

CHAPTER 3

94320-G Phytoplankton and Nutrients

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PHYTOPLANKTON AND NUTRIENTS  
PROJECT 9430G

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## **Abstract**

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.

In 1994 we collected 831 samples from several platforms including 6 cruises on chartered vessels and daily sampling at two locations at the Wally Noerenberg Hatchery on Ester Island. 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 (as cloud cover permits).

Because of administrative delays in project initiation, we were unable to place observers in the field before late May. The consequence of this is that only the moored instrument recorded the spring bloom of phytoplankton. All our other data is post-bloom and therefore, we presume, less significant in determining the transfer of energy to upper trophic levels.

In addition to collecting new data in 1994, we resurrected a large file of historical data collected in Prince William Sound from 1979 to 1989 by McRoy and colleagues. These data include 2867 samples of nutrients and chlorophyll from 359 oceanographic stations in the sound.

Our results confirm the reports of previous studies of the sound. The spring phytoplankton increase is strongly influenced by light and mixing. The subsequent decline of phytoplankton biomass is a result of nutrient, primarily nitrogen but possibly silicate, depletion and grazing. The timing of the increase varies by several weeks between years and this apparently transfers up the food web to other trophic levels. This is a mechanism for translating "lake" or "river" circulation modes into the food web. Close correlation occurred between the timing of the phytoplankton increase and the zooplankton biomass increase in 1993 and 1994.

## Introduction

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 production 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 SEA 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 and, after September 1994, use satellite-measured surface chlorophyll concentrations to determine the effect of advection on the observed chlorophyll field. In 1995 we are assuming 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.

## 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 1994 were:

1. Preliminary analysis of summer phytoplankton community ecology in PWS.
2. Preliminary estimation of basin-wide patterns of temperature, nutrients and chlorophyll from satellite and ship-board observations.
3. Provide data for interpretation of CLAB data and integrated modeling.
4. Develop field and laboratory sampling protocols in conjunction with other component projects.

## Methods

### a) 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.

### b) Phytoplankton Primary Production:

The biomass pattern provides a picture of what is present, but it does not provide information on the phytoplankton dynamics. In 1994 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  $^{14}\text{C}$  by phytoplankton in containers under neutral density filters (Strickland and Parsons, 1972; Parsons et al., 1984).

### c) 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 25 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 magnification, all visible cells in the sample are counted. On high magnification, fields are counted until a total of 300 cells is reached. The procedure is labor intensive and only a portion of the samples collected can be counted.

### d) 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.

d) Moored Instrument Array: The CLAB Buoy

In 1994 Dr. Cooney had responsibility for the CLAB moored instrument program. We assume this responsibility in 1995 and are working with Dr. Cooney to insure the quality of the data. The buoy continuously acquires wind speed and direction, barometric pressure, air temperature, sea surface temperature, chlorophyll fluorescence, and ocean temperature at 10 depths. The moored instruments provide a mechanism to integrate other discrete observations collected from ships.

e) 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.

f) Personnel:

The following people made data gathering and analysis possible:

B. Begeron	Technician
D. Clayton	Technician
C. Morrow	Technician
A. Ward	Graduate Student
M. Donovan	Graduate Student
G. Holmes	Graduate Student

## Results

### Sample Collection

The field season began in late May and extended until late September. Platforms for sample collection included ships and shore-based facilities. In 1994 we collected 831 samples from 6 cruises and 2 shore-based stations from a hatchery (Table 1). In addition, we resurrected data collected on a series of oceanographic cruises in Prince William Sound in 1979-89 (Table 2). The chartered vessels provided some geographical coverage of the sound for oceanographic and biological parameters although emphasis was on the southwestern portion of the region, the so-called 'survival bottleneck' region (see Appendices I and II for station locations). This region received more intensive study due to emphasis on predator/prey relationships.

The Phytoplankton-Nutrient Component database includes dissolved nutrients (nitrate+nitrite, phosphate, and silicate), dissolved oxygen, CTD (salinity, temperature, depth), chlorophyll *a*, and particulate carbon and nitrogen from all sampling platforms. Samples for phytoplankton enumeration are being processed but cell identification and counting is time consuming so results are slow to be tabulated. 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 Lake Bay (Ester Island) and with satellite temperature images to elucidate basin-wide patterns and processes.

A dual objective of the 1994 field season was to develop and implement sampling techniques for nutrients, chlorophyll and particulates that could be effectively used by platforms dedicated to other components. We have in place in Cordova and Fairbanks the readily deployable sampling equipment and protocols needed to collect samples for these measurements. We also demonstrated that the hatchery facilities can be used as a base to collect samples for these measurements.

### Time Series Measurements: CLAB Buoy Phytoplankton

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 (Figure 1.) The data describe a seasonal cycle of phytoplankton biomass that begins with a sharp increase in mid-April and an abrupt decline by the last week of May



**Table 1. Sample collections and types of analyses for the 1994 field season in Prince William Sound.**

<i>Platform</i>	<i>Dates</i>	<i>Stations</i>	<i>Samples</i>	<i>Analyses</i>
FV Alaska Beauty	4 May- 17 Jun	66	66	nutrients, CTD
FV Alaska Beauty	18-30 Jun	28	38	nutrients, CTD
FV Alaska Beauty	6-20 Jul	39	39	nutrients, CTD
FV Auklet	23 Jun- 17 Jul	55	55	nutrients, CTD
USCGS Sweet Briar	19-20 Jul	7	63	nutrients, CTD
MV Bering Explorer	18-28 Sep	43	215	nutrients, oxygen, chlorophyll, phyto species, CTD
WN Hatchery Ester Is.	28 May-23 Jul	71	355	nutrients, oxygen, chlorophyll, phyto species, particulate C/N, CTD
<b>TOTAL</b>		<b>309</b>	<b>831</b>	

**Table 2. Historical sample collections and analyses from Prince William Sound available to the SEA data base.**

<i>Platform</i>	<i>Dates</i>	<i>Stations</i>	<i>Samples</i>	<i>Analyses</i>
RV Acona	13-19 Jul 79	39	312	CTD, nutrients
RV Acona	14-25 Aug 79	24	192	CTD, nutrients
RV Acona	4-12 Dec 79	28	224	CTD, nutrients, chlorophyll
RV Alpha	11-25 Aug 80	47	376	CTD, nutrients
RV Alpha	11-21 Nov 80	70	560	CTD, nutrients
RV Alpha	3-11 Dec 80	36	324	CTD, nutrients
RV Alpha	2-18 Apr 89	44	352	CTD, nutrients, chlorophyll, primary productivity
RV Alpha	5-11 May 89	41	287	CTD, nutrients, chlorophyll, primary productivity
RV Alpha	1 - 7 Jun 89	30	240	CTD, nutrients, chlorophyll, primary productivity
<b>TOTAL</b>		<b>359</b>	<b>2867</b>	

# Time Series Stations

1994

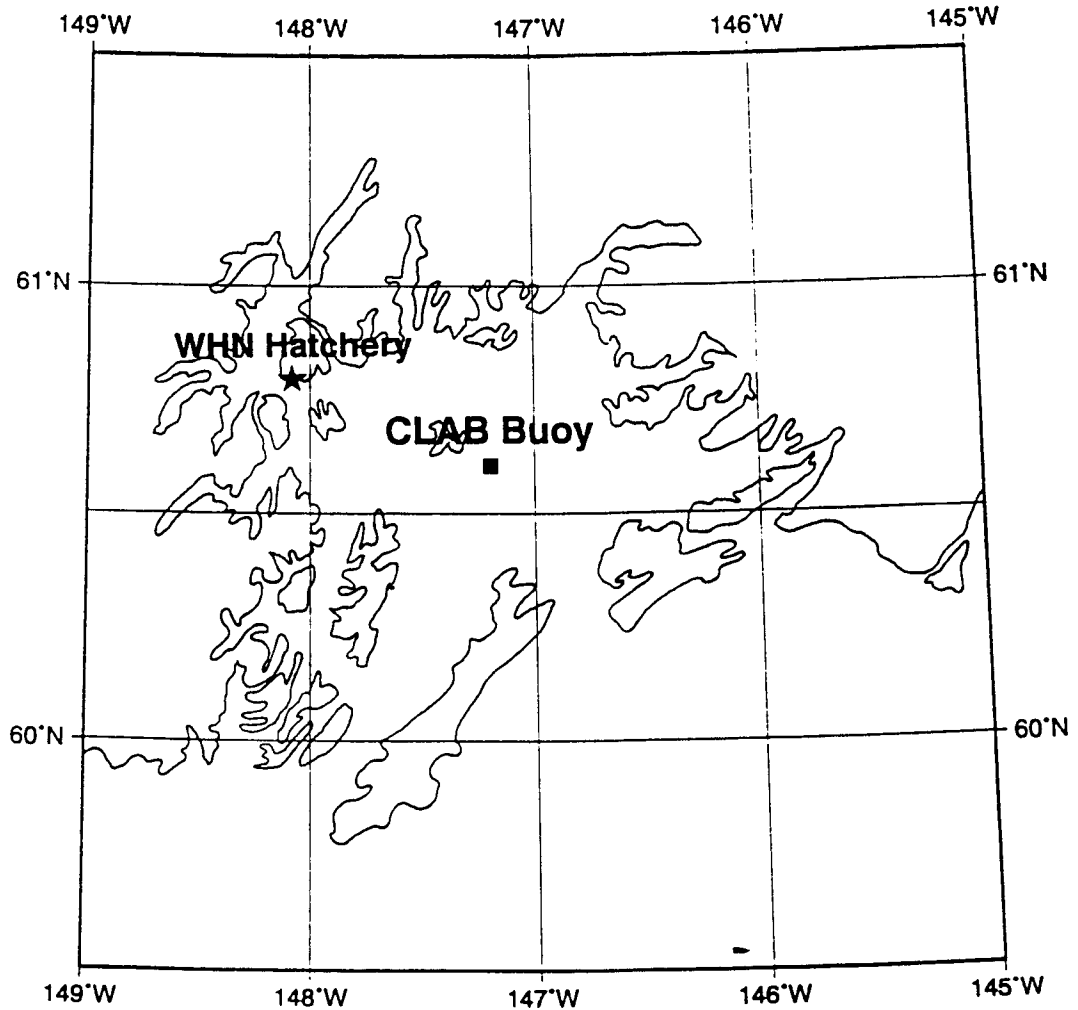


Figure 1. Location of time series stations (Wally Noerenberg Hatchery in Lake Bay, Ester Island and the CLAB Buoy) in Prince William Sound for 1994.

(Figure 2). 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.

#### **Time Series Measurements: WHN Hatchery Phytoplankton**

The other time series data in 1994 were collected in Lake Bay (WHN Hatchery) on Ester Island from 28 May to 23 July. This site is very different from the buoy. The CLAB buoy is an open, deep water area and Lake Bay is a protected, land-influenced, shallow water site. These data are actual chlorophyll *a* determinations so they are a direct proxy for phytoplankton biomass (Figure 3). The data series begins on 28 May so it describes the phytoplankton cycle following the major spring increase. The first point in the series is very high and probably suspect, but otherwise the trend of biomass is reasonably well correlated to the cycle described by the CLAB mooring. Both stations show a general decline as summer progresses but small increases occur at both locations, presumably due to mixing events. The increase at the CLAB location precedes that at Lake Bay by a few days, suggesting a propagation of the mixing event from open water shoreward.

The time series data for phytoplankton biomass, particulate organic nitrogen and particulate organic carbon were examined for close correlations to each other and to oceanographic parameters (Table 3). In the linear regression analysis, significant relationships ( $r^2$  above 0.5) occurred between POC and PON and both with chlorophyll (Figure 10). No close relationship was found with nutrients or other oceanographic parameters indicating that the forcing functions are either not linear or not included in the analysis (e.g., zooplankton grazing). The close relationship between POC and PON is of course expected; that both are directly related to the chlorophyll measurement indicates that the phytoplankton were a major component of the small particulate fraction as sampled, again reassuring.

