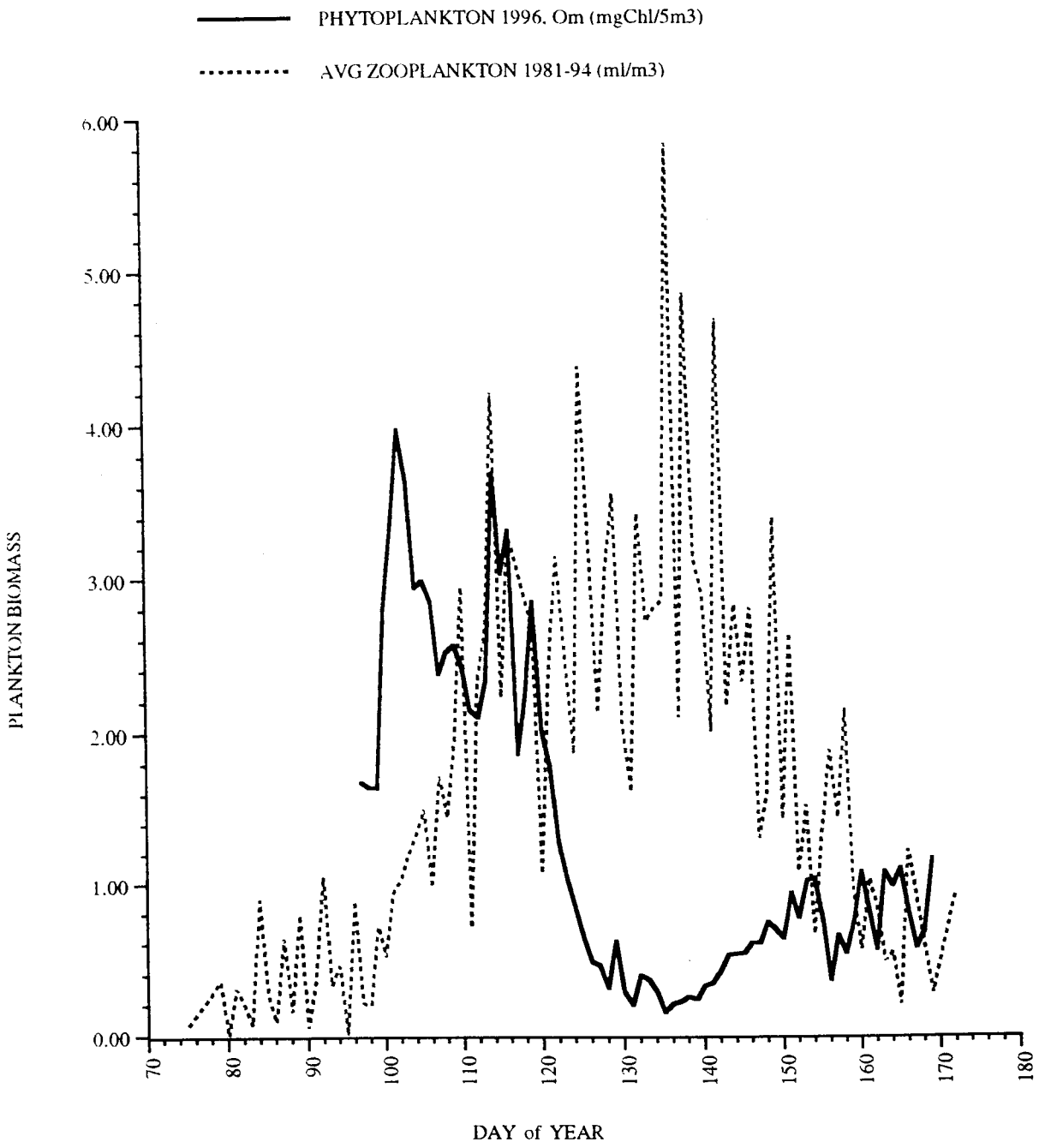

Figure 6. Time series of phytoplankton biomass (surface Chlorophyll a) from Station AFK96.2 and long-term average net zooplankton abundance near AFK hatchery.

