TEMPORAL AND SPATIAL VARIABILITY OF PHYTOPLANKTON IN COASTAL
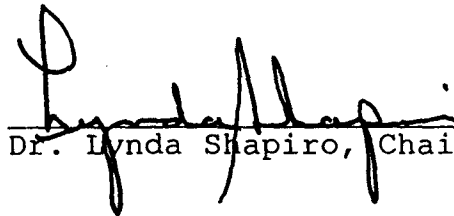
AND ESTUARINE HABITATS IN COOS BAY, OREGON
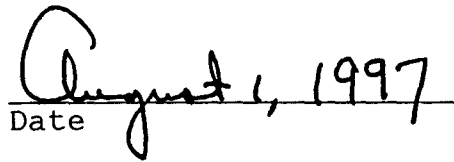
by

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A THESIS

Presented to the Department of Biology
and the Graduate School of the University of Oregon
in partial fulfillment of the requirements
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Master of Science

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"Temporal and Spatial Variability of Phytoplankton in Coastal and Estuarine Habitats in Coos Bay, Oregon" a thesis prepared by Margaret P. Hughes in partial fulfillment of the requirements for the Master of Science degree in the Department of Biology. This thesis has been approved and accepted by:

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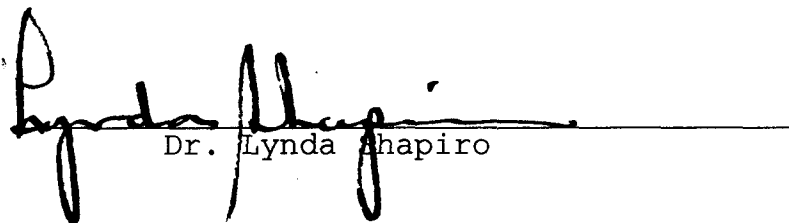
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An Abstract of the Thesis of

Margaret P. Hughes   for the degree of   Master of Science

in the Department of Biology   to be taken   August 1997

Title: TEMPORAL AND SPATIAL VARIABILITY OF PHYTOPLANKTON IN

   COASTAL AND ESTUARINE HABITATS IN COOS BAY, OREGON

Approved: _____
                    Dr. Lynda Shapiro

The abundance and distribution of phytoplankton were
compared over a two year period at a coastal station off the
central Oregon coast to determine probable successional
patterns. Abundance and distribution of phytoplankton were
compared over a one year period in the lower, middle, and
upper regions of the Coos Bay estuary to assess species
composition. Spring and fall blooms were evident in both
study years and the increase in biomass associated with
these blooms were due to the the addition of larger cells to
a base level of cells.   Bloom patterns in coastal and
estuarine sites varied between phytoplankton categories and
between sites. This variation is probable due to
differences in environmental conditions. Phycoerythrin-
containing cyanobacteria and minute chlorophyll-dominant
eukaryotes were an important component at all sites.
Cryptomanads were more prevalent at estuarine sites.

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CHAPTER I

INTRODUCTION

Background Information

Community succession of plants and animals has been described as a regular and predictable process. Investigators have proposed general patterns of seasonal succession in fresh water lakes, coastal areas, and the open ocean (Pearsall 1932; Colebrook et al. 1965; Stewart et al. 1986; Boney 1989). Components thought to trigger and regulate phytoplankton succession include both allogenic and autogenic factors. Allogenic successions are driven by changes in external geophysico-chemical forces (i.e., temperature, salinity and light). Autogenic successions are a result of biological processes in the absence of changing abiotic influences (i.e., nutrient regeneration, competition and predation) (Smayda 1980; Begon et al. 1990). This study will investigate the influence of the allogenic factors, water temperature and salinity, on phytoplankton succession in a coastal marine habitat over a two year period. A second phase of this study will compare species composition patterns and abundance of phytoplankton communities in the

tidally influenced estuary of South Slough, Charleston, Oregon.

Seasonal Patterns

Annual abundance and successional patterns of phytoplankton in aquatic environments are well described and it is known that these patterns vary regionally. Boney (1989) described five geographically related annual patterns of abundance from the Arctic seas to the Antarctic seas (Fig. 1). Each area shows unique seasonal amplitudes of phytoplankton production. These range from one major peak in the Arctic to a somewhat constant but low abundance throughout the year in tropical seas. Colebrook and Robinson (1965) have described distinct seasonal patterns of phytoplankton biomass that vary with distance from shore (Fig. 2). Common patterns have been observed in many aquatic habitats, e.g. small celled diatoms, capable of rapid cell division and requiring high nutrient levels, are known to start the seasonal progression. Following the small diatoms are slower growing medium size diatoms. Finally, motile species of several algal classes such as dinoflagellates (Smayda 1980; Boney 1989) proliferate.

The Atlantic vs the Pacific

Our understanding of ocean ecology has been dominated by studies conducted in the Atlantic Ocean. More recent investigations have shown that the ecology of the Atlantic and Pacific Oceans are distinct. The Pacific is larger, colder and less saline than the Atlantic (Parsons and Lalli 1988). Additionally, the subarctic North Pacific is a nutrient replete area (for major nutrients such as Si, P, and N) but does not experience a major seasonal spring phytoplankton bloom as does the North Atlantic (Miller et al. 1991).

Parsons and Lalli (1988) have nicely summarized some of the major differences between North Pacific and the North Atlantic. In brief, these include differences in:

✺ Factors that limit the seasonal cycle of phytoplankton. The North Pacific (NP) is limited by low temperatures and zooplankton grazing while the North Atlantic (NA) is limited by depth of the mixed layer and by nutrient exhaustion.

✺ The size and annual generation in copepod populations. The subarctic NP is dominated by large-sized copepods having a single generation per year while the NA copepod population is dominated by smaller species having several generations per year.

✺ Trophic structures and efficiency. The NP is dominated by a highly efficient food chain involving nano-phytoplankton → micro-zooplankton → macro-copepods, while the NA is dominated by a less efficient microphytoplankton → macro-copepod community.
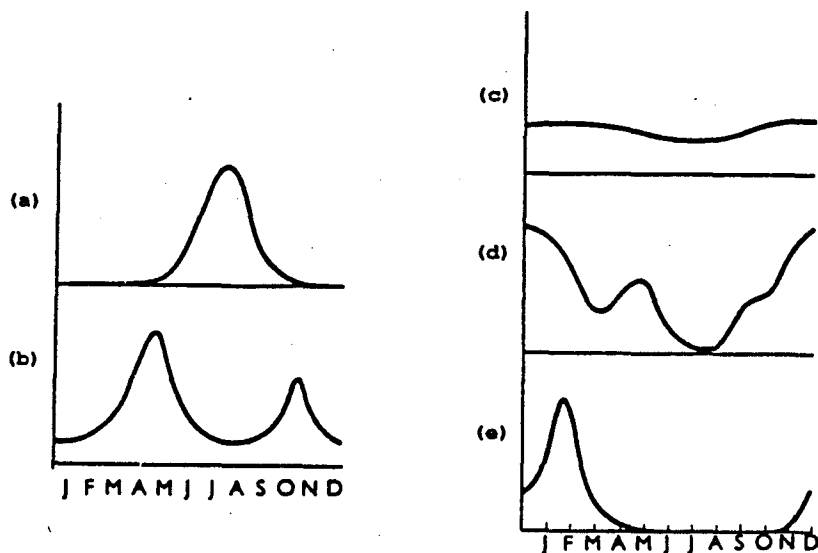
FIGURE 1: Seasonal amplitudes of phytoplankton production. (a)Arctic seas. (b) North temperate seas. (c) Tropical seas. (d) Antarctic seas - northern region. (e) Antarctic seas - southern region. Modified from Boney p. 52.
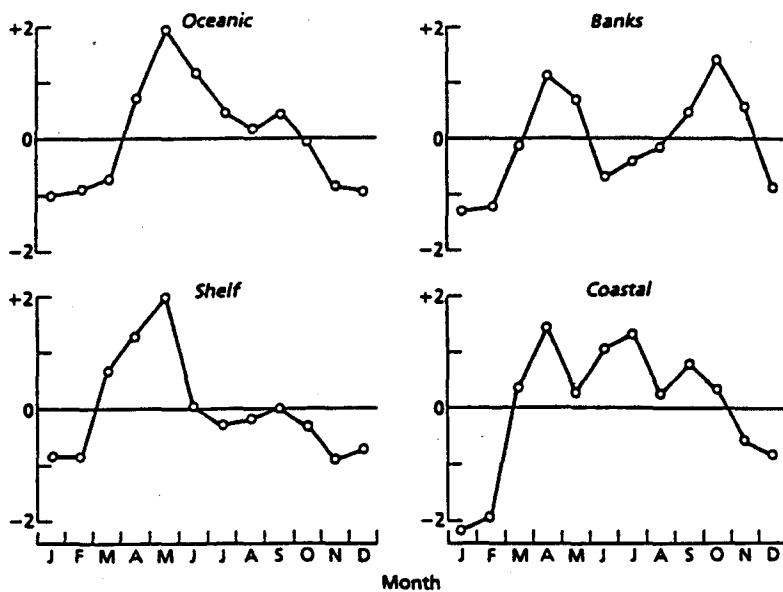
FIGURE 2: Seasonal patterns in chlorophyll abundance. Modified from Colebrook and Robinson (1965) and Mann & Lazier, p. 158.

  * Species assemblages among the plankton.
  The NP is dominated by a flagellate-micro-
  zooplankton food chain in contrast to the diatom-
  macroozooplankton food chain in the NA.

The North Pacific is described as a balanced ecosystem where

phytoplankton stocks are kept in check by increased grazing

capacity by micro- and macrozooplankton in the spring and

summer.

Size Structure

The importance of ultraplankton has become evident in

the past 20 years. Ultraplankton, as described by Shapiro

et al. (1985), are plankters < 5 μm in diameter (and are

able to pass through a 3 μm Nuclepore filter). The

subarctic Pacific phytoplankton assemblage is dominated by

small cells. Investigators have found that 80% of the

biomass is made up of ultraplankton (Booth 1988; Parsons and

Lalli 1988). Total cell numbers for small cells range up to

10^5 c·l^{-1} in the North Pacific but are approximately an

order of magnitude lower in the Atlantic (Parsons & Lalli

1988). However, diatoms are reported to be one to two

orders of magnitude greater in the Atlantic (Parsons & Lalli

1988).

Fractionation of phytoplankton into different size

groups has been used extensively to determine seasonal

changes in their distribution. Studies show that

photosynthetic prokaryotic and eukaryotic picoplankton do

contribute a significant proportion of the total carbon production in lakes and oceans. Picoplankton as defined by Sieburth et al. (1978), are cells 0.2 - 2.0 μm in diameter. The prokaryotic phytoplankton would be included under this terminology, whereas the larger eukaryotic phytoplankton (as much as 5 or 6 μm in diameter), would fall in the nanoplankton category (Shapiro and Guillard 1985). Therefore, investigators have found the term "ultraplankton" more appropriate because it includes both the chroococcoid cyanobacteria and phototrophic eucaryotic cells (Shapiro and Guillard 1985).

Synechococcus sp., a phycoerythrin-rich photosynthethic cyanobacteria about 1 μm in diameter, have been observed in high concentrations (10^5 - 10^8 c·l^{-1}) throughout the world's oceans and coastal waters (Johnson and Sieburth 1979; Waterbury et al. 1979; Glover et al. 1985; Murphy and Haugen 1985). Cell concentrations tend to be highest in surface water and near the coasts and lowest in the central oligotrophic ocean (Murphy and Haugen 1985; Olson 1990). Murphy and Haugen (1985) in a study carried out in the North Atlantic found that cyanobacterial abundance decreased with increasing latitude and decreasing temperature and distance from shore.

As with cyanobacteria, the existence of very small (0.5 - 5 μm) chlorophyll dominant eukaryotic cells has likewise been reported from many areas of the world. However, little is known about their distribution or taxonomy. These small

eukaryotes are, in general, numerically less abundant than cyanobacteria in surface waters (Murphy and Haugen 1985). However, they tend to equal or outnumber cyanobacteria around the thermocline (near the bottom of the euphotic zone) and their numbers remain constant while cyanobacteria decrease with increasing north latitude in the Atlantic (Murphy and Haugen 1985).