#### **Time Series Measurements: Nutrients and Particulates**

Samples for nutrient analysis were collected from Lake Bay and from several of the chartered vessels used by other components of SEA. Data are presented as plots of nutrient vs. nutrient (e.g., nitrate vs. phosphate) since these relationships can reveal both the

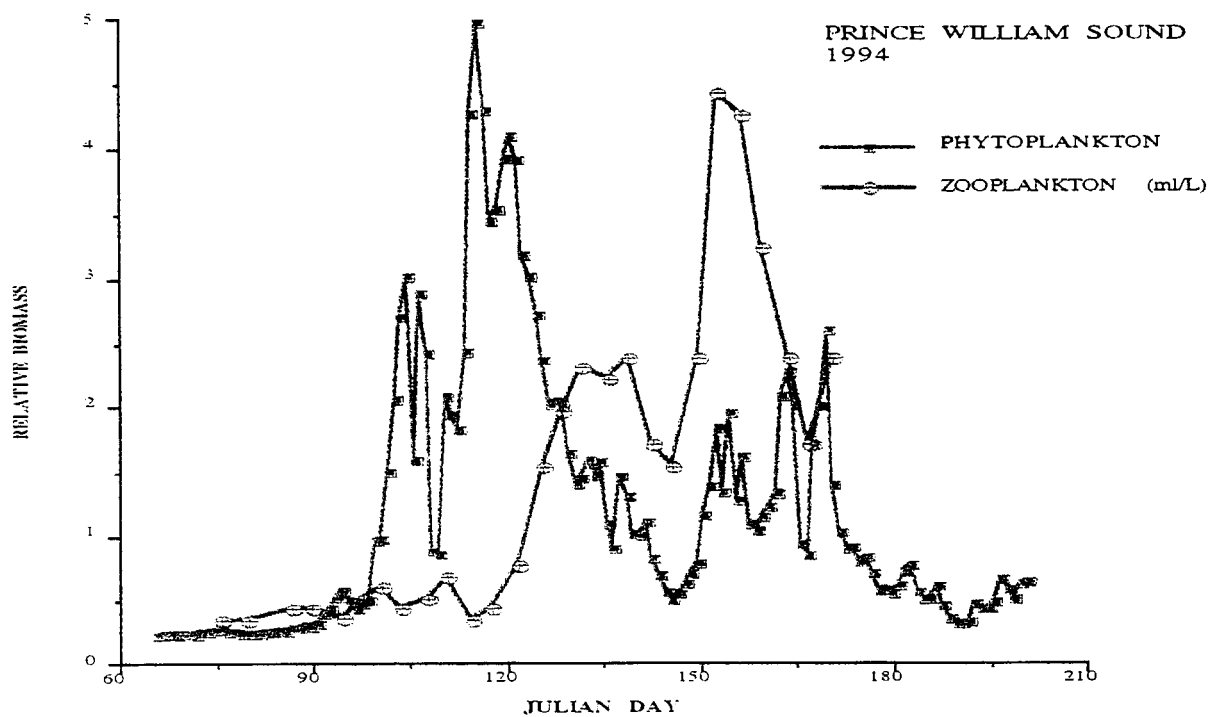
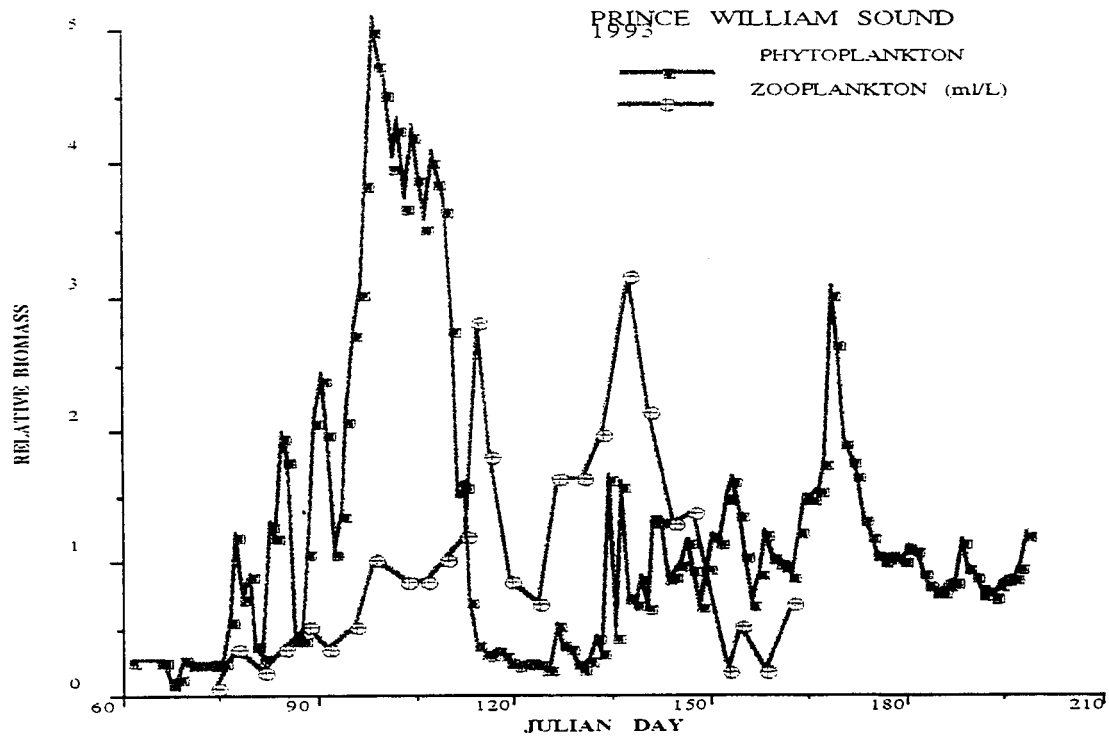


Figure 2. Phytoplankton biomass (from CLAB Buoy) compared to net zooplankton (from AFK Hatchery, Cooney unpubl. data) for 1993 and 1994.

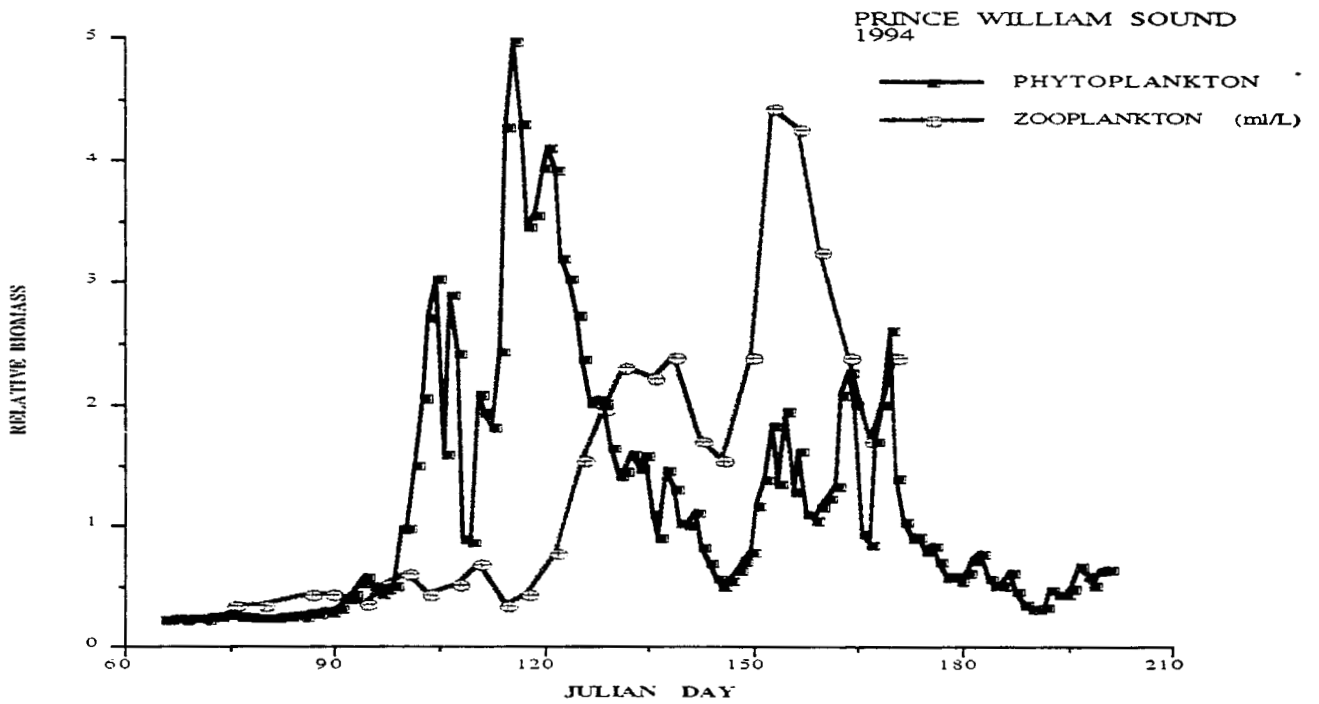
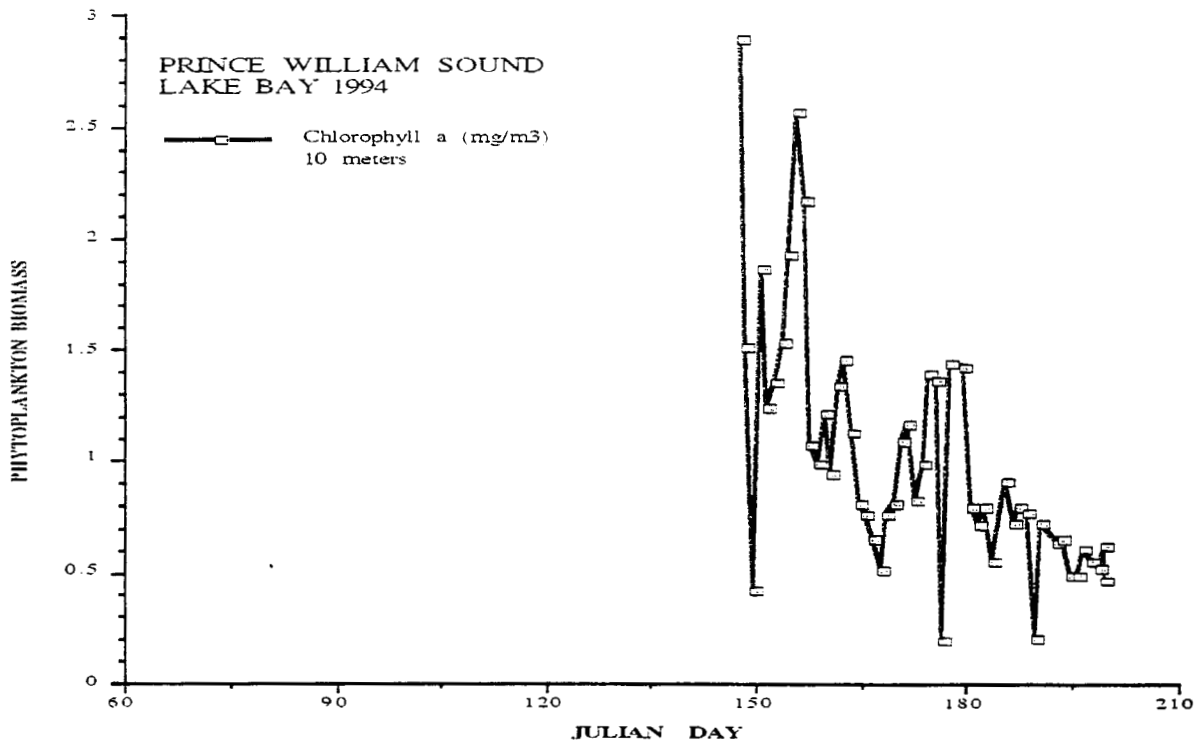


Figure 3. Phytoplankton biomass (chlorophyll a) in Lake Bay (WN Hatchery) compared to CLAB phytoplankton (fluorometer) and net zooplankton (AFK, Cooney, unpublished) for 1994.

Table 3. Comparison of predictive relationships between phytoplankton, particulates and ocean parameters for 1994 in Lake Bay (WNH) Prince William Sound ranked by R<sup>2</sup> values. Relationships with R<sup>2</sup> values above 0.50 are highlighted.

Platform	Julian Dates	Parameter X	Parameter Y	Regression Equation	R <sup>2</sup>
WNH 1	148-204	POC	PON	-0.35+0.17X	0.91
WNH 2	148-204	POC	PON	-0.07+0.15X	0.85
WNH 2	148-204	Chlorophyll	PON	5.60+11.22X	0.54
WNH 1	148-204	Chlorophyll	POC	48.16+59.01X	0.53
WNH 1	148-204	Chlorophyll	PON	7.10+10.61X	0.53
WNH 2	148-204	Chlorophyll	POC	41.87+67.65X	0.52
WNH 2	148-204	Chlorophyll	Temperature	14.53-4.62X	0.40
WNH 1	148-204	Chlorophyll	N+N	7.81-5.33X	0.32
WNH 1	148-204	PON	Oxygen	4.14+0.29X	0.32
WNH 2	148-204	POC	C/N	7.88-X	0.3
WNH 1	148-204	Chlorophyll	Phosphate	0.93-0.47X	0.28
WNH 1	148-204	Chlorophyll	Silicate	10.99-5.47X	0.27
WNH 1	148-204	PON	Temperature	17.30-0.30X	0.27
WNH 2	148-204	PON	Temperature	14.74-0.20X	0.26
WNH 2	148-204	Chlorophyll	Oxygen	6.79+2.93X	0.24
WNH 2	148-204	PON	Oxygen	6.24+0.17X	0.24
WNH 2	148-204	Chlorophyll	C/Chl	545-454X	0.22
WNH 1	148-204	POC	Temperature	16.98-0.04X	0.22
WNH 2	148-204	PON	C/N	8.76-0.13X	0.22
WNH 1	148-204	POC	Oxygen	4.96+0.04X	0.20
WNH 2	148-204	Chlorophyll	N+N	8.32-6.41X	0.19
WNH 1	148-204	Chlorophyll	Oxygen	6.89+2.88X	0.18
WNH 2	148-204	C/N	C/Chl	-394+95.7X	0.18
WNH 1	148-204	Chlorophyll	C/Chl	374-226X	0.17
WNH 2	148-204	Chlorophyll	Phosphate	0.86-0.42X	0.15
WNH 2	148-204	POC	Oxygen	6.66+0.02X	0.15
WNH 2	148-204	POC	Temperature	14.12-0.02X	0.15
WNH 1	148-204	Chlorophyll	Temperature	14.18-2.85X	0.14
WNH 1	148-204	PON	C/N	7.10-0.06X	0.14
WNH 2	148-204	Chlorophyll	Silicate	11.32-6.35X	0.13
WNH 2	148-204	PON	C/Chl	564-22.9X	0.12
WNH 2	148-204	POC	C/Chl	554-3.28X	0.10
WNH 2	148-204	C/N	Temperature	7.42+0.67X	0.10
WNH 1	148-204	POC	C/Chl	391-2.04X	0.09
WNH 1	148-204	PON	C/Chl	369-10.6X	0.08
WNH 1	148-204	C/N	Oxygen	15.13-0.96X	0.08
WNH 2	148-204	Chlorophyll	C/N	7.82-1.14	0.07
WNH 2	148-204	C/N	Oxygen	11.81-0.48X	0.07
WNH 1	148-204	Chlorophyll	C/N	6.54-0.47X	0.04
WNH 1	148-204	POC	C/N	6.64-X	0.03
WNH 1	148-204	C/N	Temperature	9.25+0.43X	0.01
WNH 1	148-204	C/N	C/Chl	193+3.09X	0.0

general type of phytoplankton (e.g., diatoms or flagellates) and the limiting conditions. As with the phytoplankton data, all nutrient data are subjected to regression analysis to identify fortuitous or causal relationships (Table 4).