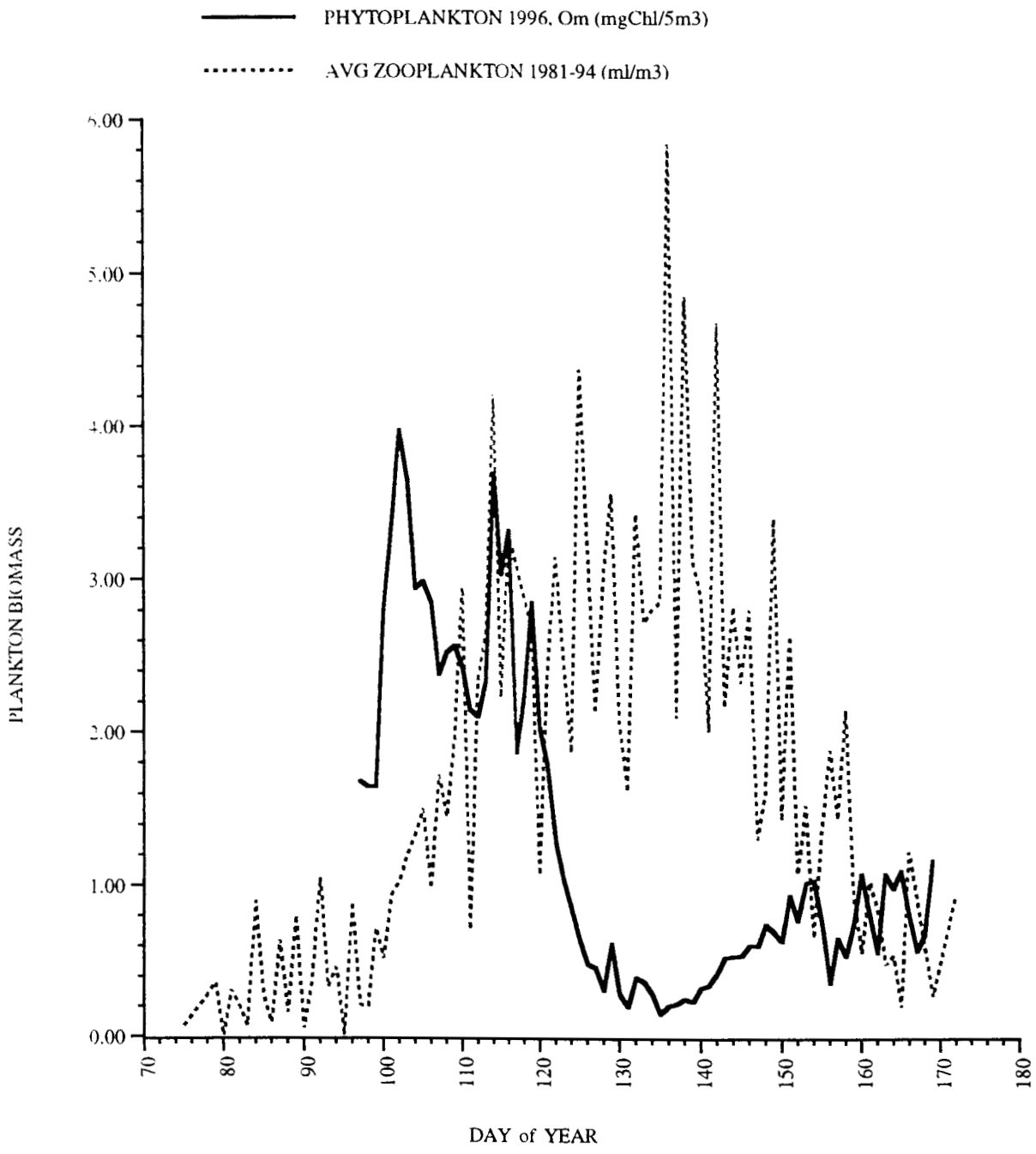

Figure 6. Time series of phytoplankton biomass (surface Chlorophyll a) from Station AFK96.2 and long-term average net zooplankton abundance near AFK hatchery.