Characteristic of temperate zones is the formation of a spring phytoplankton bloom. As described by Gran (1931 and 1935) and Sverdrup (1953), one mechanism thought to underlie this seasonal bloom is shallowing of the mixed layer to less than the critical depth (the depth at which photosynthesis is balanced with respiration). Winter storms cause turbulent mixing of the entire water column bringing nutrients to the surface. As spring approaches solar radiation increases causing surface warming and formation of a shallower mixed water layer. With stratification phytoplankton are held in the euphotic zone where they multiply rapidly.

Large phytoplankton do exist in the Pacific but do not produce blooms comparable to those in the oceanic North Atlantic (Clemons and Miller 1984). Summer assemblages of large cells consist primarily of a centric diatom *Corethron criophilum* which can range in diameter from 29 to 47 µm and can be as long as 177 µm (Clemons and Miller 1984). Autumn-winter large cell assemblages are dominated by a centric diatom which can reach a length up to 3.6 mm, *Thalassiothrix*

longissima Cleve. (Clemons and Miller 1984). Overall though, smaller, nanoplankton-sized cells dominate.

Estuaries

Simplistically, estuaries are defined as transitional ecosystems located at the interface of terrestrial and marine environments (Nybakken 1988). Salinity and temperature gradients are primary features which vary seasonal, with topography, and with the tides. Therefore, estuaries experience dynamic temporal and spatial variability which can create a stressful environment for organisms (Cloern 1995).

Like coastal upwelling zones, estuaries are areas of high biological productivity. However, their physical environment is distinct from lakes and the open ocean (Cloern 1991). Physical characteristics (e.g. riverine freshwater inflow and tidal stirring) deliver varying amounts of sediments and nutrients. These influence the physical/chemical structure of the water column (e.g. increasing turbidity and decreasing dissolved oxygen content of bottom waters) and thereby influence the biological community of estuaries. Phytoplankton population changes are influenced seasonally by variability of river flow and daily by the tides (Cloern 1991). Nybakken describes a successional pattern for estuaries in temperate zones. Low phytoplankton populations are characteristic in the late

fall and winter due to reduced light and high turbidity. This is followed by a later winter diatom bloom which terminates in the spring thought to be due to depletion of nitrogen sources. Populations remain low in the summer due to low nutrients and grazing.

Seasonal Variation in Temperature and Salinity

Oregon's coastal waters are affected by local seasonal processes that modify surface water properties such as temperature and salinity (Pattullo et al. 1965; Reed et al. 1973; Huyer 1977). During the winter season (December-February), coastal water is influenced by rainfall, runoff, cooling and wind stress, the latter being predominantly from the south. The influx of fresh water from rainfall and runoff dilutes coastal water and thus lowers salinity.

The major processes affecting the summer months (June-August) are heating and upwelling. The Columbia River plume and wind stress which is predominantly from the north also impacts coastal water in summer months. Upwelled water can normally be characterized as cold, dense and nutrient replete. Oregon experiences four or five strong upwelling events during summer months which give rise to bursts of productivity (Barber and Smith 1981; Mann and Lazier 1991). Although upwelling exerts the most influence during summer months, it can and does occur at other times of the year when the winds are blowing from the north.

Primary Questions and Hypotheses

Temporal Study

The first part of this study focused on phytoplankton successional patterns using abundance in different size classes to quantify the relative success of those size classes. I will compare seasonal patterns of phytoplankton succession in both study years (93-94 and 94-95). To describe the typical pattern in this area I addressed the following questions: (1) Do variations in chlorophyll size structures occur seasonally and, if so, are these variations due to the addition of large cells to a base level of small cells? (2) Do phycoerythrin containing cyanobacteria and small (< 3 μm) chlorophyll-dominant eukaryotic phytoplankton tend to occur at the same time? (3) Are cryptophytes a important component of the flora in coastal and estuarine environments? (4) Do phytoplankton composition/dominance pattern changes occur at the same time as changes in temperature or salinity?

Spatial Study

The second part of this study will compare three different environments to assess the variation in size fraction, composition and abundance of protistan components in the lower, middle, and upper regions of the Coos Bay

estuary. My primary question is: Do the Boat House (upper Slough), mid-Slough and lower-Slough represent a single environment? Specifically, does the presence of certain taxa (e.g., Cryptophyta) at a single region predict their presence throughout the estuary?

I propose the following hypotheses:

1. The abundance and dominance pattern of phytoplankton changes seasonally at all three regions with increasing overall abundance at all sites in the spring and summer months due to the addition of larger cells to a constant component of small ones.

2. Specific taxa (eg., cryptomonads and dinoflagellates) vary seasonally and vary between sites.

CHAPTER II

MATERIALS AND METHODS

Description of Study Site

This study was conducted in the South Slough of Coos
Bay, Oregon, USA between September 1993 and October 1995 at
the dock of the Oregon Institute of Marine Biology,
University of Oregon which is located at the entrance to the
bay and, between September 1994 and October 1995, at three
sites, OIMB's dock and two areas within the South Slough of
the Coos Bay (Fig. 3). The South Slough is a National
Estuarine Research Reserve (NERR).

Temporal Study Site

Temporal sampling was conducted September 93 - October
95 at OIMB's dock (Fig. 3). This location was chosen due to
its close proximity to the mouth of Coos Bay. The water
column is expected to be well mixed coastal water at high
tide.

Spatial Study Sites

The spatial study was conducted September 94 - October 95. The three sites for the spatial study include the boat house dock and two estuarine sites located within the South Slough (Fig. 3). The two estuarine sites are the South Slough Pilings and Hinch Road Bridge. The South Slough Pilings site is part of the North Creek watershed and is immediately north of the South Slough NERR Interpretive Center. North Creek flows down a deep ravine to Rhodes Marsh, a formerly diked marsh which is now reverting to saltmarsh due to natural erosion of the dikes. The Pilings site is known to have a salinity gradient from 32 $^0/_{00}$ in the summer to brackish salinities of about 20 $^0/_{00}$ in the winter.

The third site, Hinch Road Bridge, is part of the Winchester Creek tidelands. It is located at the southern end of NERR. The salinity gradient is much greater compared to the Pilings. Previous studies have found that the salinit ranges from undiluted seawater in the summer with about 32 $^0/_{00}$ to totally fresh water in the winter months.

Sampling Techniques

Temporal Sampling

From September 1993 through September 1994, water

Oregon Institute of
Marine Biology

Boat House

South Slough
Pilings

Hinch Road
Bridge

Coos Bay
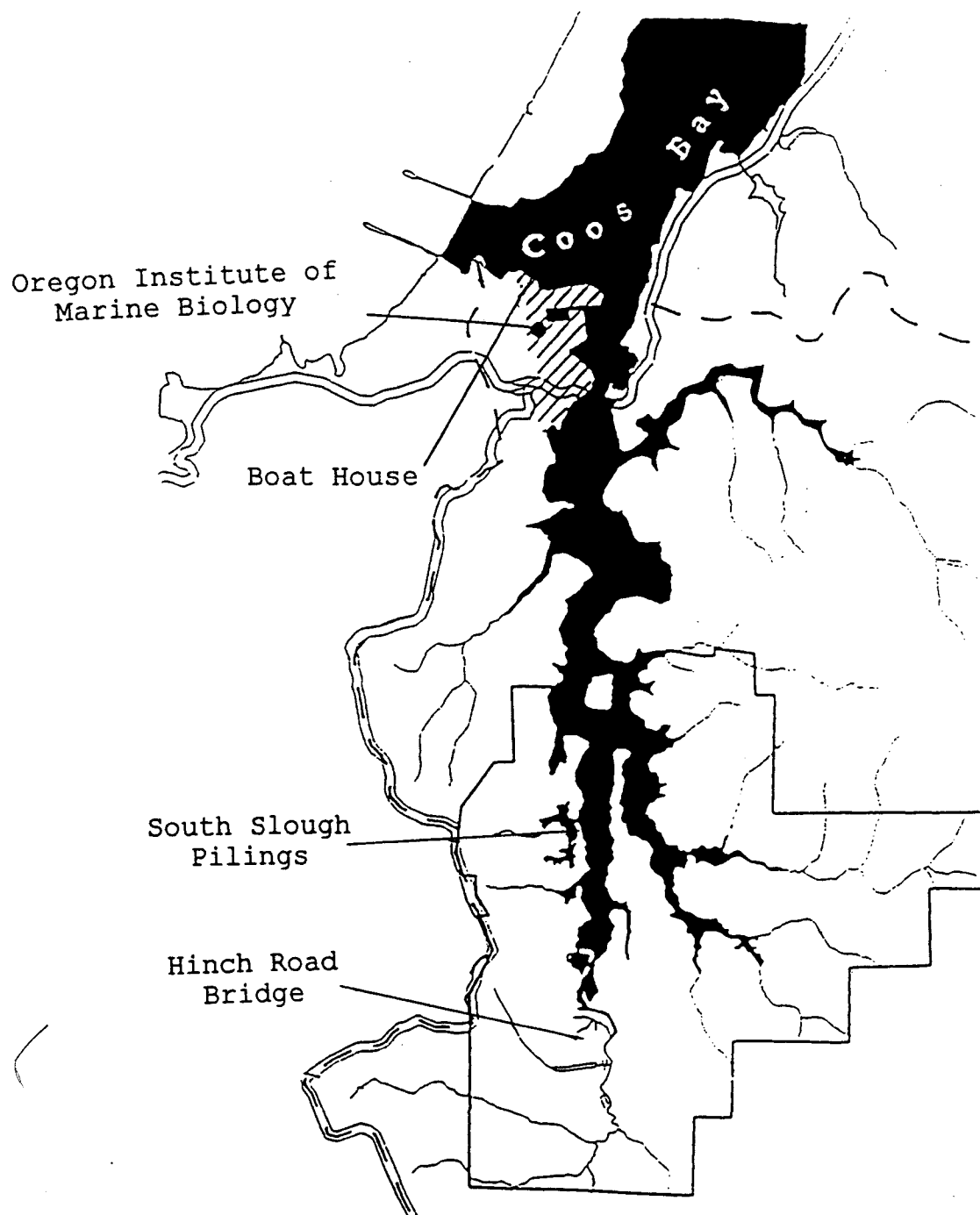
FIGURE 3: Study sites.

samples were collected weekly from OIMB's dock. Sampling was conducted one hour before high tide to ensure a marine sample. An aliquot of sample was fixed with EM grade glutaraldehyde to a 0.5% final concentration. After one hour of fixation in the dark at 4^0C, the sample was filtered sequentially through a 3.0 μm, 1.0 μm, and 0.2 μm polycarbonate filter. The filters were mounted on glass slides with a drop of immersion oil on top of the filter and a cover slip over that. The slides were then frozen in a light resistant slide box until examination (usually within one week of sampling but no longer than six months after sampling). Slides were examined under blue light using an epifluorescence Leitz Laborlux S standard microscope equipped with a 100-W Mercury light source. The 0.2 and 1.0 μm filters were enumerated into phycoerythrin-dominant photosynthetic cyanobacteria and chlorophyll-dominant eukaryotes. The 3.0 μm filter was enumerated using the same categories plus phycoerythrin-containing cryptophytes. Categories were based on the color of fluorescence: cyanobacterial cells of the genus *Synechococcus* fluoresced yellow, photoautotrophic eukaryotes fluoresced red and cryptophytes fluoresced orange.

Beginning in October 1994, samples were collected and fixed using the methods stated above but in addition to fixation the samples were stained with a nuclear stain, 4',6-diamidino-2-phenylindole (DAPI). DAPI was used in order to locate heterotrophic organisms and to better

differentiate dinoflagellates based on their distinctive nucleus. A 1 mg/ml stock solution of DAPI was thawed immediately before usage (Porter and Feig 1980). Samples were then incubated at a final concentration of .01 µg/ml of DAPI at 4^0C in the dark for ten minutes prior to filtration. Samples were filtered sequentially as stated above; however, an 8.0 µm filter was added to the series to better separate large organisms. Slides were examined under UV light for analysis of DAPI stained cells. The size classes were enumerated as above except that the 3 and 8 µm filter sizes were further enumerated for centric and pennate diatoms, autotrophic and heterotrophic dinoflagellates, and other unidentified heterotrophs.