Strong correlation, an  $r^2$  of 0.9 in many cases, exists between nitrate-nitrite and silicate in Lake Bay water samples and in other samples from the sound no matter the depth, location or time (Figures 4, 5, 6, and 7). Similarly strong correlation occurs between nitrate-nitrite and phosphate and between silicate and phosphate for Lake Bay and other regions. These relationships indicate close coupling between phytoplankton, the microbial community and dissolved inorganic nutrients, i.e., the nutrient content of upper-layer waters in summer reflects biological activity (mineralization) rather than advection. In addition, the close correlation between silicate and nitrate shows that the major constituent of the phytoplankton community is diatoms, a result that the cell counts confirm. The Lake Bay data also suggest that the phytoplankton is ultimately limited by nitrogen (Figure 4), but in some areas silicate may be the limiting nutrient (e.g., Figure 5).

A correlation between dissolved oxygen and temperature exists at one station in Lake Bay but this trend was not consistent in the data set so it may indeed be fortuitous (Figure 11).

#### **Time Series Measurements: Phytoplankton Community**

The counting and identification of phytoplankton cells is a laborious procedure that continues. Obviously, it is much easier to collect a sample of water than it is to count and identify everything in it. So far about 18% of the samples collected for community composition have been enumerated and identified (Table 5). A species list is developing but more samples must be processed to present adequate quantitative results. Generally, the summer phytoplankton community consists of small-cell species of flagellates and diatoms.

#### **Spatial Measurements: Current and Historical**

Spatial coverage of the sound in spring and summer of 1994 was restricted by the availability of sample platforms. Using the other SEA project vessels, we obtained a single depth sample series from the western sound during the trawling cruises. Only in September did we get more detailed coverage of the entire sound (Appendix I).

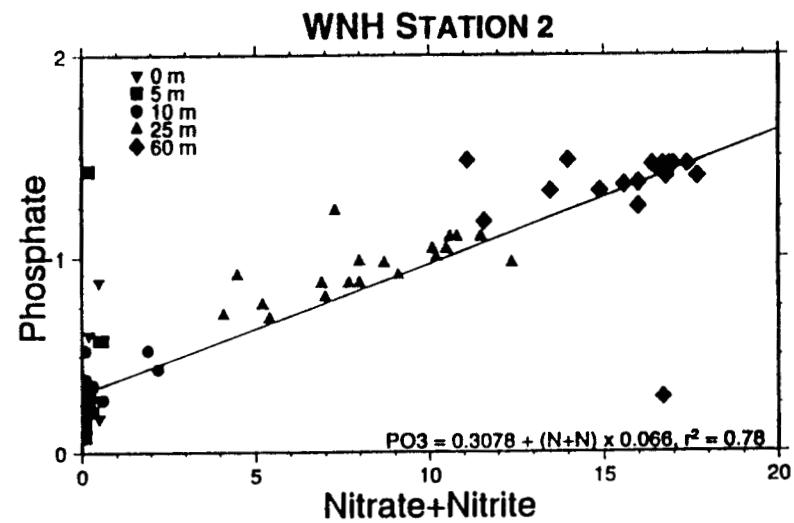
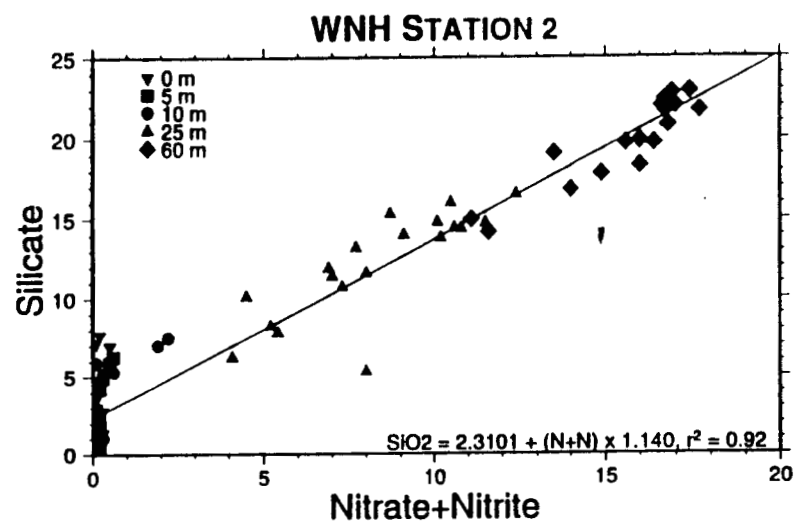
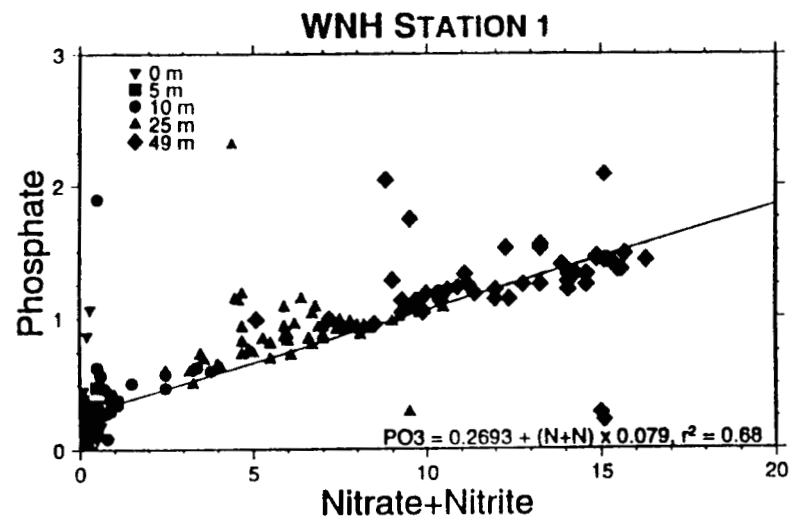
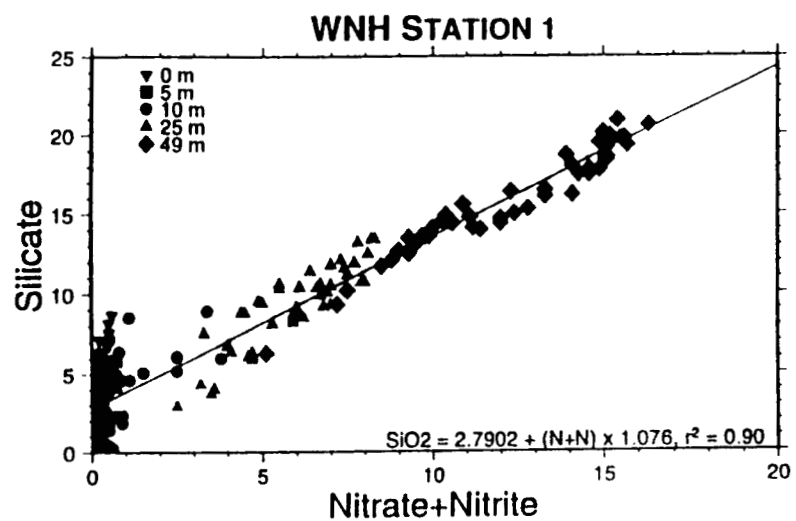
In May nutrients were somewhat low in the western sound with a pattern of increasing concentrations from north to south;

Table 4. Comparison of predictive relationships between nutrients and ocean parameters for 1994 in Lake Bay (WNH) and other areas (see cruise tracks) of Prince William Sound ranked by R<sup>2</sup> values. Relationships with R<sup>2</sup> values above 0.50 are highlighted.

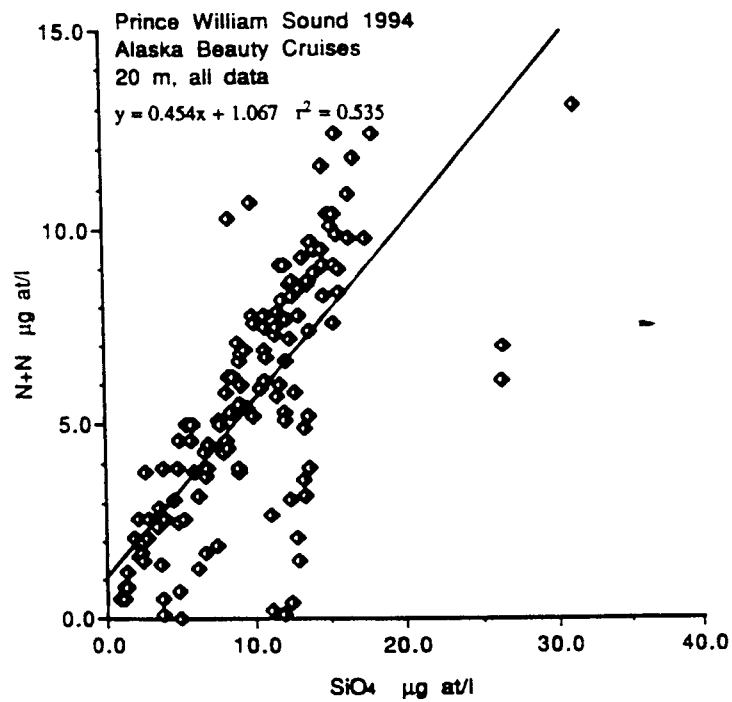
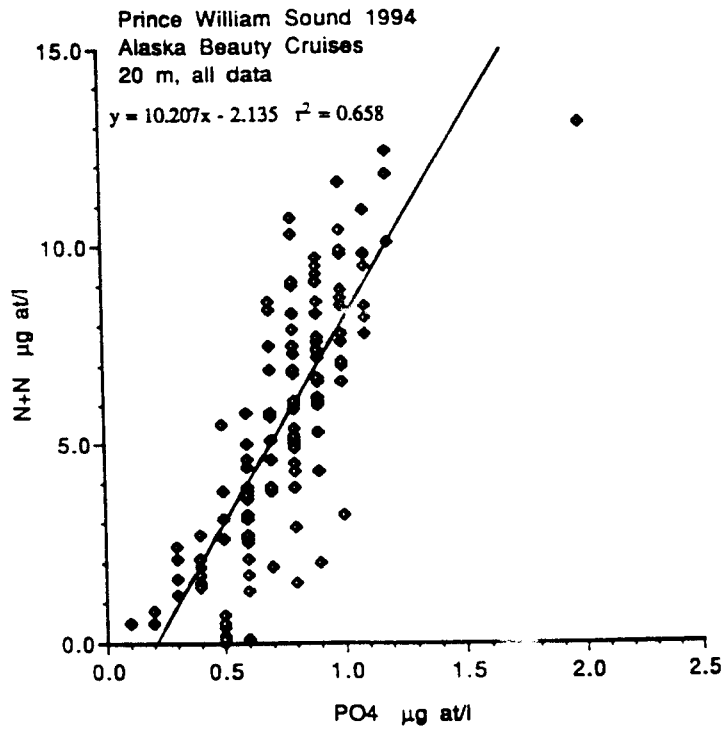
<i>Platform</i>	<i>Julian Dates</i>	<i>Parameter X</i>	<i>Parameter Y</i>	<i>Regression Equation</i>	<i>R<sup>2</sup></i>
WNH 2	148-204	N+N	Silicate	2.31+1.14X	0.92
WNH 1	148-204	N+N	Silicate	2.79+1.08X	0.90
S. BRIAR	200-201	Phosphate	N+N	13.41X-4.50	0.90
S. BRIAR	200-201	Silicate	N+N	0.91X-3.91	0.87
WNH 2	148-204	N+N	Phosphate	0.31+0.07X	0.78
AUKLET	174-201	Silicate	N+N	0.57X+0.12	0.78
WNH 2	148-204	Phosphate	Silicate	-0.81+13.63X	0.75
WNH 1	148-204	N+N	Phosphate	0.27+0.08X	0.68
AK BEAUTY	124-201	Phosphate	N+N	10.21X-2.14	0.66
WNH 1	148-204	Phosphate	Silicate	1.75+9.05X	0.59
WNH 2	148-204	Oxygen	Temperature	19.70-0.91X	0.59
WNH 1	148-204	N+N	POC	114-6.63X	0.57
WNH 1	148-204	N+N	PON	19.27-1.16X	0.54
AK BEAUTY	124-201	Silicate	N+N	0.45X+1.07	0.53
WNH 1	148-204	Phosphate	POC	125-64.4X	0.51
WNH 1	148-204	Silicate	POC	125-5.31X	0.47
WNH 1	148-204	Phosphate	PCN	21.12-10.9X	0.46
WNH 1	148-204	Silicate	PCN	21.03-0.89X	0.42
WNH 2	148-204	N+N	PCN	15.14-0.68X	0.37
AUKLET	174-201	Phosphate	N+N	6.79X+0.40	0.37
WNH 2	148-204	N+N	POC	99-3.86X	0.35
WNH 2	148-204	N+N	Temperature	12.89-4.07X	0.35
WNH 2	148-204	Silicate	Oxygen	7.61+0.44X	0.35
WNH 1	148-204	Temperature	Oxygen	17.72-0.63X	0.31
WNH 2	148-204	Silicate	Temperature	12.94-0.47X	0.29
WNH 2	148-204	Silicate	POC	103-2.89X	0.28
WNH 2	148-204	Silicate	PCN	15.70-0.46X	0.27
WNH 2	148-204	N+N	C/Chl	130+34.3X	0.26
WNH 1	148-204	N+N	Temperature	12.98-3.35X	0.25
WNH 2	148-204	Phosphate	POC	108-42.4X	0.24
WNH 2	148-204	Phosphate	PCN	16.37-6.81X	0.24
WNH 2	148-204	Silicate	C/Chl	78.62+27.54X	0.23
WNH 1	148-204	Silicate	Oxygen	7.54+0.55X	0.23
WNH 2	148-204	Phosphate	C/Chl	36.0+415X	0.22
WNH 1	148-204	N+N	Oxygen	8.39+2.73X	0.21
WNH 2	148-204	N+N	Oxygen	7.97+2.53X	0.19
WNH 2	148-204	N+N	C/N	6.56+0.12X	0.18
WNH 1	148-204	Silicate	Temperature	13.43-0.49X	0.18
WNH 2	148-204	Silicate	C/N	6.41+0.10X	0.15
WNH 1	148-204	N+N	C/Chl	126+22.0X	0.14
WNH 2	148-204	Phosphate	Oxygen	7.78+2.61X	0.13
WNH 1	148-204	Phosphate	C/Chl	86.5+214X	0.12