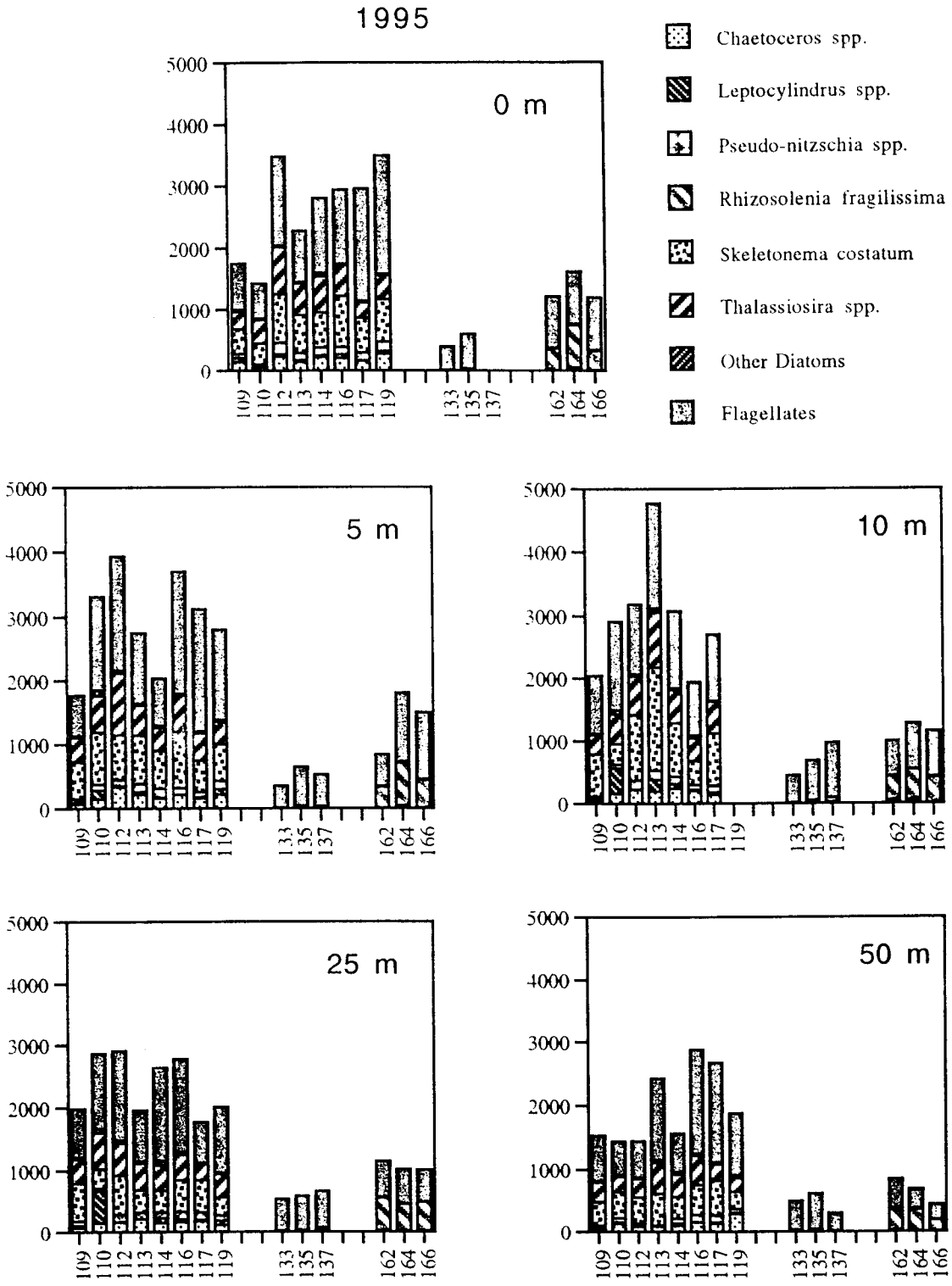

Figure 7. Abundance (cells/ml) of major diatoms and flagellates from 5 sample depths at Station AFK 95.2, during 19 Apr -15 Jun 95 (Days 110-167).