Temperature and salinity were recorded at the time water samples were collected. A mercury thermometer with 0.2^0C gradations was placed in a rinsed bucket filled with sea water. The thermometer was read while the bulb was still immersed and after the mercury had stabilized at a fixed temperature. Density was measured using a hydrometer. A cylinder was filled with sea water from a bucket. The hydrometer was inserted in the cylinder and allowed to stabilize prior to taking a reading. The temperature and density reading were used to determine salinity. Wind speed and direction information were obtained from the U.S. Coast Guard's local station. Daily precipitation information was obtained from the weather service at North Bend Municipal airport.

Temperature and salinity have been measured almost daily at the Boat House for a number of years. Therefore, in order to look for temperature and salinity patterns I incorporated the station's data with my own. I divided the data into typical seasons (Fall constituting September, October and November; Winter -December, January and February; Spring - March, April and May; and Summer - June, July and August)to show seasonal information e.g. seasonal averages and ranges (Fig. 11-14).

Spatial Sampling

Water samples were collected from the three environments described above one hour before high high tide twice monthly. Water was collected at a depth of 1 meter using a 2-liter Niskin bottle. The samples were fixed in the field with glutaraldehyde and stored on ice in the dark until returning to the lab. The samples were then stained with DAPI, filter-fractionated, and examined by epifluorescence microscopy as above.

Water temperature and salinity were measured using a field thermometer and a field refractometer. While not as precise as a hydrometer, the refractometer was easier to transport and use in the field and was precise enough to document the wide range of salinities in the slough.

Cell Enumeration

Cells were enumerated using one of two comparable
computations for calculating cells per milliliter. First,
field of view analysis was calculated by counting cells in
either 20 fields of view or up to a total of 200 cells of
the most dominant organism using the lowest magnification
(smallest objective) possible.   Second, when density of
cells was low a strip area count was used with the 0.2 μm
and 1.0 μm filters. A strip consisted of one to five 1/2 mm
transects using oil immersion 50X objective until at least
200 cells had been counted. Prior work has shown that when
cells are randomly distributed on a filter, counting at
least 20 fields of view or 200 cells provide statistically
significant counts (Uehlinger 1964; Shapiro 1985; Booth
1987). Therefore, replicate counts were deemed not
necessary. Due to the known patchiness of phytoplankton
distribution, difference among water masses and the degree
of mixing at the three study sites abundance counts are a
snap shot in time of the organisms in that particular place
at that particular time. Since replicate counts were not
made any measure of variability can not be made.

Enumerations were converted to cells per ml using the
following conversion:

Fields of view:

(total number of cells in a field)*(objective
magnification factor)/(# of fields of view)*(total
volume filter) = cells ml^{-1}.

Transects:

(total filter area)*(total number of cells
counted)/(area of a transect)*(# of transects)*(total
volume filtered) = cells ml^{-1}.

Organisms were combined in the following manner:
Synechococcus counted on all filters were combined into one
total, chlorophyll-dominant eukaryotes counted on the .2 and
1 μm filters were combined into one total and are
represented as chlorophyll-dominant eukaryotes < 3 μm, all
cryptomonads were combined, and chlorophyll-dominant
eukaryotes counted on the 3 and 8 μm filter were combined
and represented as chlorophyll-dominant eukaryotes > 3 μm.

Analysis

Study year 1 was compared to study year 2 using graphic
analysis of cell abundances. Year 1 included 9/27/93
through 9/26/94 and year 2 included 10/3/94 through
10/24/95. Coefficients of variance were determined by
dividing the standard deviation by the means of each group
of organisms. In all analyses, a "bloom" was determined to
be an increase above the mean abundance that was at least a
doubling over the previous observation.

Biovolume

In order to determine if an increase in cell abundance is due to the addition of large cells to a base level of small cells biomass, cell carbon or cell volume can be calculated. Cell volume (biovolume) is based on cell dimensions and can be calculated for each species by applying cell dimensions to formulae for solid geometric shapes most closely matching the shape of the cells (Kovala and Larrance 1966; Wetzel and Likens 1991). Even though cell dimensions were not measured as a part of this study, a rough estimate of biovolume can be calculated by assigning equivalent spherical diameters to cells passing through different size filters. For example, cells passing through the 3μm filter were assumed to have a spherical diameter of $\cong 1\mu m \cong 1\mu m^3$. Cells passing through an 8 μm filter and collected on a 3 μm filter were assumed to have a spherical diameter of $\cong 5 \mu m \cong 100 \mu m^3$. Cells collected on an 8 μm filter were assumed to have a spherical diameter of $\cong 10\mu m \cong 10^3\mu m^3$. Biovolume was estimated using the formula for a sphere $V = (\pi/6)*D^3$ (where D refers diameter of the cell). Since some of the samples for year 1 were lost, only data for year 2 was used to estimate biovolume contributions of different size fractions of phytoplankton.

CHAPTER III

RESULTS

Temporal Study

Cyanobacteria (*Synechococcus sp.*)

Year 1 (93-94)

Two major blooms occurred in Year 1 of the study, the first in fall 1993 with cell abundance reaching over 4×10^4 cells per milliliter($c \cdot ml^{-1}$) (Fig. 4). The second bloom began in late summer 1994 and ended in early fall 1994 with cell numbers reaching 1×10^5 $c \cdot ml^{-1}$. A smaller bloom occured in spring 1994 with cell abundance reaching 2×10^4 $c \cdot ml^{-1}$. In all, cell abundance varied from 3.7×10^{-1} to 1×10^5 $c \cdot ml^{-1}$. Cell numbers were lowest during the winter. Samples from spring 1994 through mid summer 1994 were lost due to an electrical failure. Between early winter 1993 and spring 1994 the average monthly cell abundance was 1×10^3 $c \cdot ml^{-1}$.

FIGURE 4: *Synechococcus* 9/93-11/95.
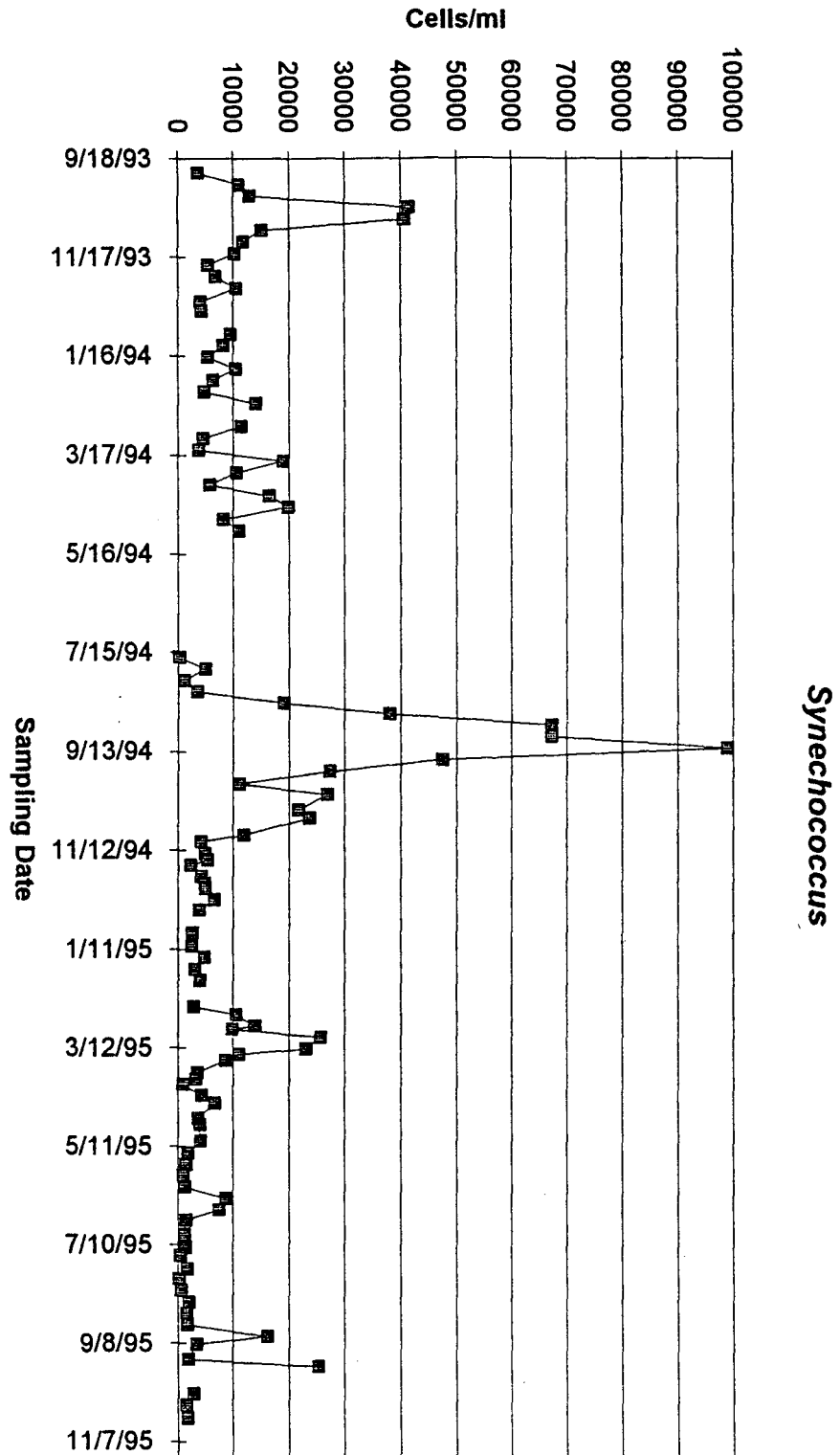
Year 2 (94-95)

Three major blooms occurred in Year 2 of this study (Fig. 4). The blooms occurred in fall 1994, spring 1995 and early fall 1995 with cell abundances of 2.5 X 10^4 c·ml^{-1}. Maximum cell abundance occurred on fall 1994 while the minimum occurred on mid summer 1995.

Similarities:

The two years are similar in that they both had increases in cell abundance in the fall and spring. The coefficient of variance for year 1 (9/27/93 to 9/26/94) and year 2 (10/3/94 to 10/24/95) was 1.19 and 1.12 respectively. Decreases occurred through winter in both years.

Differences:

Year 1 experienced much higher cell abundance than Year 2. Mean cell abundance and maximum cell number for year 1 was 1.7 X 10^4 c·ml^{-1} and 9.9 X 10^4 c·ml^{-1} respectively. Mean cell abundance and maximum cell number for year 2 was 6 X 10^3 c·ml^{-1} and 2.7 X 10^4 c·ml^{-1} respectively.

Chlorophyll-dominant Eukaryotes < 3 μm

Year 1 (93-94)

Major blooms occurred in fall 1993 and late summer 1994 with cell abundances at 1.2×10^4 and 1.5×10^4 c·ml^{-1} respectively (Fig. 5). These small eukaryotes increased and decreased rapidly showing short-lived blooms with rapid declines. Each bloom was successively smaller (1.2×10^4, 8.9×10^3, 7.3×10^3 and 4.4×10^3 respectively). Mid-winter 1994 through spring 1994 a period of low cell abundance occurred with a decrease in cell number of one to two orders of magnitude. Late winter 1994 experienced the lowest cell abundance with 10^1 c·ml^{-1}. Samples for the spring and summer 1994 were lost.

Beginning in mid-summer 1994 cell abundance increased in successively larger blooms with rapid declines between blooms.

Year 2 (94-95)

The abundance of chlorophyll dominant eukaryotes (< 3 μm) fluctuated irregularly throughout Year 2 (Fig. 5). Sporadic blooms occurred in fall 1994 and spring, summer and fall 1995 with cell abundances of 1.3×10^4, 1.4×10^4, 1.3×10^4 and 1.8×10^4 c·ml^{-1} respectively. Also between the

major blooms there were six minor blooms indicating rapid increases and decreases in abundance over a short period of time. The maximum number of cells appeared in early fall with 1.7 X 10^4 c·ml^{-1}. The minimum number of cells occurred mid-summer with 3.1 X 10^2 c·ml^{-1}.

Similarities:

In both sampling years cell abundances increased and decreased rapidly - showing several major blooms followed by rapid declines. The biggest blooms occurred repeatedly in September of each year.

Differences:

The mean number of cells was greater in year 2 of sampling (4 X 10^3 c·ml^{-1} as compared to 2.4 X 10^3 c·ml^{-1} in year 1). Year 1 was more variable (CV of 1.12) than year 2 (CV of 0.92). This was the reverse of prokaryotes where abundance was greater in year 1. The mean number of cells was larger in year 2.