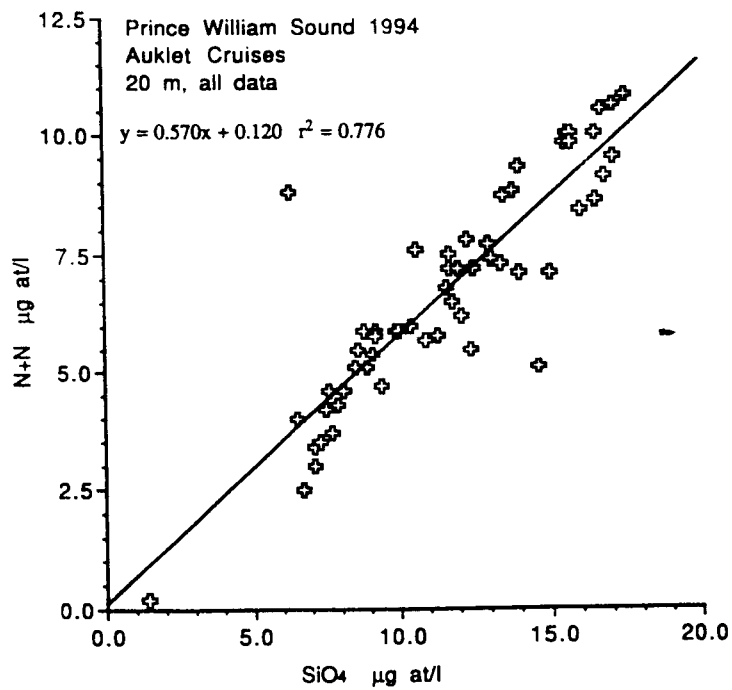
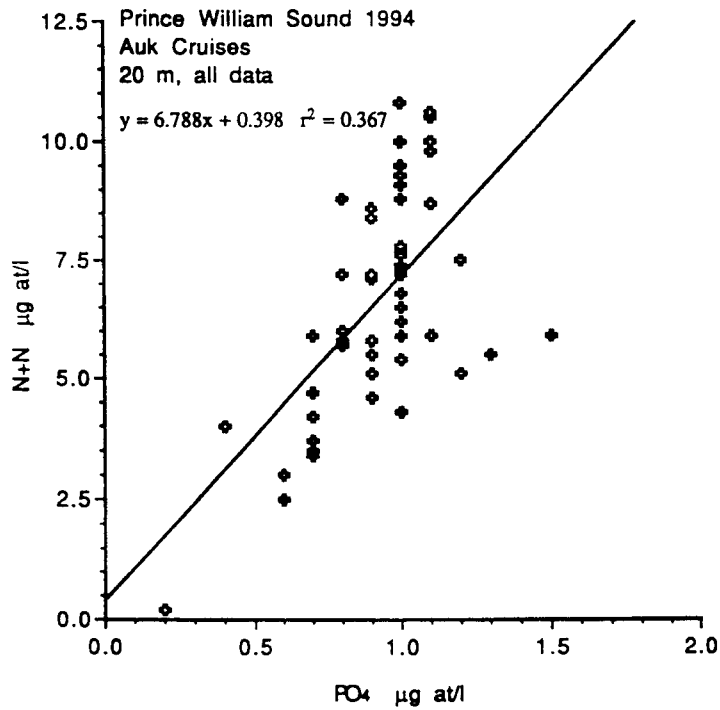
<b>Table 4. cont. Platform</b>	<b>Julian Dates</b>	<b>Parameter X</b>	<b>Parameter Y</b>	<b>Regression Equation</b>	<b>R<sup>2</sup></b>
WNH 2	148-204	Phosphate	C/N	6.36+1.27X	0.10
WNH 1	148-204	N+N	C/N	5.93+0.07X	0.08
WNH 2	148-204	Phosphate	Temperature	12.59-2.29X	0.07
WNH 1	148-204	Phosphate	Temperature	12.61-3.01X	0.05
WNH 1	148-204	Silicate	C/N	5.89+0.44X	0.04
WNH 1	148-204	Phosphate	C/N	5.98+0.38X	0.02
WNH 1	148-204	Phosphate	Oxygen	8.89+1.73X	0.02



**Figure 4. Nutrient-nutrient plots for water samples collected from stations 1 & 2 in Lake Bay (Wally Noerenberg Hatchery) during 28 May to 17 July 1994.**



**Figure 5. Nutrient-nutrient plots (Nitrate+Nitrite vs. Phosphate, upper; Nitrate+Nitrite vs. Silicate, lower) for water samples from 20 m collected during F/V Alaska Beauty cruises in May and June 1994 (see Appendix I for stations).**



**Figure 6. Nutrient-nutrient plots (Nitrate+Nitrite vs. Phosphate, upper; Nitrate+Nitrite vs. Silicate, lower) for water samples from 20 m collected during F/V Auklet cruises in June 1994 (see Appendix I for stations).**

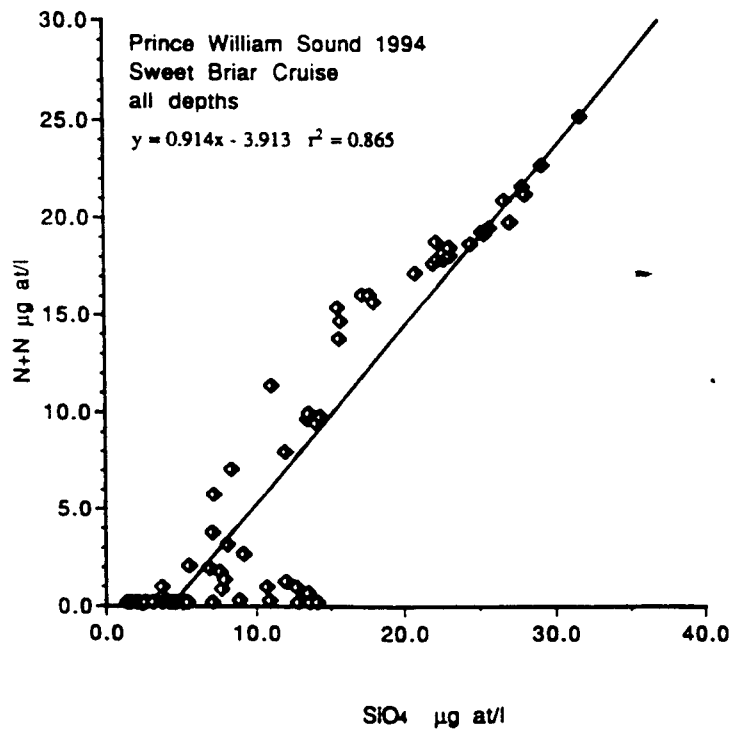
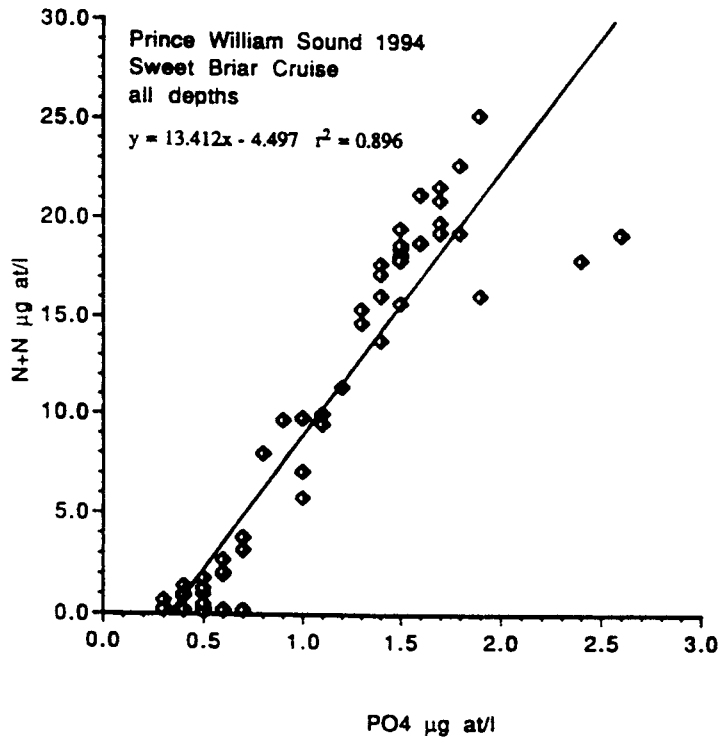
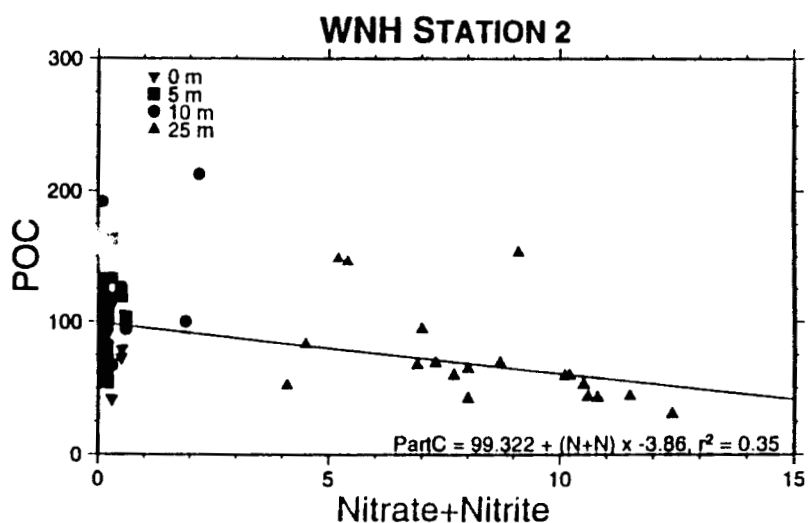
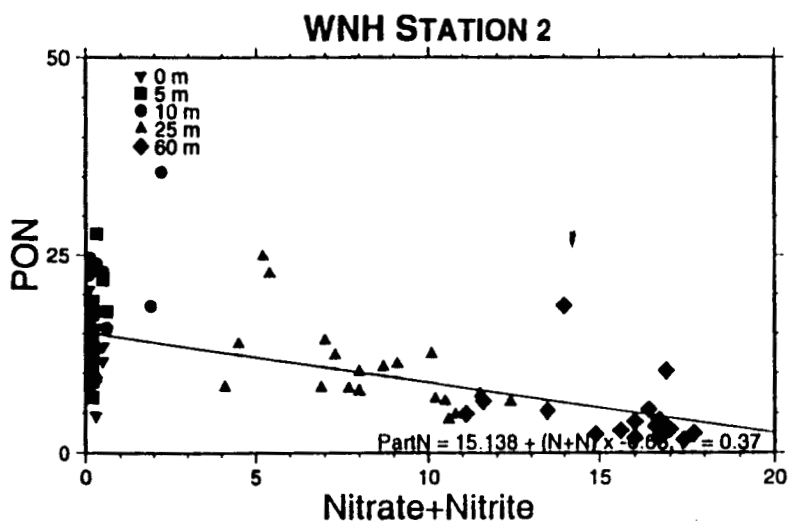
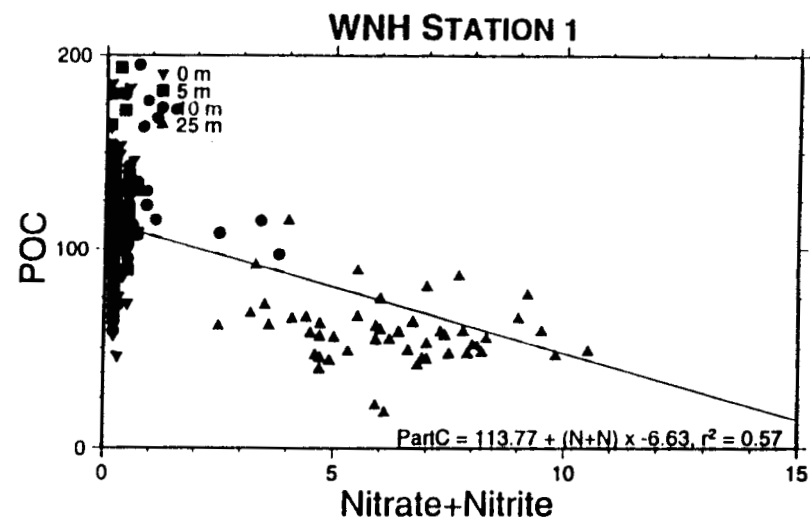
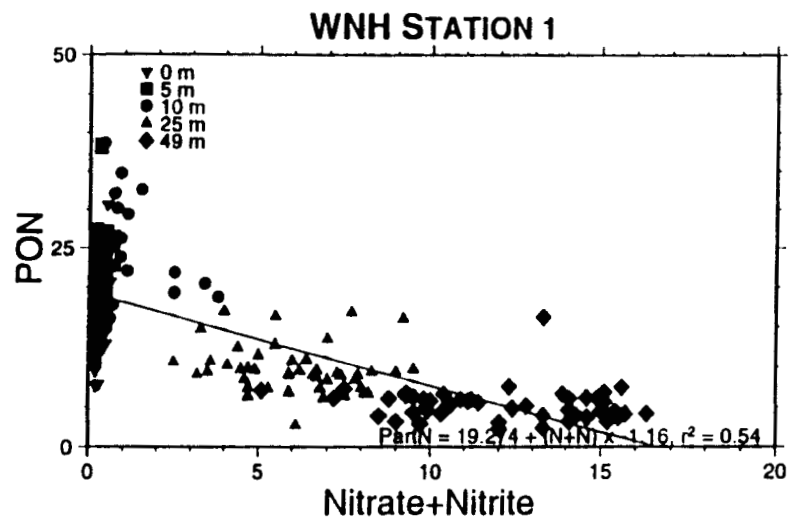
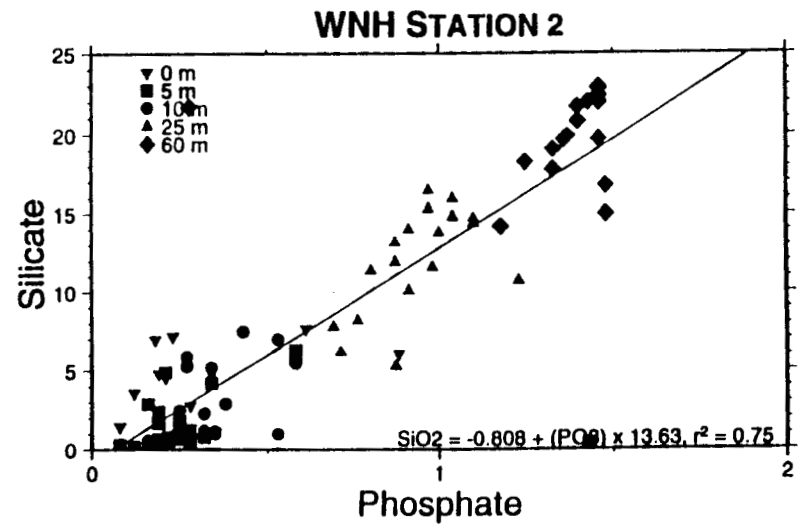
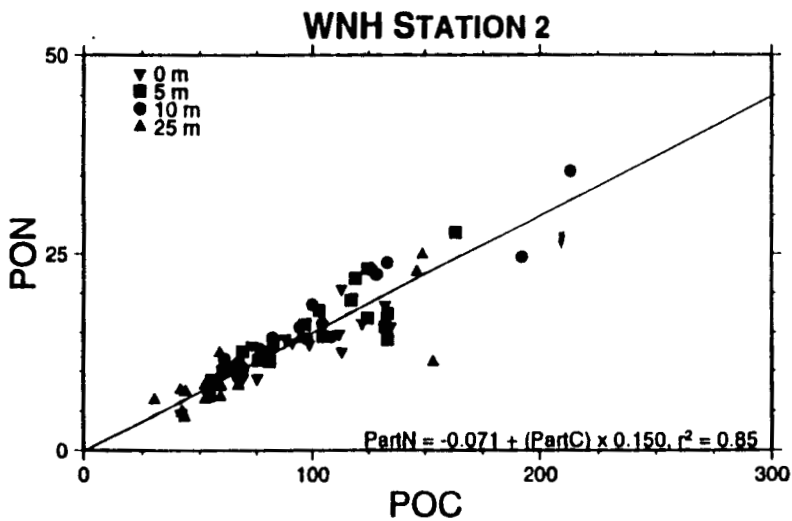
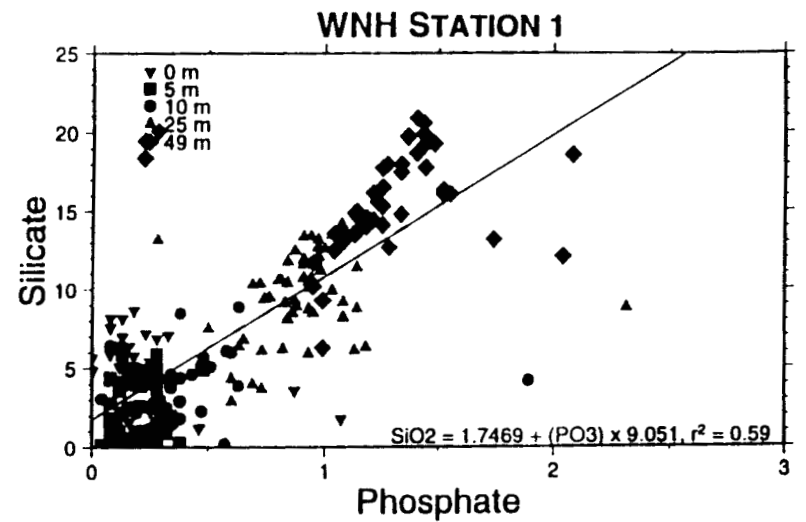
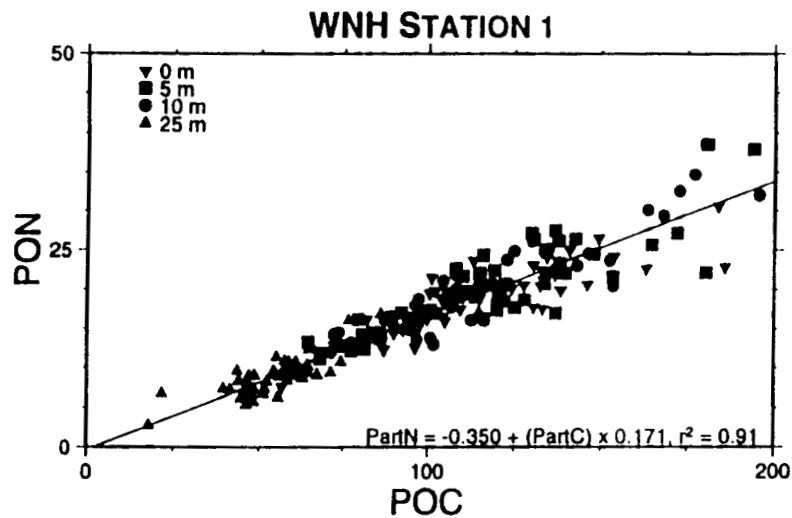