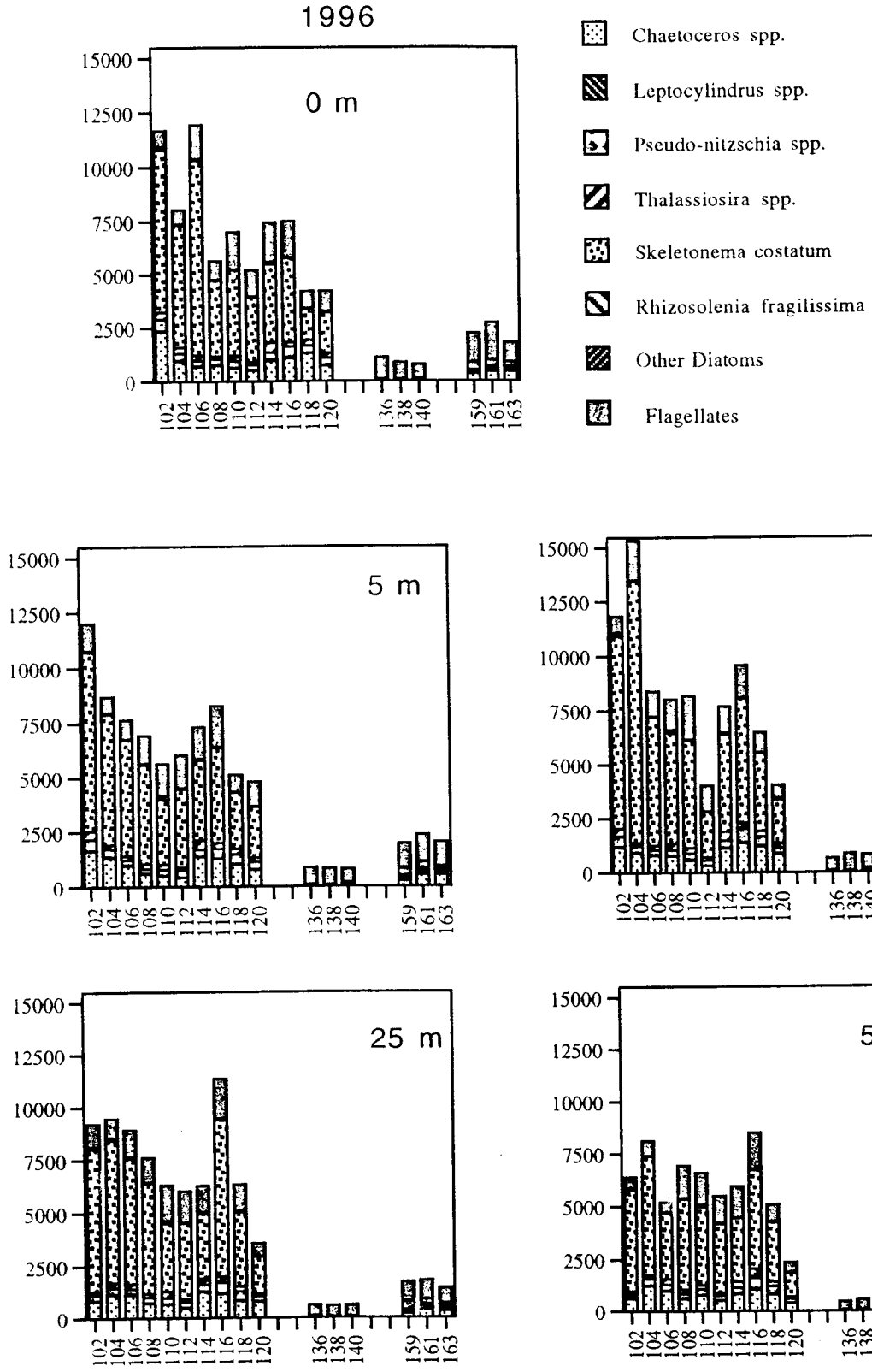

Figure 8. Abundance (cells/ml) of major diatoms and flagellates from 5 sample depths at Station AFK 96.2, during 11 Apr -11 Jun 96 (Days 102-163)