FIGURE 5: Chlorophyll-dominant eukaryotes < 3 μm, 9/93-11/95.
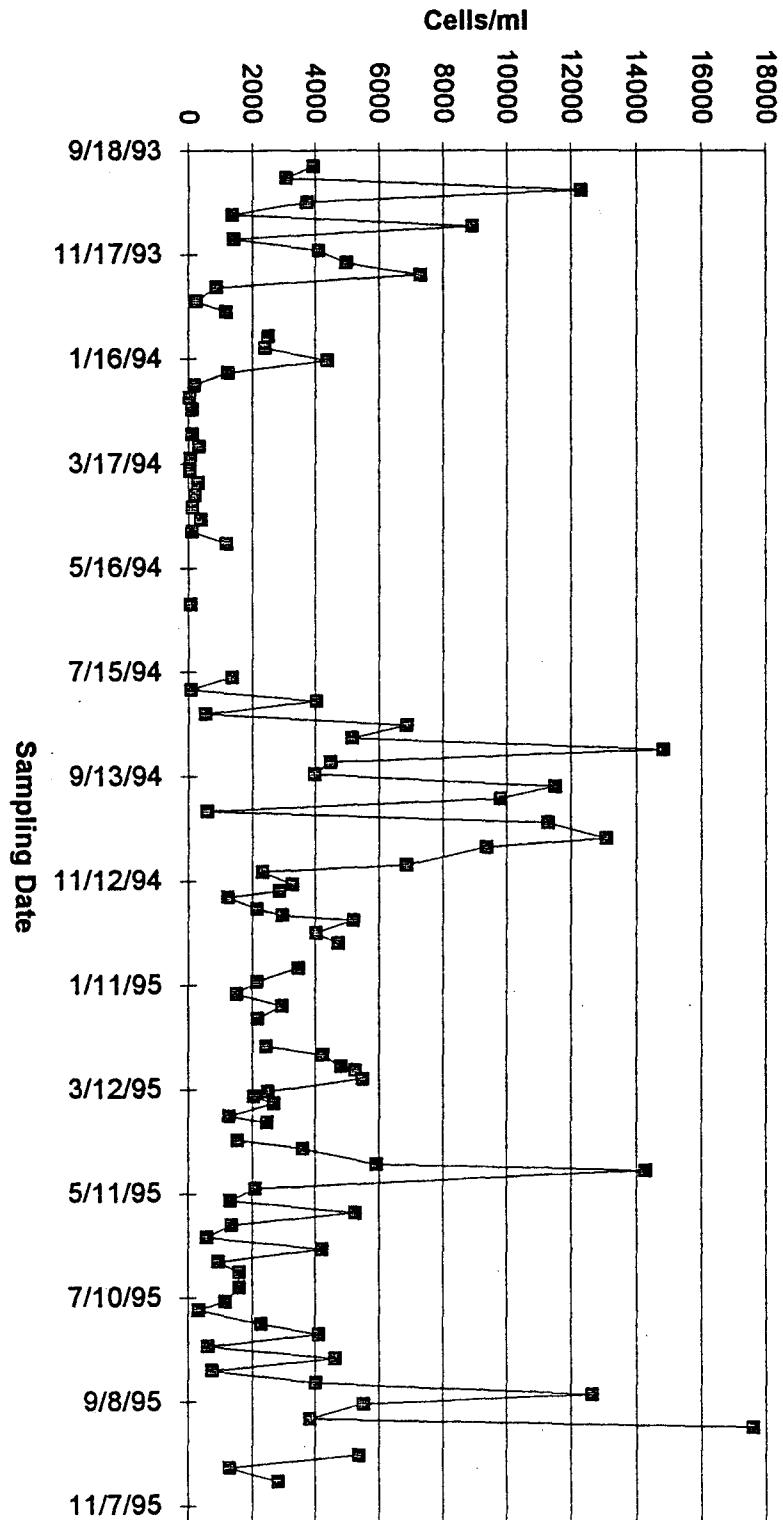
Year 1 (93-94)

During year 1 two major blooms occurred; fall 1993 (6.3 X 10^2 c·ml^{-1}) and summer 1994 (9 X 10^2 c·ml^{-1}) (this was also the maximum number of cells occurring this sampling year) (Fig. 6). A third smaller bloom occurred in early fall 1994 with a cell abundance of 4.5 X 10^2 c·ml^{-1}. The minimum number of cells occurred in summer 1994 with 1.5 X 10^1 c·ml^{-1}. Between the two major blooms the maximum number of cells was 1.9 X 10^2 c·ml^{-1}.

Year 2 (94-95)

One major bloom occurred in fall 1994 with cells reaching 1 X 10^3 c·ml^{-1} (Fig. 6). Eliminating the one major bloom, the average number of cells were 1.2 X 10^2 and range was 2.8 X 10^2 and 9 c·ml^{-1}.

Similarities:

In both sampling years Cryptomonads showed a major increase in cell abundance in the fall. Mid-winter through spring cell abundance were under 1.5 X 10^3 c·ml^{-1} showing a fairly constant and steady abundance. Samples from spring

FIGURE 6: Cryptomonads 9/93-11/95.
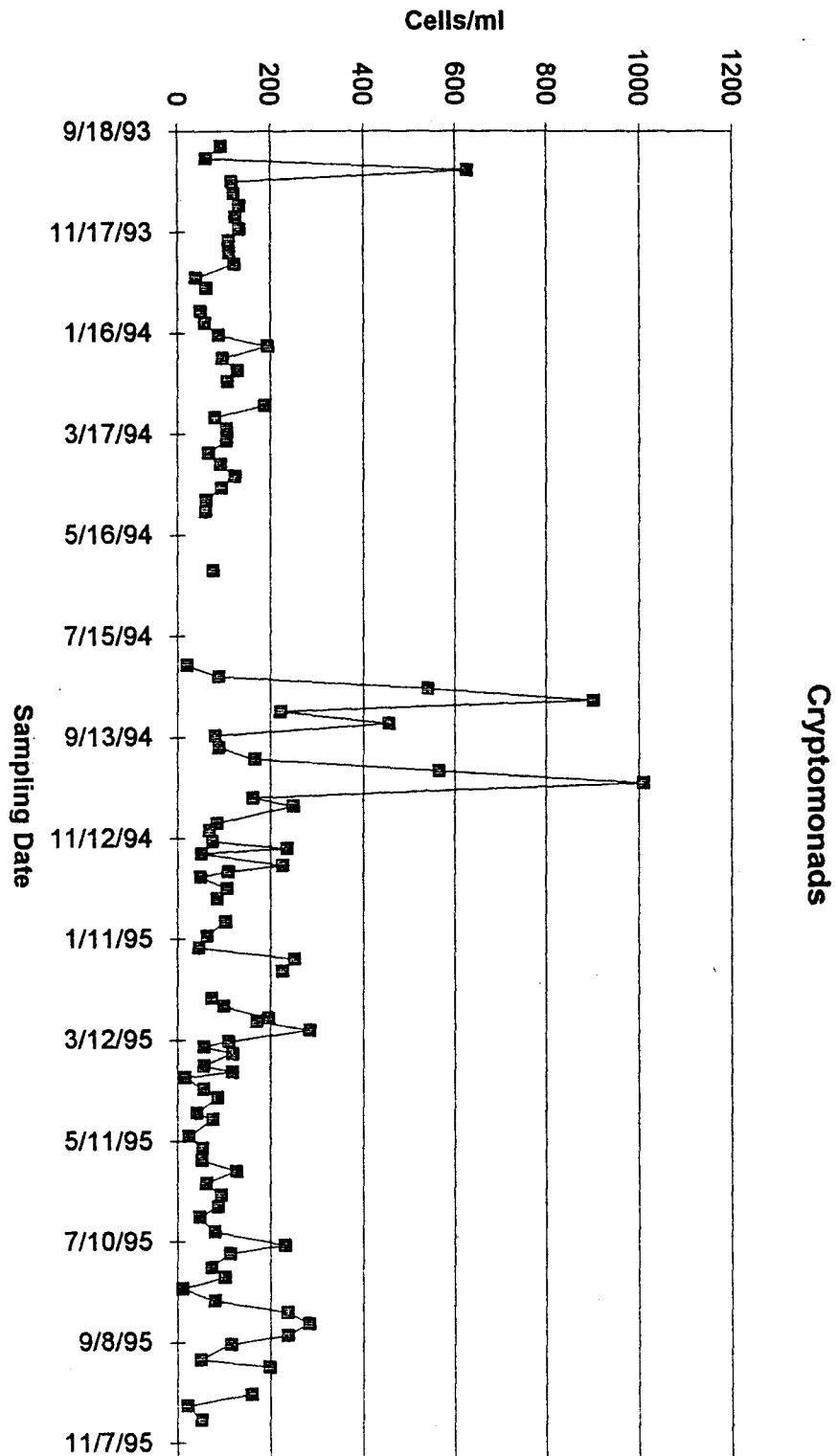
1994 through summer 1994 were lost. Mean abundances in Year 1 and Year 2 were 1.6 X 10^2 and 1.4 X 10^2 $c \cdot ml^{-1}$ respectively.

Differences:

During the first year of sampling, Cryptomonads had much higher abundance in late summer and early fall (1994) with cell abundances reaching over 3.5 X 10^2 $c \cdot ml^{-1}$ in late summer. The fall blooms seen in Year 1 did not reoccur in Year 2. Year 1 was more variable (CV of 1.12) than year 2 (CV of 1.09).

Chlorophyll-dominant Eukaryotes > 3 μm

Year 1 (93-94)

The first year of sampling showed several minor blooms and two major blooms (Fig. 7). The minor blooms occurred in fall 1993 and spring 1994 with cell abundances of 4 X 10^3 $c \cdot ml^{-1}$ and 4 X 10^3 $c \cdot ml^{-1}$ in both years. In mid-summer 1994 the first major bloom occurred with 7 X 10^3 $c \cdot ml^{-1}$ followed by a bloom in late-summer 1994 with 9.2 X 10^3 $c \cdot ml^{-1}$ (which was the maximum cell abundance for that sampling year). The minimum number of cells occurred in fall 1993 with 2 X 10^2 $c \cdot ml^{-1}$.

FIGURE 7: Chlorophyll-dominant eukaryotes > 3 µm 9/93-11/95.
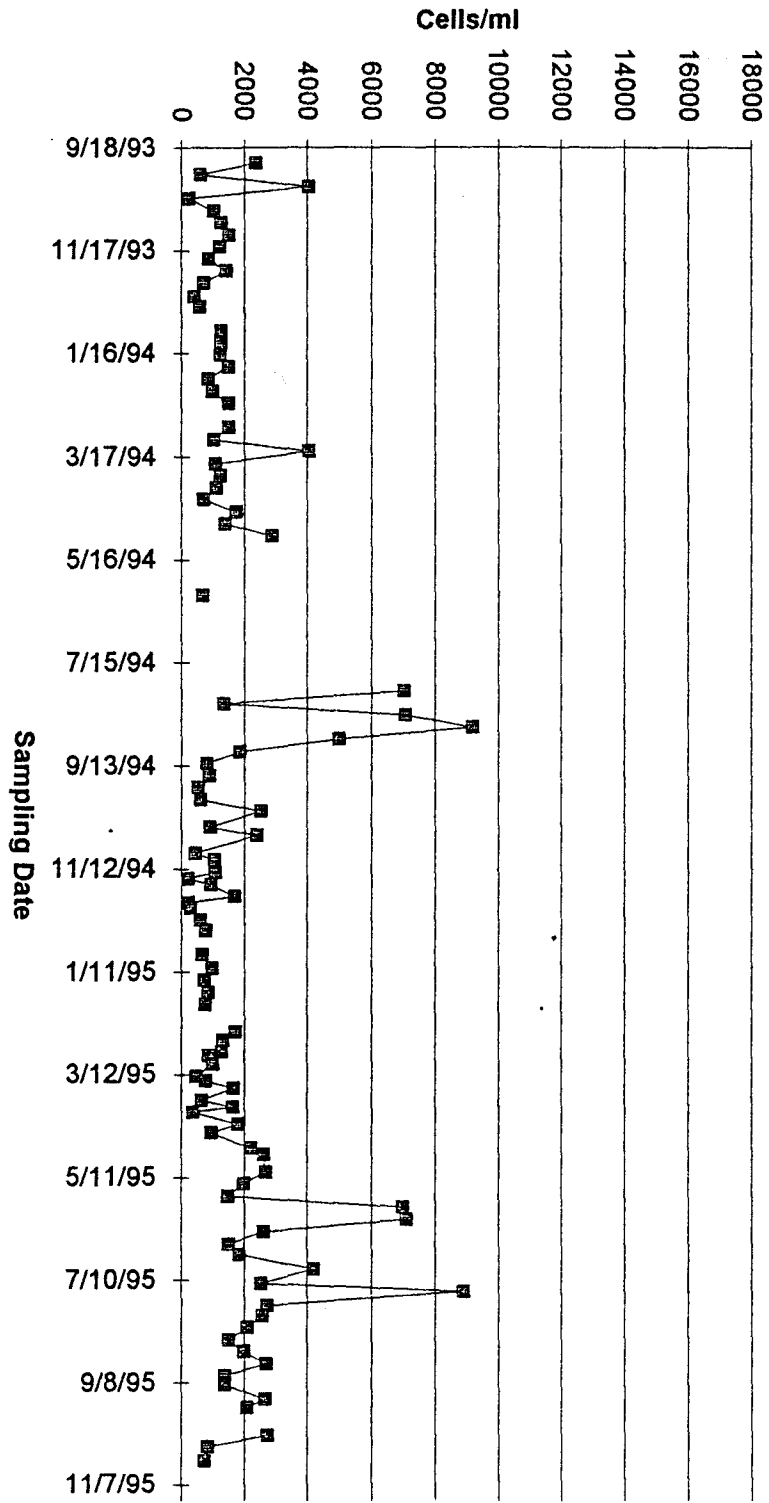
<u>Year 2 (94-95)</u>