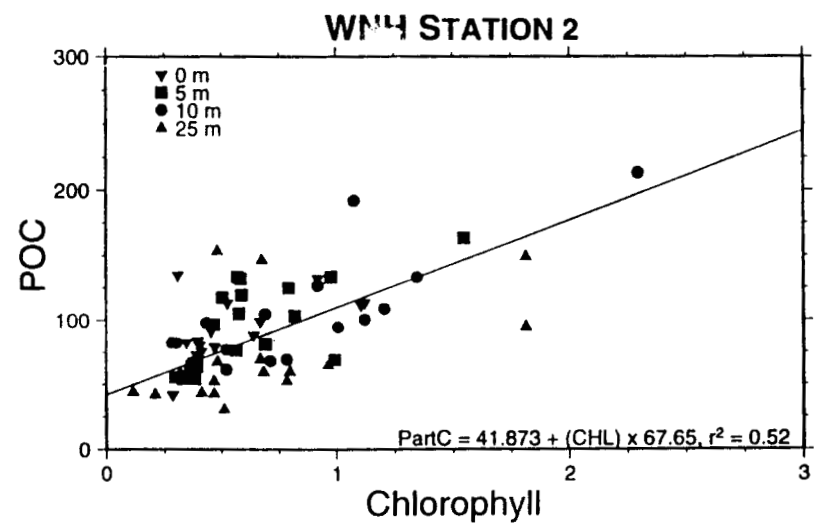
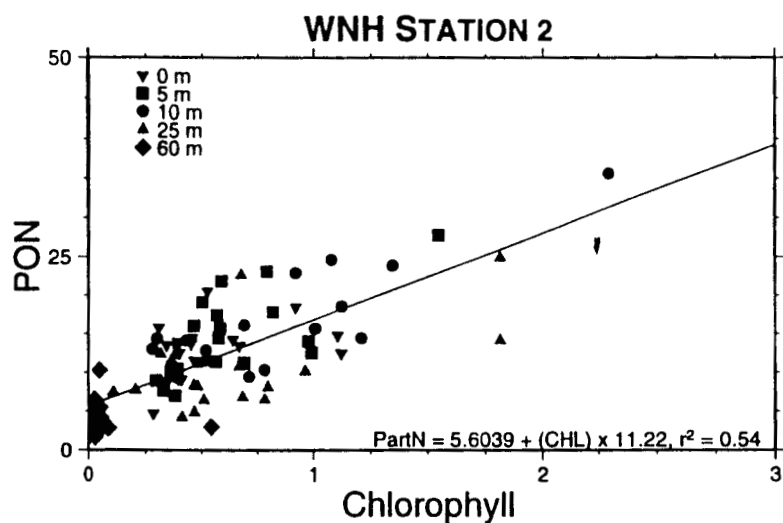
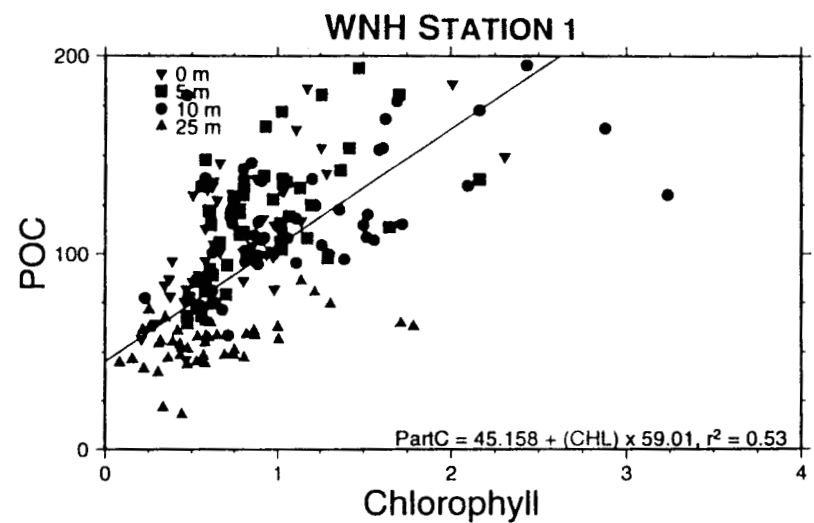
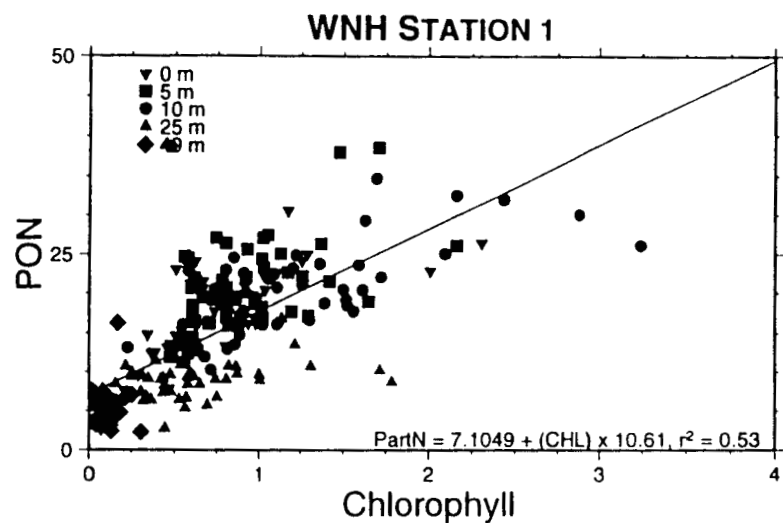
Figure 7. Nutrient-nutrient plots (Nitrate+Nitrite vs. Phosphate, upper; Nitrate+Nitrite vs. Silicate, lower) for water samples from 0 to 100 m depths collected during USCG Sweet Briar cruises in August 1994 (see Appendix I for stations).



**Figure 8. Nitrate+Nitrite vs. Particulate Organic Nitrogen (PON) or Particulate Organic Carbon (POC) for particles in water samples collected from stations 1 & 2 in Lake Bay (Wally Noerenberg Hatchery) during 28 May to 17 July 1994.**