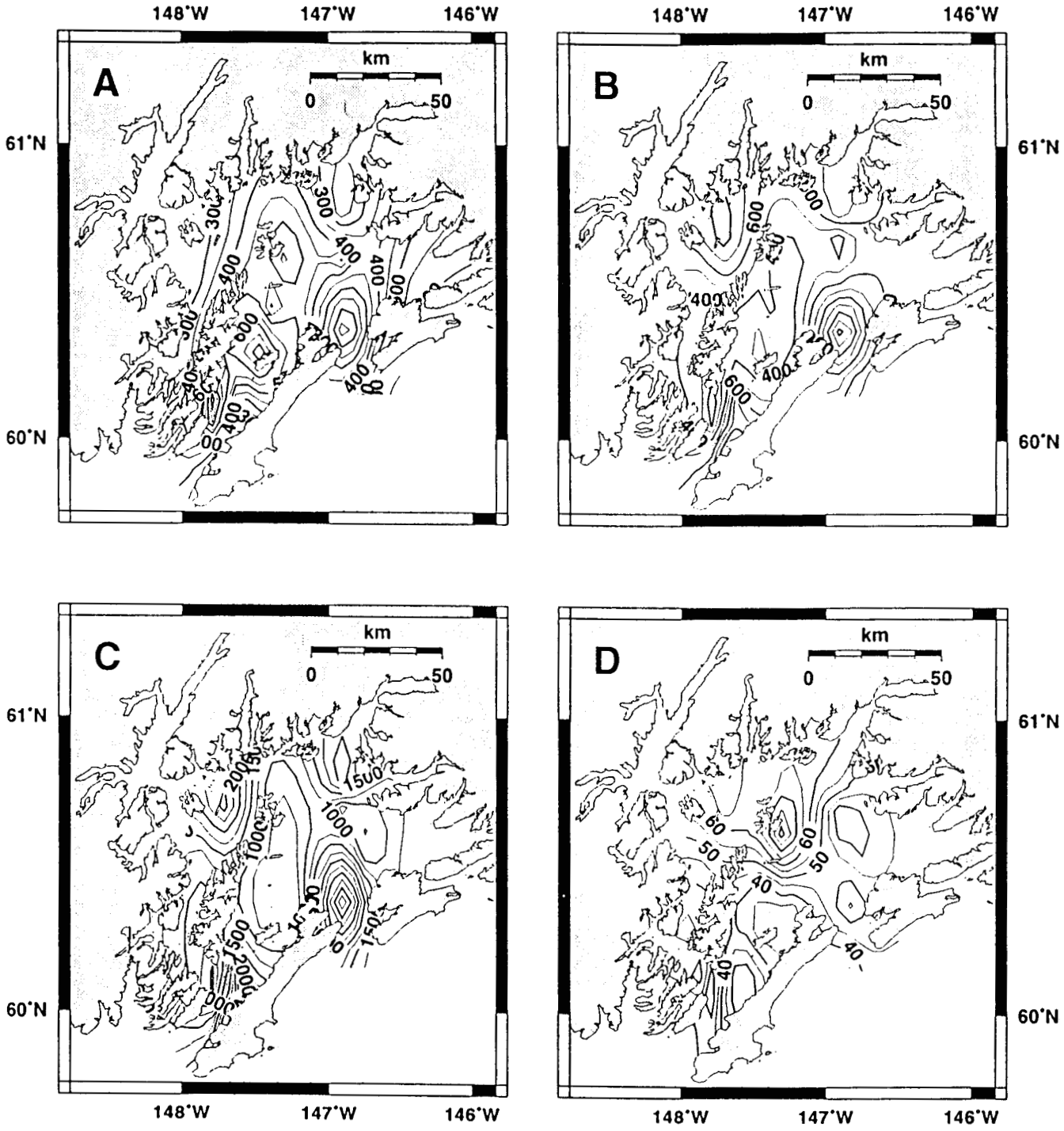

Figure 9. Distribution in Prince William Sound of integrated (upper 50 m) phytoplankton (mg/m^2) and nutrients ($mmol/m^2$) in April 1996: A. Chlorophyll a; B. N+N; C. Silicate; D. Orthophosphate.