Two high readings occurred in spring 1995 and early-summer 1995 with 7×10^3 and 7.1×10^3 c·ml^{-1} respectively (Fig. 7). The second major bloom occurred in mid-summer 1995 with 8.9×10^3 c·ml^{-1} (this was the maximum number of cells that occurred during this sampling period).

Minimum cell abundance occurred in fall 1994 with 1.9×10^2 c·ml^{-1}.

<u>Similarities:</u>

Between fall and spring of both sampling years cell abundance did not go above 2×10^3 c·ml^{-1}. Despite missing samples in the first sampling year, increases in abundance obviously occurred in summer. Mean cell abundances for both years were about the same with 1.9×10^3 and 1.8×10^3 c·ml^{-1} respectively.

<u>Differences:</u>

The spring bloom of year 1 did not reoccur in year 2. The summer bloom of year 1 lasted until fall while the summer bloom of year 2 ended in the beginning of Aug., however, cell numbers did remain above winter abundances.

Year 1 was more variable than year 2 (CV of 1.05 and 0.91
respectively).

Biovolume

Biovolume calculations weight the contributions of
phytoplankton on the basis of size (Fig. 8). This rough
calculation permitted comparisons that indicated that
biovolume increases are due to the addition of larger cells
to a base level of small cells.

Temperature and Salinity

The temperature range during the two-year study period
was 8.9^0C to 16.1^0C with the lowest temperature occurring
Fall 93 and highest temperature occurring Fall 95 (Fig. 9).
temperatures occur in fall and winter. Additionally,
salinities ranged from 22.5 $^0/_{00}$ Winter 95 to 34.6 $^0/_{00}$
Summer of 95 (Fig. 10). I have compared the daily station
data with my weekly data. In both data sets maximum water
temperatures occur in fall and in summer while minimum
highest salinities occur in summer and fall while lowest
salinities occur in winter and spring. Seasonal temperature
and salinity graphs show distinct seasonal patterns and
between year variations (Fig. 11-14). Fall and summer
salinities cluster above 32 $^0/_{00}$ while winter and spring

FIGURE 8: Biovolume Distribution.
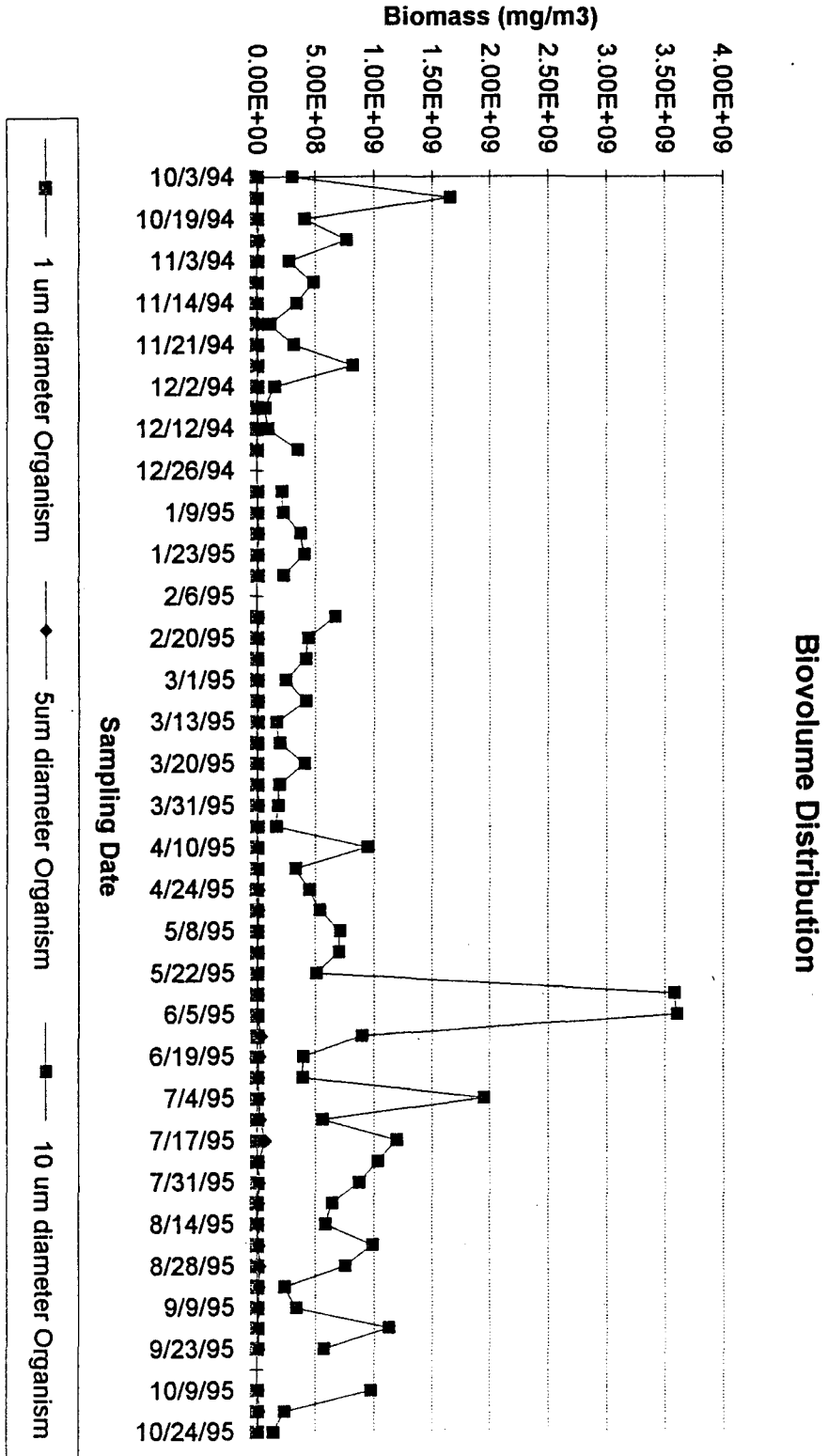
salinites cluster below 32 $^0/_{00}$. Water temperature shows
a large range in summer and fall and clusters below 12 ^0C in
winter and spring.

Yearly rainfall for 1993 and 1994 was 63.12 and 60.55
inches respectively. Rainfall for 1995 was 89.73 inches
(Fig. 15).