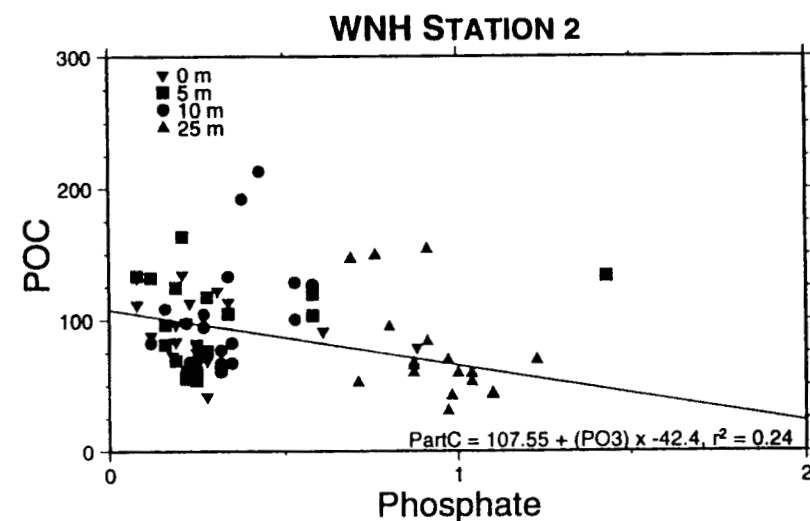
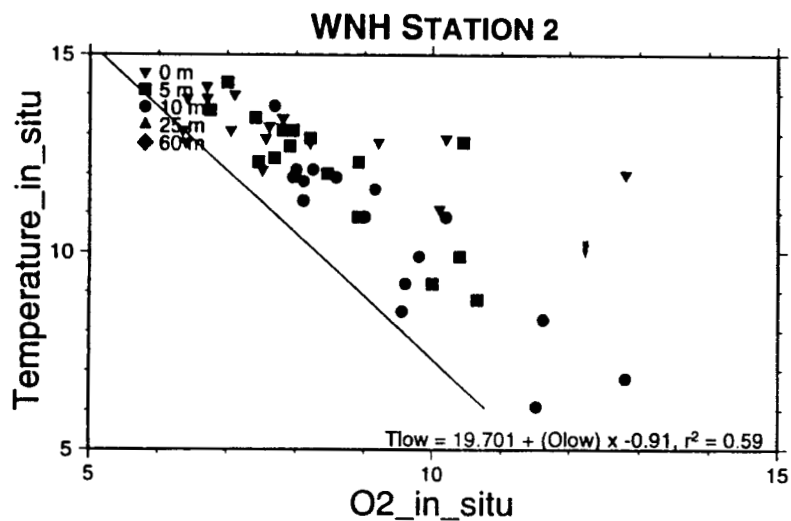
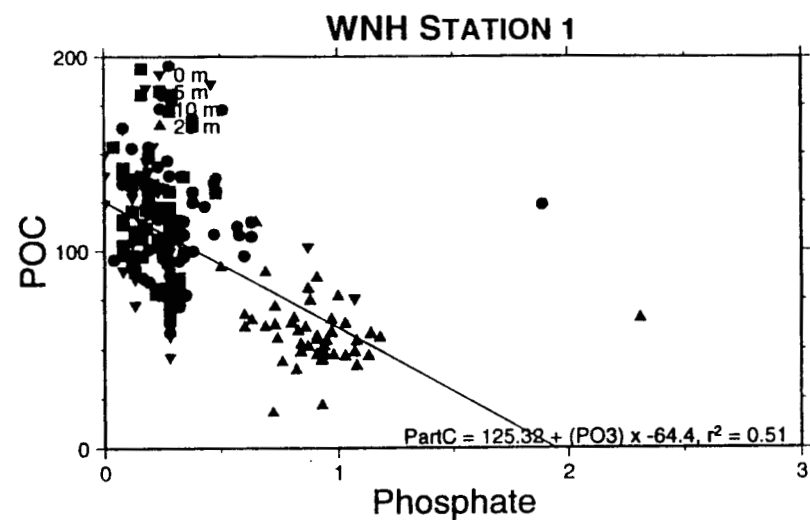
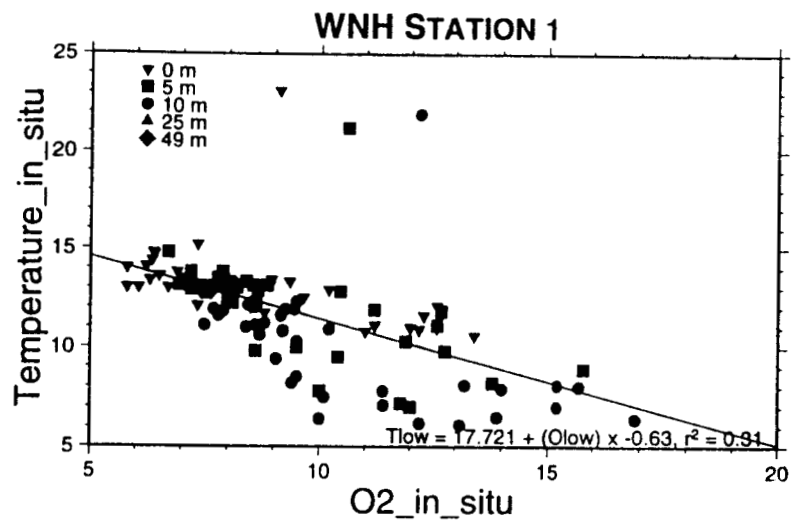


**Figure 9. Particulate Organic Nitrogen (PON) vs. Particulate Organic Carbon (POC) and Silicate vs. Phosphate for particles and water samples collected from stations 1 & 2 in Lake Bay (Wally Noerenberg Hatchery) during 28 May to 17 July 1994.**



**Figure 10. Particulate Organic Nitrogen (PON) or Particulate Organic Carbon (POC) vs. Chlorophyll a for particles in water samples collected from stations 1 & 2 in Lake Bay (Wally Noerenberg Hatchery) during 28 May to 17 July 1994.**





**Figure 11. Temperature vs. Dissolved Oxygen and Particulate Organic Carbon (POC) vs. Phosphate for water samples and particles collected from stations 1 & 2 in Lake Bay (Wally Noerenberg Hatchery) during 28 May to 17 July 1994.**

Table 5. List of phytoplankton species identified from water samples collected in Lake Bay (WNH) during June 1994 .

DIATOMS

*Achnanthes* sp.  
*Asterionella kariana*  
*Bacteriostrum* sp.  
*Biddulphia* sp.  
*Chaetoceros concavicornis*  
*Chaetoceros* sp.  
*Chaetoceros wighamii*  
*Cocconeis* sp.  
*Coscinodiscus* sp.  
*Dictyocha speculum*  
*Grammatophora* sp.  
*Leptocylindrus danicus*  
*Leptocylindrus minimus*  
*Licmophora* sp.  
*Melosira* sp.  
*Navicula* sp.  
*Nitzschia closterium*  
*Nitzschia delicatissima*  
*Nitzschia longissima*  
*Nitzschia pacifica*  
*Nitzschia* sp.  
*Rhizosolenia delicatula*  
*Rhizosolenia fragilissima*  
*Rhizosolenia hebetata*  
*Rhizosolenia* sp.  
*Rhizosolenia stolterfothii*  
*Skeletonema costatum*  
*Stephanopyxis nipponica*  
*Thalassiosira nitzchoides*  
*Thalassiosira nordenskioldii*  
Unidentified centric diatom  
Unidentified diatom  
Unidentified pennate diatom

FLAGELLATES

*Ceratium fusus*  
*Ceratium* sp.  
*Dinophysis* sp.  
*Ebria tripartita*  
*Goniaulax* sp.  
*Gymnodinium* sp.  
*Peridinium* sp.  
Unidentified flagellate  
Unidentified silicoflagellate  
Unidentified dinoflagellate

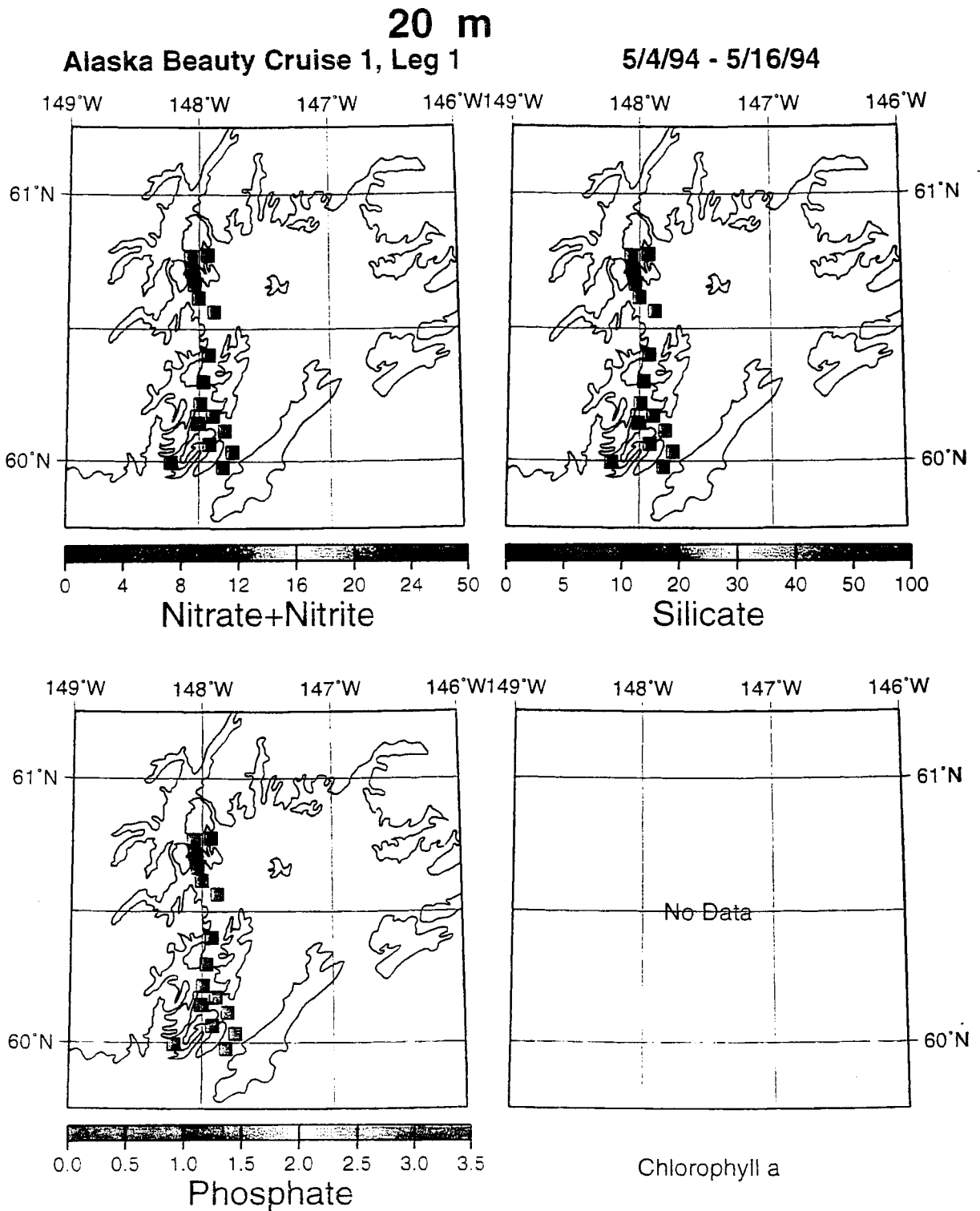
highest values occur in the outermost waters adjacent to the Gulf of Alaska (Figure 12). Although low, these concentrations are not limiting to productivity, so continued growth of the phytoplankton community should have occurred.

Similar data, more detailed in scope, were collected on a cruise of the RV *Alpha Helix* in 1989 (Figures 13 and 14). These data are from a cruise that took place just 2 weeks after the oil spill, so they provide some view of what was happening in the production cycle at the time. The pattern of nutrient distribution was more complex than that seen in May 94 and a wider range of concentrations was found. In a few locations the nutrients were low enough to be limiting to plant growth so the spring bloom was well underway. The water column chlorophyll from the time confirms the presence of the spring bloom. High values were measured in many locations, especially in the eastern sound. The suggestion is that the spring bloom proceeds from southeast to southwest following the general current flow in the sound. An extensive data set from these pre-spill cruise is available and will be incorporated into our results (see Appendix II).

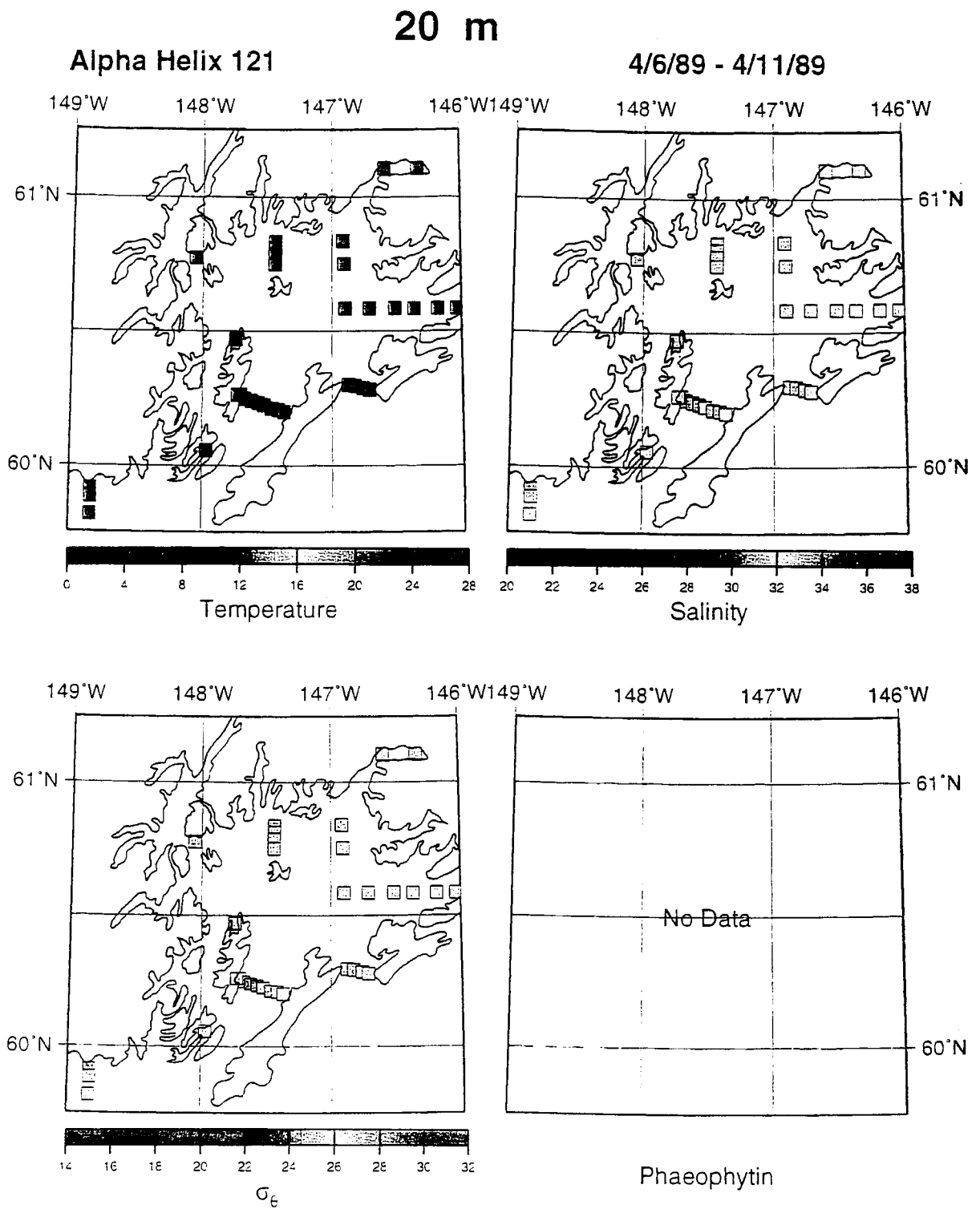
## Discussion

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).