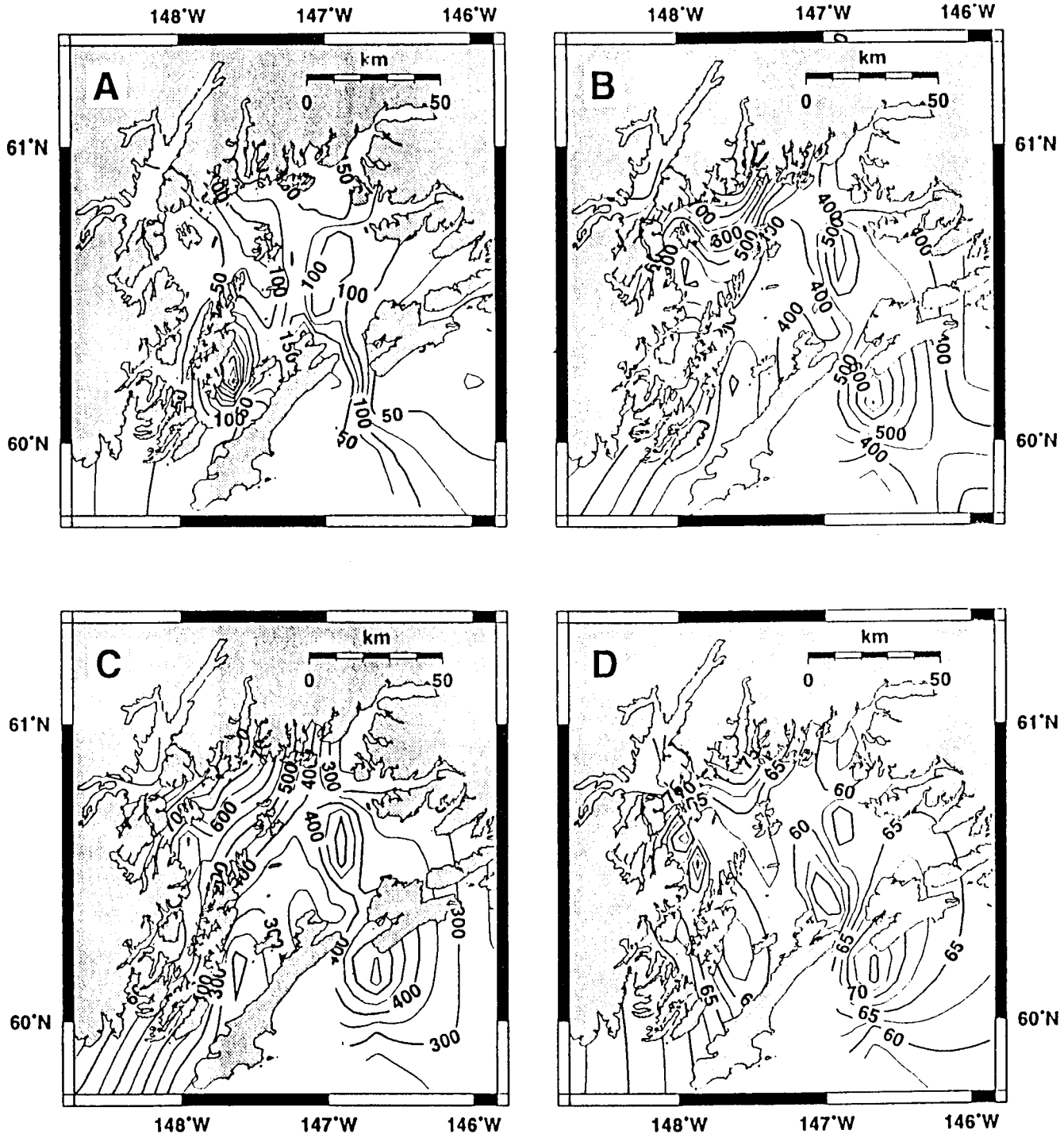

Figure 10. Distribution in Prince William Sound of integrated (upper 50 m) phytoplankton (mg/m^2) and nutrients ($mmol/m^2$) in May 1996: A. Chlorophyll a; B. N+N; C. Silicate; D. Orthophosphate.