FIGURE 9: Water temperature 9/93-11/95.
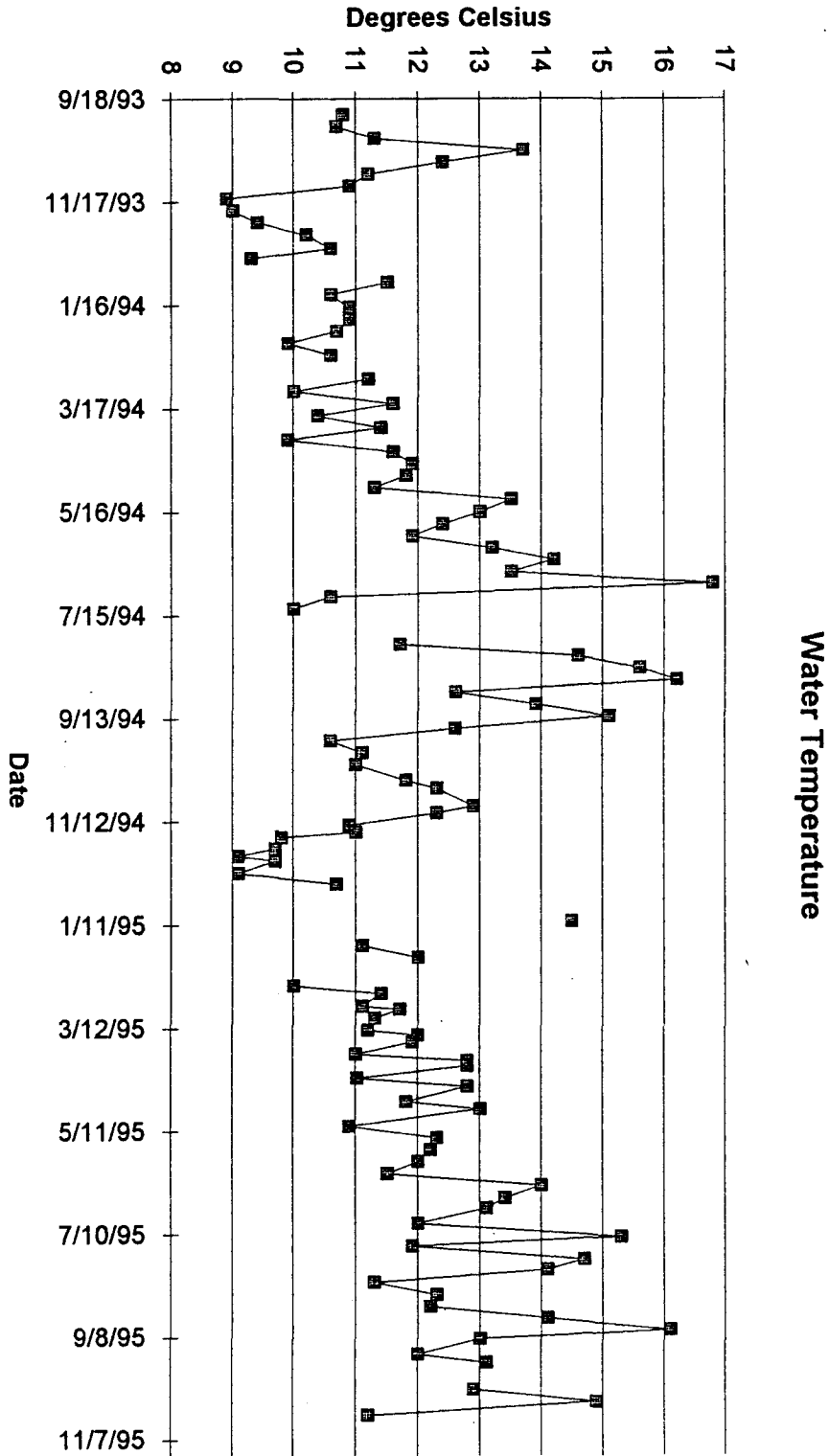
FIGURE 10: Water Salinity 9/93-11/95.
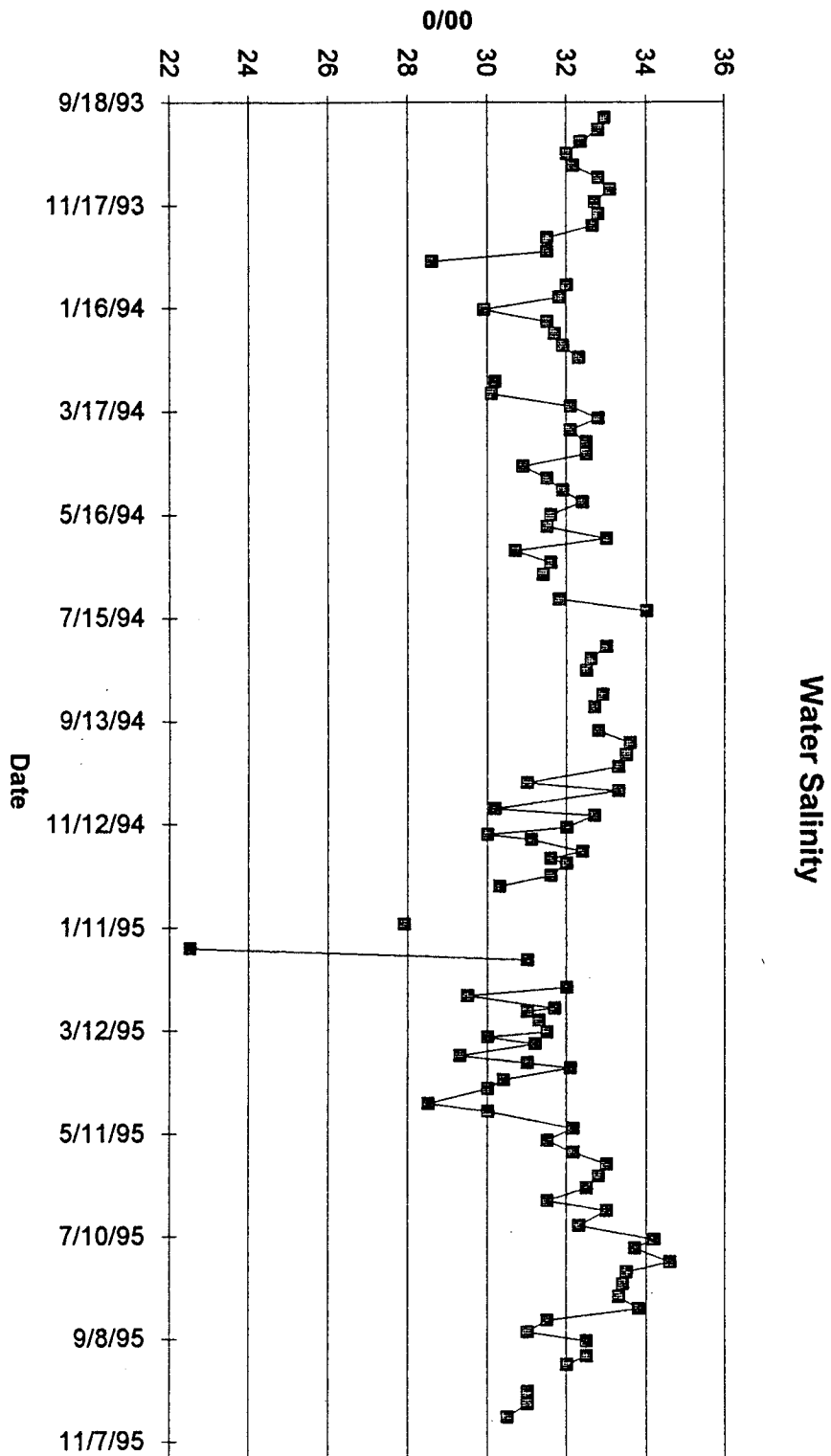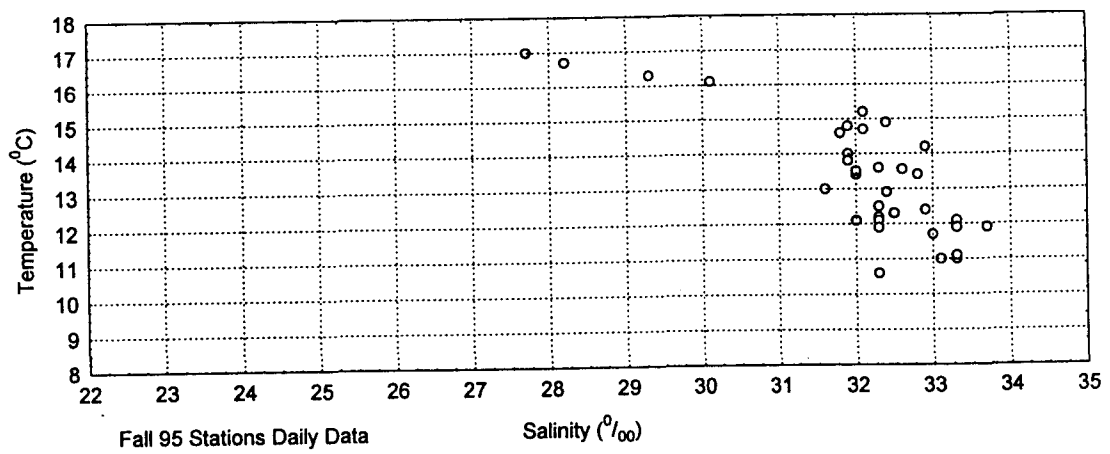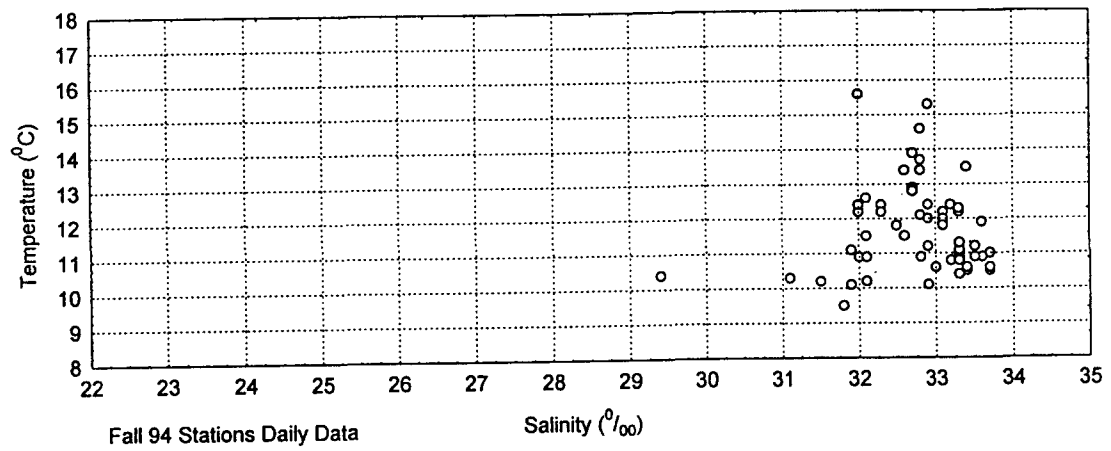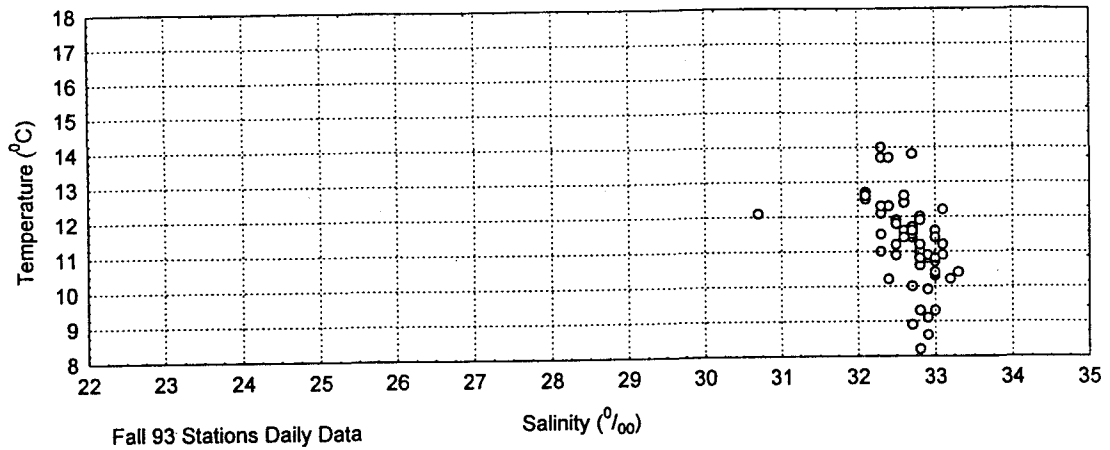
FIGURE 11: Temperature vs salinity, fall 93, fall 94, and fall 95 from Oregon Institute of Marine Biology data.
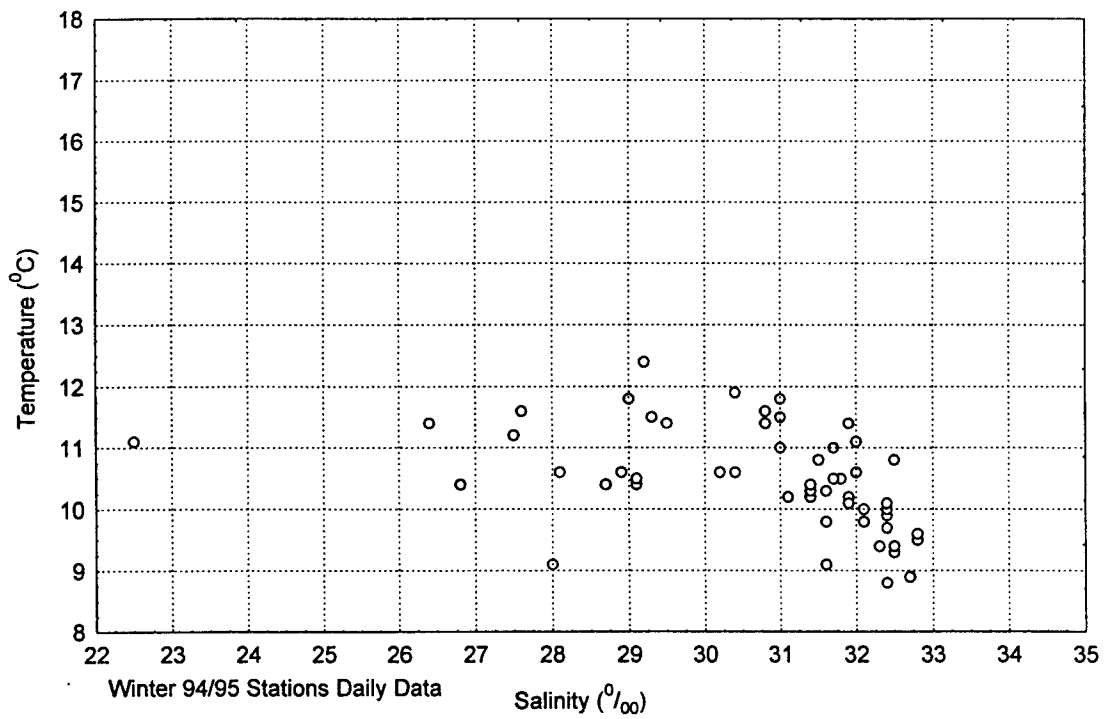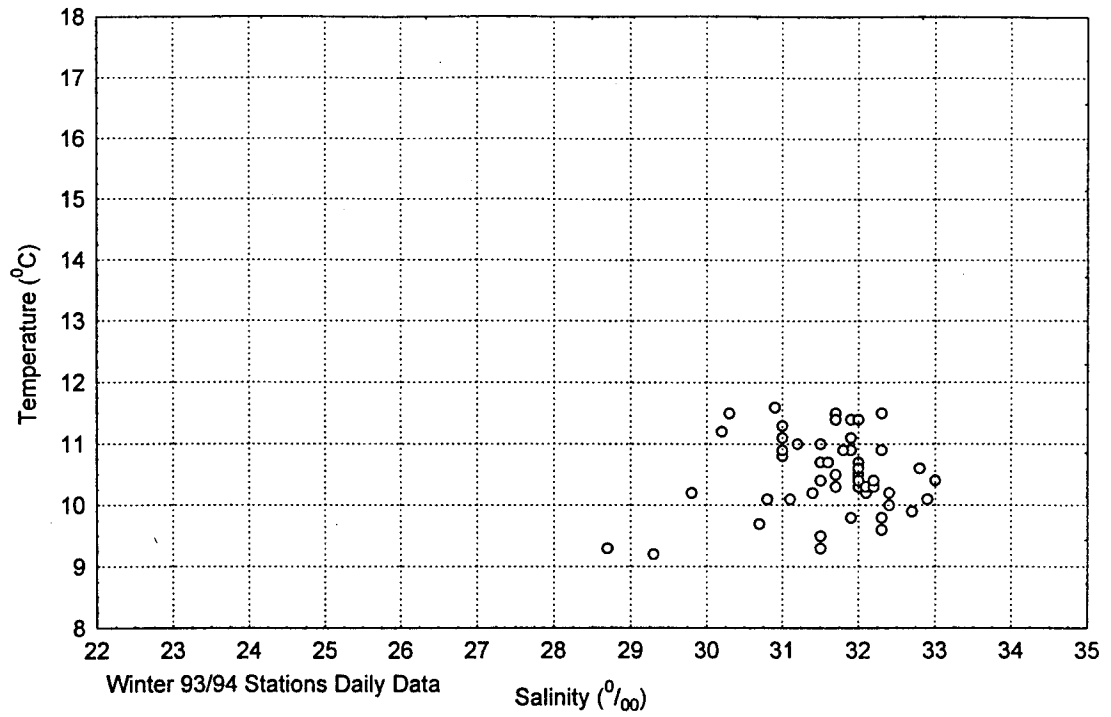
FIGURE 12: Temperature vs salinity, winter 93/94 and winter 94/95, from OIMB data.
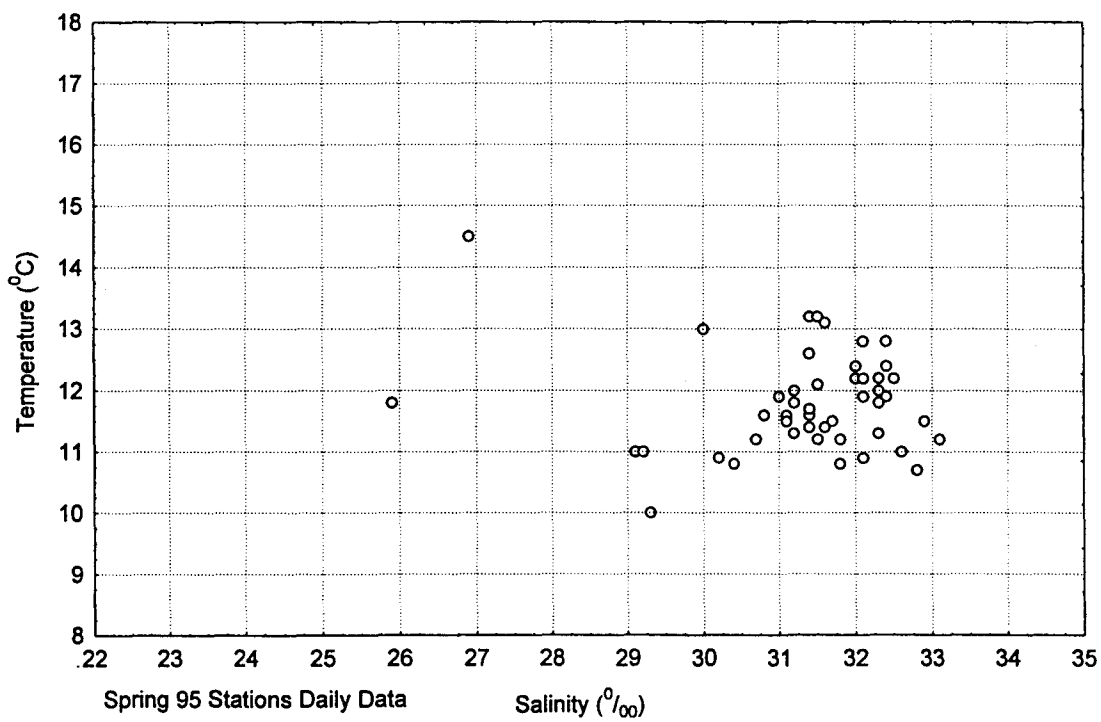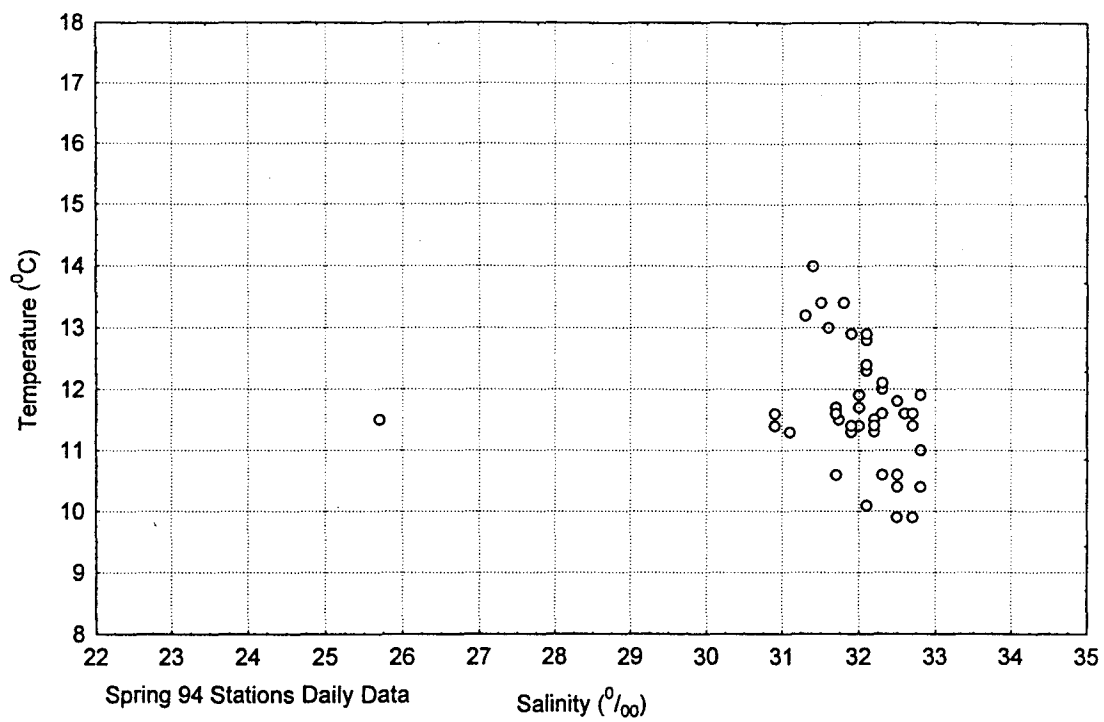
FIGURE 13: Temperature vs salinity, spring 94 and spring 95, from OIMB data.
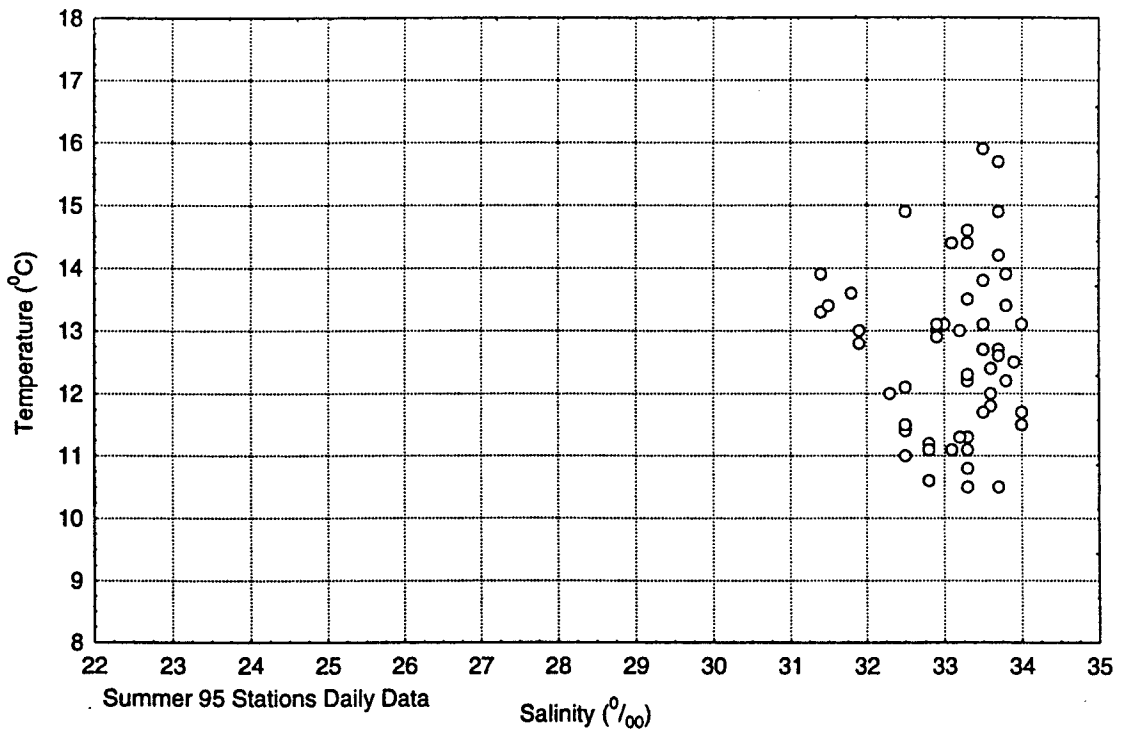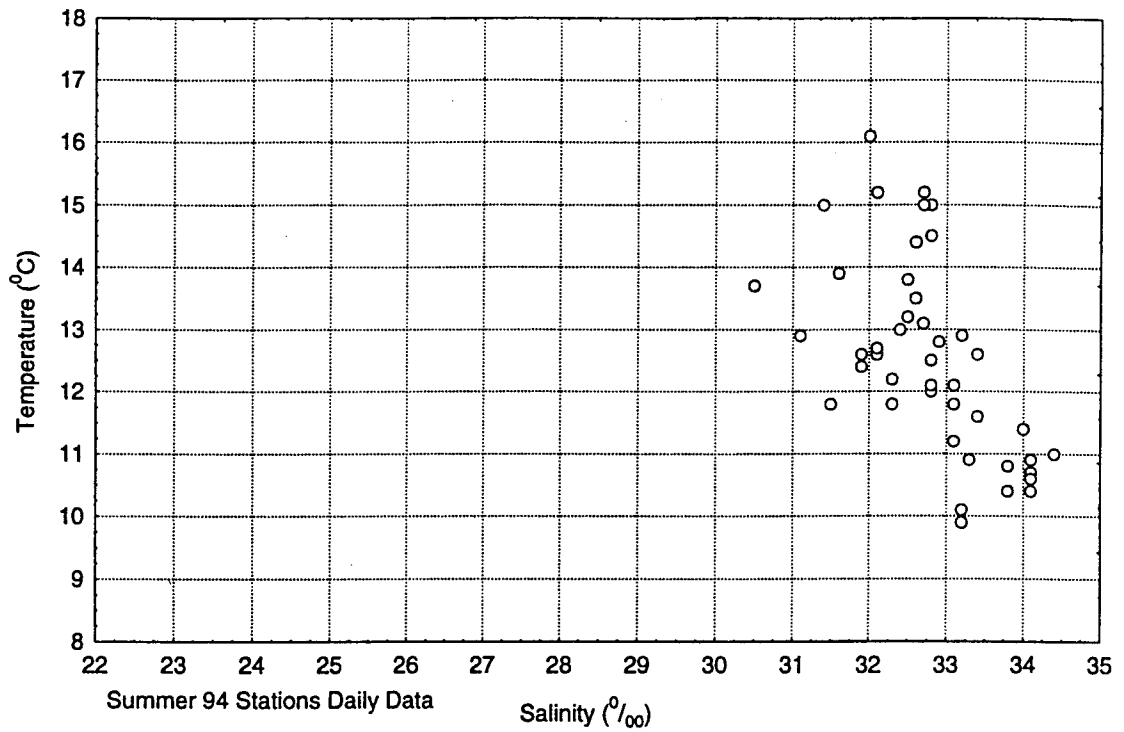
FIGURE 14: Temperature vs salinity, summer 94 and summer 95, from OIMB data.