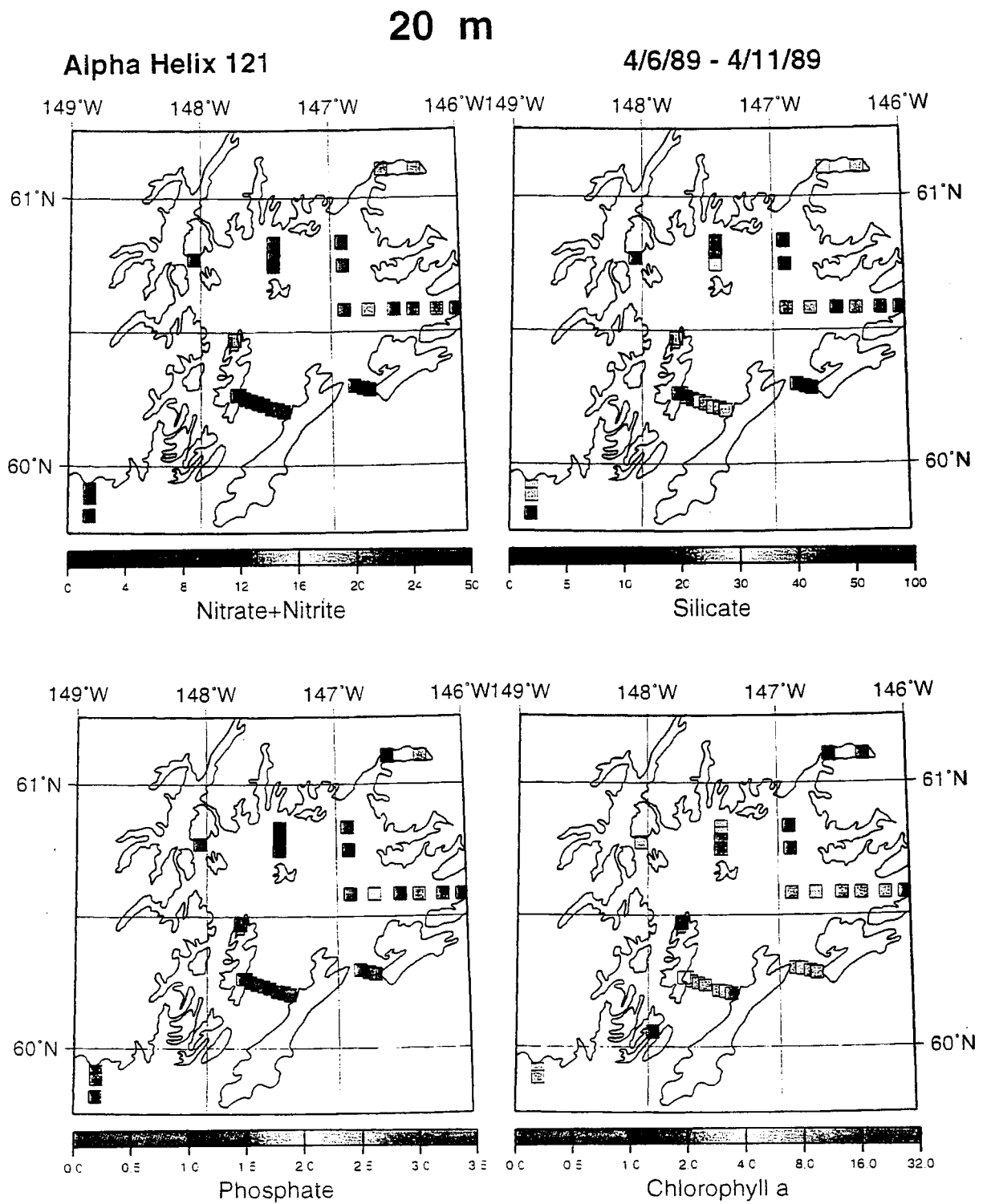
The timing of the spring bloom is apparently determined by the interaction of light and mixing in the classic relationship (Sverdrup, 1953). The interruption of the cycle by storms indicates the fragility of the relationship at this time of year and how the ocean conditions can impart an event signal 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.



**Figure 12. Spatial distribution of dissolved nutrients (Nitrate+Nitrite, Phosphate and Silicate) in the 20 m layer during 4 to 16 May 1994 (F/V Alaska Beauty)**



**Figure. 13. Spatial distribution of Temperature, Salinity and Sigma Theta (density,  $\sigma_\theta$ ) in the 20 m layer during 6 to 11 April 1989 (R/V Alpha Helix, Cruise 12, from McRoy, unpublished data)**



**Figure 14. Spatial distribution of dissolved nutrients (Nitrate+Nitrite, Phosphate and Silicate) and Chlorophyll  $a$  in the 20 m layer during 6 to 11 April 1989 (R/V Alpha Helix, Cruise 12, from McRoy, unpublished data)**

Although we do not yet have direct data (other than buoy data) from the spring bloom period, 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. While we have no data from the spring the phytoplankton community in June-July consisted of a mixture of picoplankton species including numerous flagellates. More detailed results are in progress. Horner et al. (1973) report a detailed list of phytoplankton species for Port Valdez that will be used for comparison. The diatom species 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 and are likely to only contribute to a microbial food web. Even if these small cells are an eventual energy source for larger predators, their presence in the system would result in at least one more step in the food web and a concomitant diminishing of available energy. How the "lake" or "river" circulation pattern affects the community composition could have a profound effect on the success of the upper trophic levels.

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 and 1994 indicates more bottom-up forcing than has generally been assumed in the hypotheses for this system (refer to the SEA general overview documents). We have also made a preliminary examination for some upper trophic level species

(e.g., killer whales) and the time lag in the phytoplankton bloom observed for 93 and 94 apparently propagates up the trophic web.

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. The questions poised can not yet be answered by the available data. We expect the 1995 time series to further clarify the interrelationships.

## 8. References

Alexander, V. and T. Chapman. 1980. Phytotoxicity. pp 125-142, in J.M. Colonell, ed., Port Valdez, Alaska: Environmental Studies 1976-1979. Institute of marine Science, University of Alaska, Fairbanks.

Goering, J.J., C.J. Patton, and W.E. Shiels. 1973a. Nutrient cycles. Pp. 225-248, in D.W. Hood, W.E. Shiels and E.J. Kelley. Environmental studies of Port Valdez. Institute of Marine Science, University of Alaska, Fairbanks.

Goering, J.J., W.E. Shiels, and C.J. Patton. 1973b. Primary production. Pp. 225-248, in D.W. Hood, W.E. Shiels and E.J. Kelley. Environmental studies of Port Valdez. Institute of Marine Science, University of Alaska, Fairbanks.

Horner, R.A. L.S. Dick and W.E. Shiels. 1973a. Nutrient cycles. Pp. 283-294, in D.W. Hood, W.E. Shiels and E.J. Kelley. Environmental studies of Port Valdez. Institute of Marine Science, University of Alaska, Fairbanks.

McRoy, C.P. 1988. Natural and anthropogenic disturbances at the ecosystem level. Pp. 329-334, in D.G. Shaw and M.J. Hameedi, eds., Environmental Studies in Port Valdez, Alaska, Lecture Notes on Coastal and Estuarine Studies Vol. 24. Springer-Verlag. Berlin.

Parsons, T.R., Y. Maita, and C.M. Lalli. 1984. A Manual of Chemical and Biological Methods of Seawater Analysis, Pergamon Press, New York.

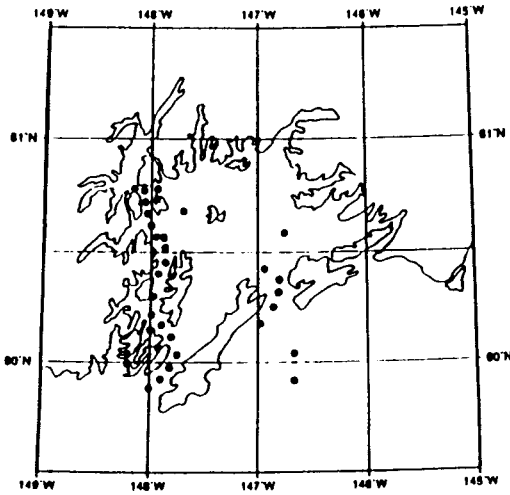


Sournia, A. 1978. "Phytoplankton manual", UNESCO, Paris, 337 pp.

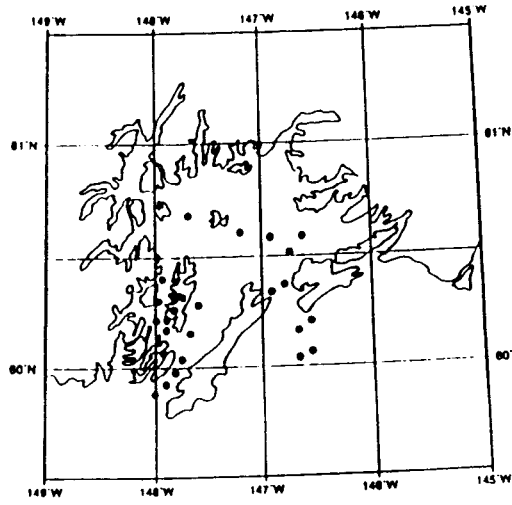
Strickland, J.D.H. and T.R. Parsons. 1972. A Practical Handbook of Seawater Analysis. Bulletin 167, Fisheries Research Board of Canada, Ottawa, 310 pp.

Sverdrup, H.U. 1953. On conditions for the vernal blooming of phytoplankton. *Cons. perm intl. Expl. Mer* 18(3):287-295.