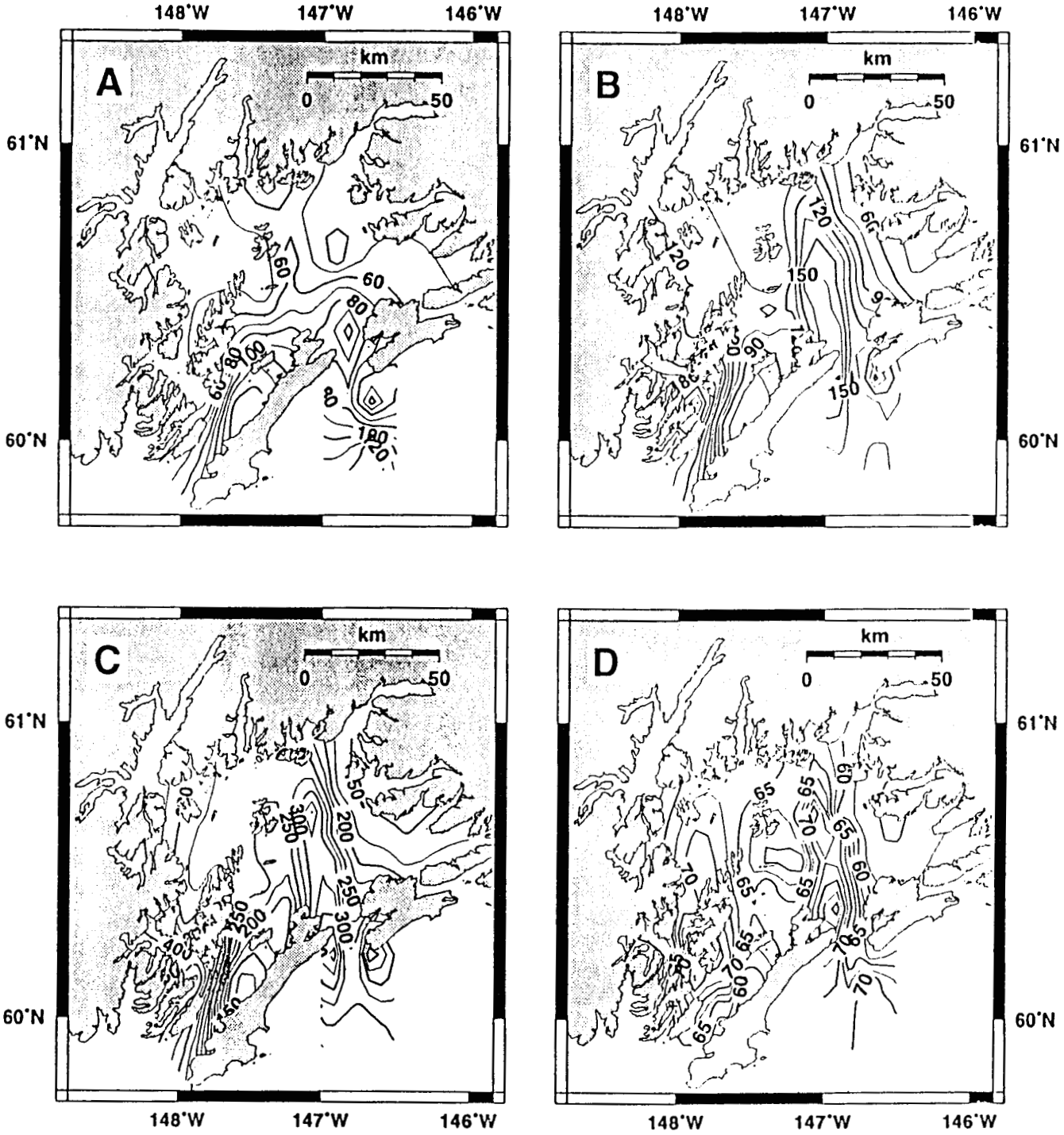

Figure 11. Distribution in Prince William Sound of integrated (upper 50 m) phytoplankton (mg/m^2) and nutrients ($mmol/m^2$) in June 1996: A. Chlorophyll a; B. N+N; C. Silicate; D. Orthophosphate.