Rainfall
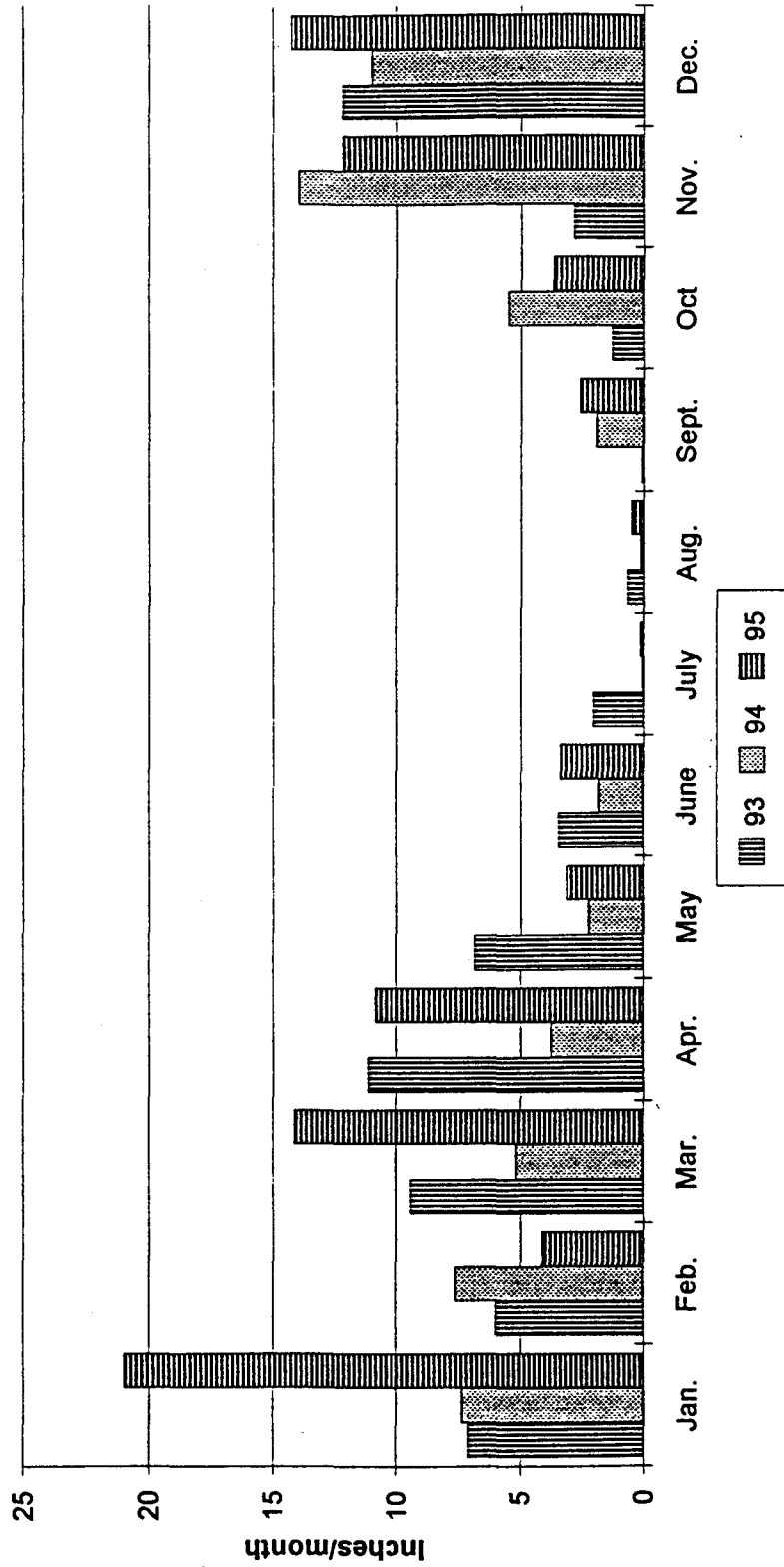
FIGURE 15: Comparison of rainfall for 93, 94, and 95 (data from North Bend Airport.