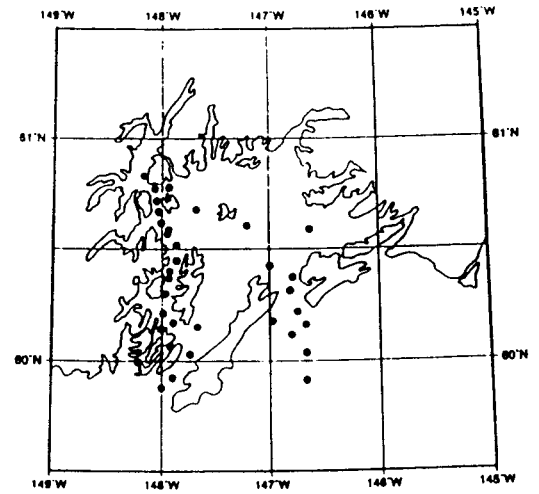
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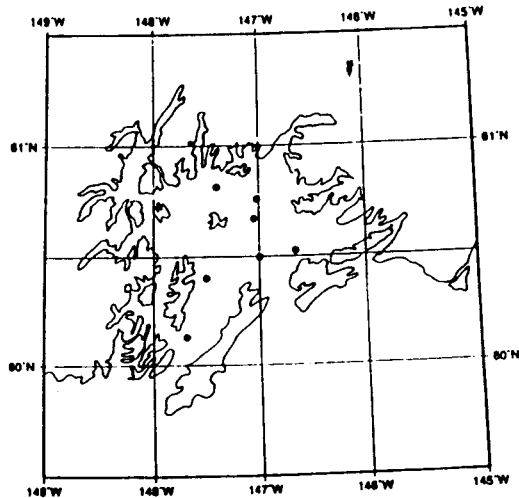
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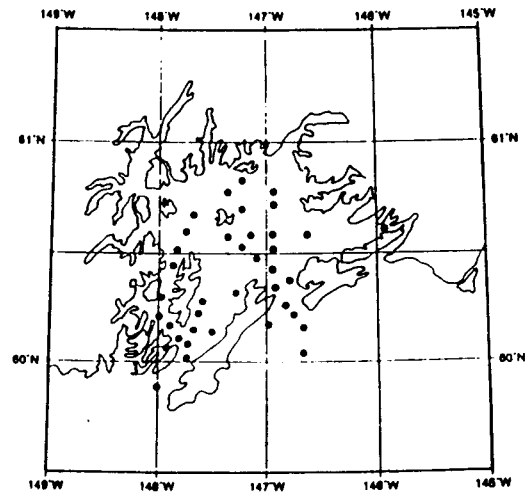
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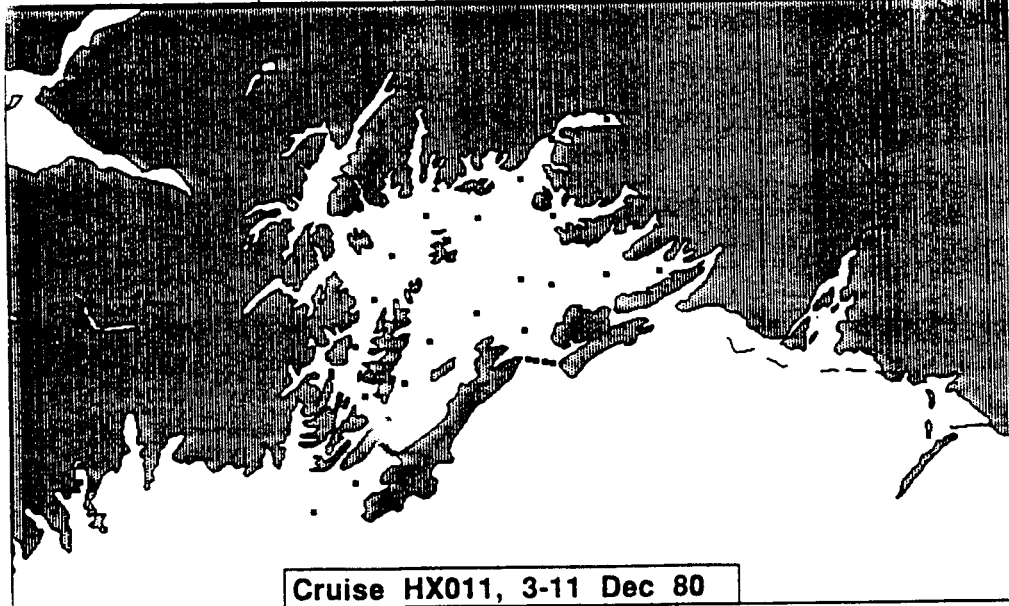
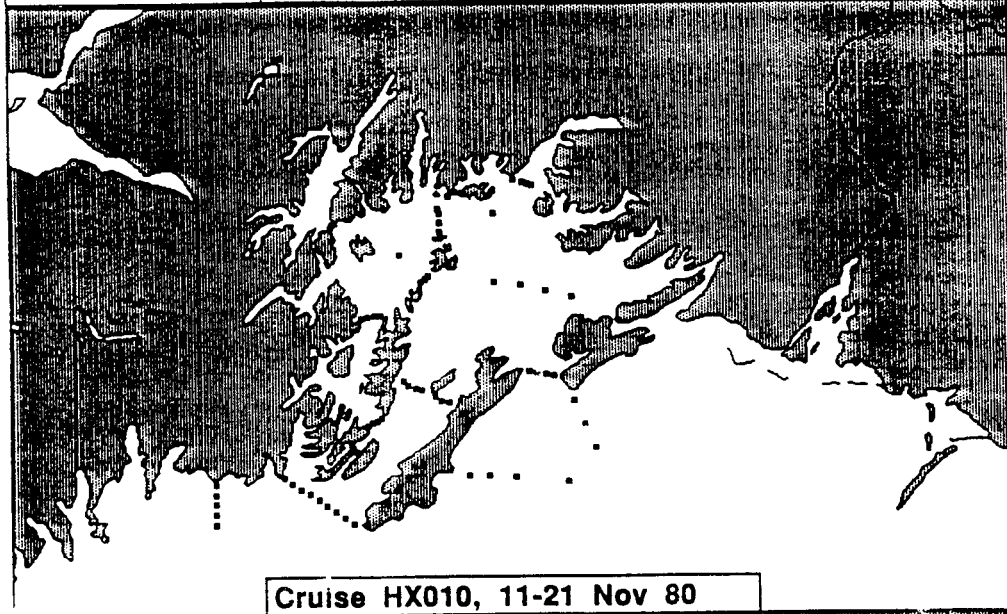
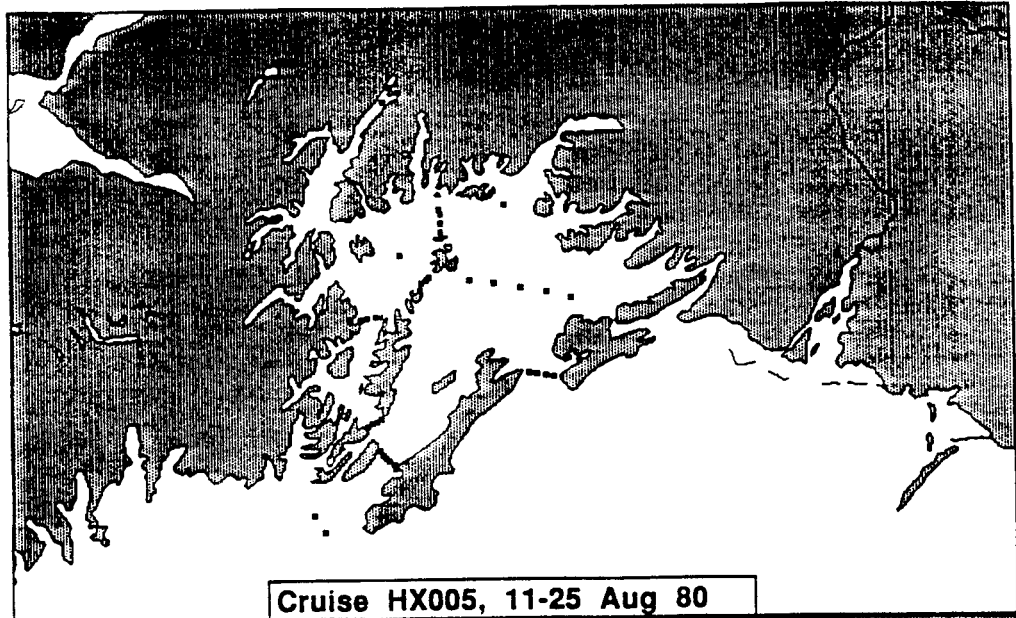
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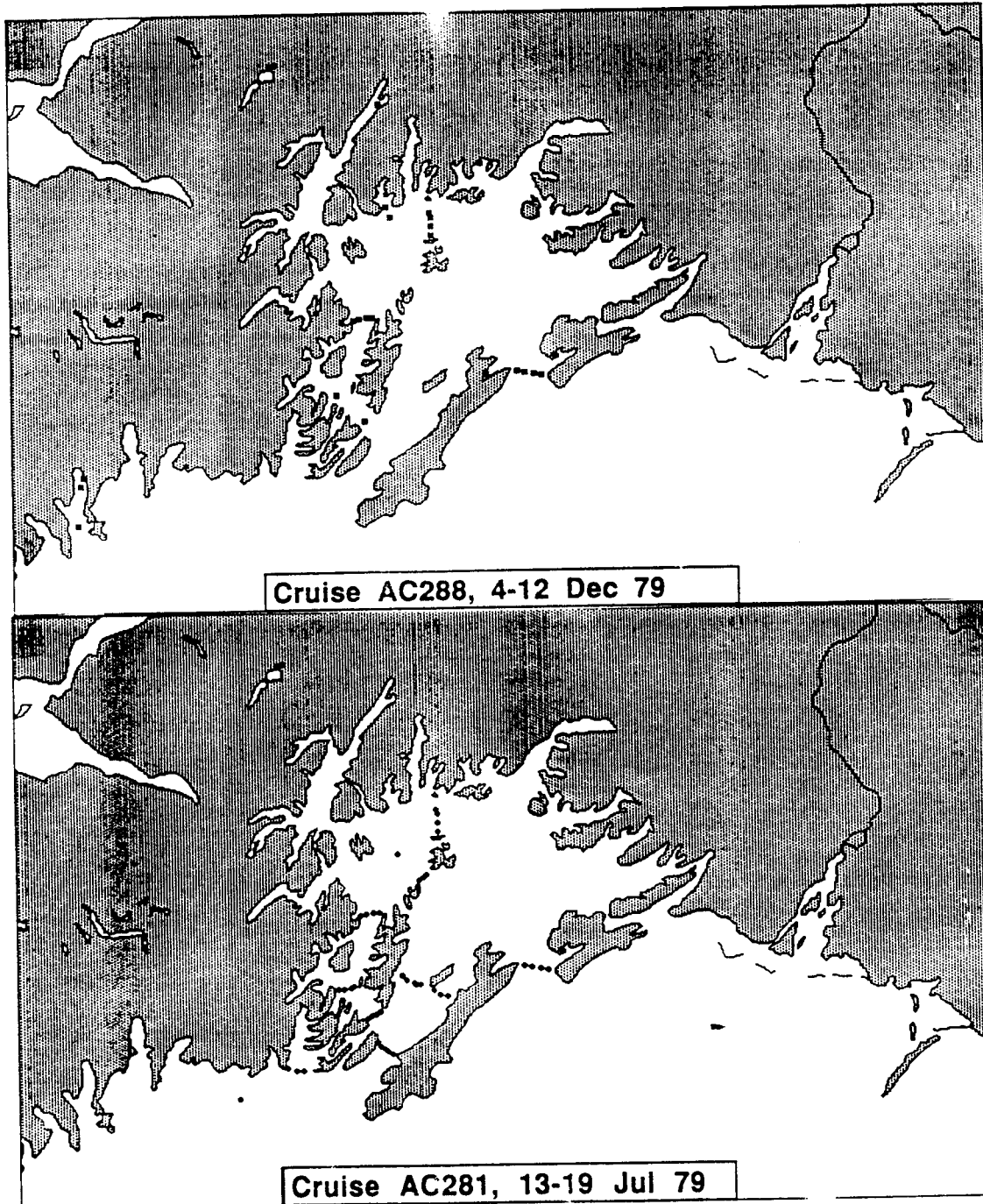
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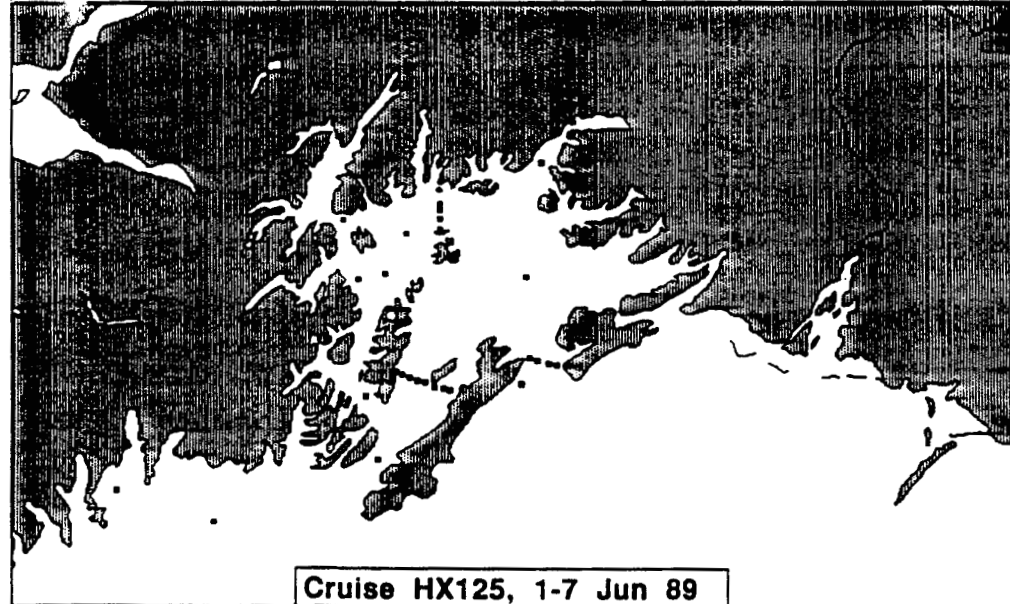
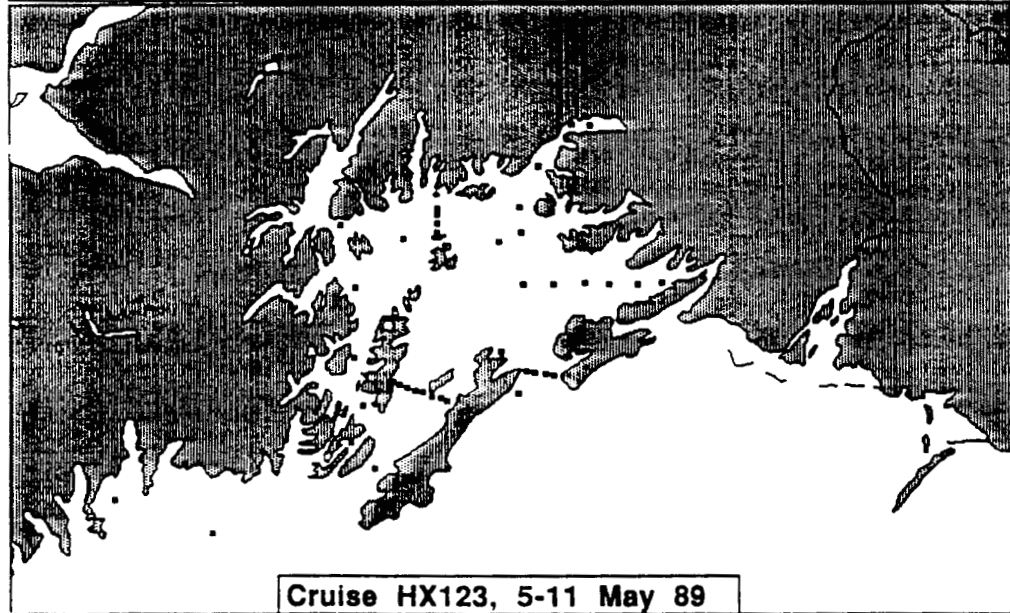
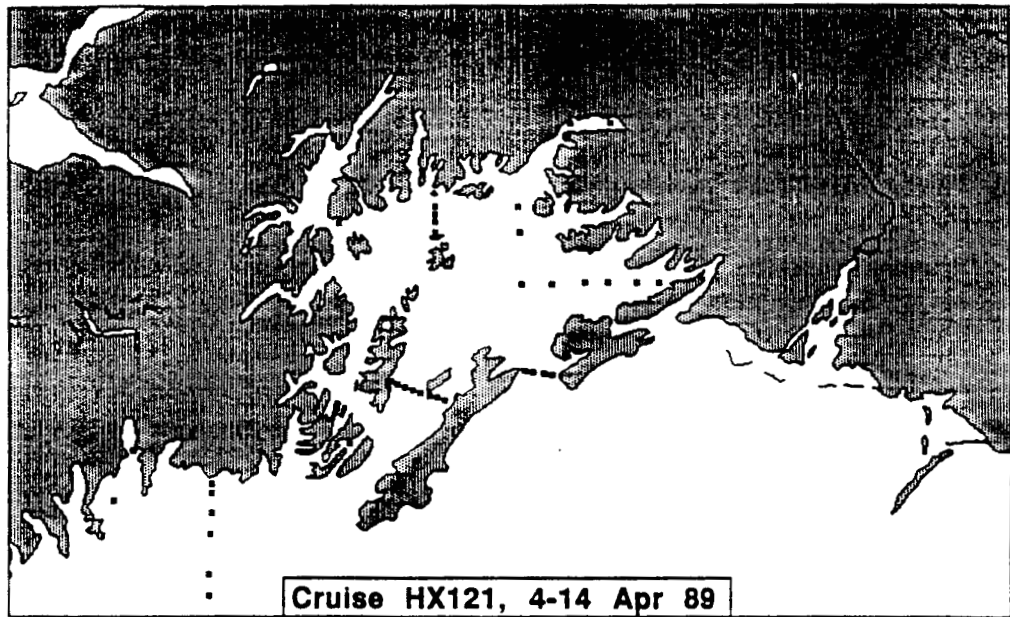
Appendix I: Station Locations for Samples from 1994 Cruises



Appendix II. Station locations for previous oceanographic cruises.



**Appendix II. Station locations for previous oceanographic cruises.**



Appendix II. Station locations for previous oceanographic cruises.