Spatial Study

Site 1, Boat House

Synechococcus

Between fall 1994 and fall 1995 three blooms of *Synechococcus* occurred in the spring, summer and fall with cell abundances of 2.2 X 10^4, 1.1 X 10^4, and 2.5 X 10^4 c·ml^{-1} respectively (Fig. 16). The lowest abundance of cells occurred in fall 1995 with 6.6 X 10^2 c·ml^{-1}.

Small Chlorophyll-Dominant Eukaryotes

Phototrophic eukaryotes < 3 µm experienced three blooms occuring at the same times as *Synechococcus* blooms with cell abundances of 1.3 X 10^4, 1.4 X 10^4 and 1.8 X 10^4 c·ml^{-1} respectively. The lowest abundance of cells occurred in mid summer with 1.1 X 10^3 c·ml^{-1} (Fig.17).

Cryptomonads

On four occasions, cell numbers exceeded 2 X 10^2 c·ml^{-1} (Fig. 18). These occurred without regard to season. The lowest abundance of cryptomonads occurred in winter with 10^1 c·ml^{-1}.

Centric and Pennate Diatoms

Centric diatoms began blooming mid-spring reaching a peak abundance of 5.9 X 10^3 c·ml^{-1} in late spring/summer (Fig. 20). Two smaller blooms occurred in mid-summer (9.9 X 10^2 c·ml^{-1}) and in late summer (8.3 X 10^2 c·ml^{-1}). The lowest cell abundance occurred in mid-winter with < 10 c·ml^{-1} (Fig. 19).

Pennate diatoms bloomed in the spring, summer and fall. Peak abundances occurred in the summer (8 X 10^2 c·ml^{-1}). Lowest cell abundance occurred in early spring (2 x 10^2 c·ml^{-1}).

Phototrophic Dinoflagellates and Heterotrophic Dinoflagellates

Phototrophic dinoflagellates experienced eight blooms during the study year. The largest bloom occurred in mid-summer (4.8 X 10^1 c·ml^{-1}) (Fig. 21). On five sampling dates no phototrophic dinoflagellates were seen in the sample. This occurred in all seasons except spring but occurred most frequently in mid- to late-fall.

Heterotrophic dinoflagellates bloomed on six occasions during the sampling period (Fig. 22). The largest bloom occurred early-fall with cells reaching 4 X 10^1 c·ml^{-1}.

Other Chlorophyll-Dominant Phototrophs (> 3μm) and
Heterotrophs

Chlorophyll dominant phototrophs experienced multiple
blooms the largest of which occurred late-spring (7×10^3
$c \cdot ml^{-1}$) (Fig. 23). The lowest abundance of cells occurred
in late fall with cell numbers dropping to 1.9×10^2 $c \cdot ml^{-1}$.

Heterotrophs also experienced multiple blooms - the
largest of which occurred in early-summer with cell numbers
reaching 2.9×10^3 $c \cdot ml^{-1}$ (Fig. 24). The lowest cell
abundances occurred in early-spring with numbers declining
to 6.6×10^1 $c \cdot ml^{-1}$.

Salinity and Temperature

The highest temperature and salinity occurred in
the summer (Fig. 25 & 26). The lowest temperature and
salinity occurred in the winter.

Site 2, South Slough Pilings

Synechococcus

Synechococcus bloomed on seven occasions during the
study year (Fig. 16). The blooms occurred throughout the
year except for summer. The highest abundance of cells
occurred in mid-fall (2×10^4 $c \cdot ml^{-1}$). The lowest abundance

of cells occurred in early-summer (2.2×10^2 c·ml^{-1}). The highest cell abundance during the summer was 6×10^2 c·ml^{-1}.

Small Chlorophyll Dominant Eukaryotes

Small chlorophyll dominant eukaryotes bloomed on six occasions throughout-out the spring, summer and fall (Fig. 17). The highest abundance of cells occurred in late-spring (1.4×10^5 c·ml^{-1}). In early fall cell abundance reached 3.4×10^4 c·ml^{-1}. The lowest abundance of cells occurred in the winter and early-spring dropping to 7×10^2 c·ml^{-1}.

Cryptomonads

Cryptomonads began blooming in the early-spring and experienced three blooms between early-spring and mid-fall (Fig. 18). Peak abundance of cells occurred early-summer (1.0×10^3 c·ml^{-1}).

The lowest abundance of cells occurred in mid-winter (7.4×10^1 c·ml^{-1}). The average number of cells for this study year was 4.2×10^2 c·ml^{-1}.

Centric and Pennate Diatoms

Centric diatoms showed three distinct blooms during the study year (Fig. 19). These occurred in early-spring, early-summer, and late-fall (7.5×10^1, 1.1×10^2, and 1.5

X 10^2 c·ml^{-1} respectively). The average number of cells was 3.1 X 10^1 c·ml^{-1}. No centrics were observed in the sample mid- to late-winter or early- to mid-fall.

Pennate diatoms experienced a major bloom starting in early-spring and ending in late-spring with maximum cell abundance reaching 2.1 X 10^3 c·ml^{-1} in mid-spring (Fig. 20). Pennates experienced six minor blooms throughout out the study year. Cell abundance reached its lowest mid-fall 1994 (3.2 X 10^1 c·ml^{-1}). The average cell abundance for the year was 3.1 X 10^2 c·ml^{-1}.

Phototrophic and Heterotrophic Dinoflagellates

Phototrophic dinoflagellates had several distinct blooms through-out the study period (Fig. 21). The largest bloom occurred early-spring (8.1 X 10^1 c·ml^{-1}). The yearly average cell abundance was 2.0 X 10^1 c·ml^{-1}. Heterotrophic dinoflagellates also experienced several blooms through out the year with cell maximum reaching 4.1 X 10^1 c·ml^{-1} in late-summer (Fig. 22). The average number of heterotrophic dinoflagellates during the year was 6 c·ml^{-1}.

Other Phototrophs and Other Heterotrophs

Chlorophyll dominant phototrophs (> 3 µm) experienced multiple blooms throughout out the study year (Fig. 23). The two largest blooms occurred in late-spring and late-

summer (7.1×10^3 and 8.4×10^3 c·ml^{-1} respectively). Cell abundances were low in the late-fall and early-winter when cells declined to 2.5×10^2 c·ml^{-1}.

Heterotrophs also experienced multiple blooms through out the study year (Fig. 24). The two largest occurred in late-spring and late-summer (7.3×10^3 and 7×10^3 c·ml^{-1} respectively). Cell abundances were low in the late-fall and early-winter when cells declined to 2×10^2 c·ml^{-1}.

Temperature and Salinity

The highest water temperature and salinity occurred in the summer (Fig. 25 & 26). The lowest water temperature occurred in late-fall and the lowest salinity occurred in mid-winter.

Site 3, Hinch Bridge Road

Synechococcus

There were five blooms of *Synechococcus* during the study year (Fig. 16). These blooms occurred in fall and winter with maximum abundance reaching 1.1×10^4 c·ml^{-1} in the fall of 1994. Minimum cell abundance occurred in the winter 1995 (< 10 c·ml^{-1}).

Small Chlorophyll Dominant Eukaryotes

Small chlorophyll dominant eukaryotes bloomed on seven occasions (Fig. 17). These blooms occurred during fall 1994, winter 1995, and summer and fall 1995. Maximum abundance occurred late-summer/early-fall 1995 with cell numbers reaching 4.6×10^4 $c \cdot ml^{-1}$. Minimum cell abundance occurred in winter and early-spring (1.9×10^1 $c \cdot ml^{-1}$).

Cryptomonads

There were seven blooms occurring in all seasons (Fig. 18). The major blooms occurred in early-winter , late-spring/summer, and fall with cell numbers reaching 1.5×10^3 $c \cdot ml^{-1}$ in early summer. Minimum cell abundance occurred mid-winter and lasted until late-spring.

Centric and Pennate Diatoms

Centric diatoms experienced one major bloom in mid-summer with cells reaching 7.5×10^2 $c \cdot ml^{-1}$ and two minor blooms in early-winter and late-spring (Fig. 19). There was low cell abundance throughout fall, winter and spring.

Pennate diatoms experienced six blooms the largest occurring in early-summer with cell numbers reaching 9.5×10^2 $c \cdot ml^{-1}$ (Fig. 20). Lowest cell abundance occurred in mid-winter.

Phototrophic and Heterotrophic Dinoflagellates

Phototrophic dinoflagellates experienced seven blooms the largest occurring in early-summer (1.6×10^2 c·ml^{-1}) (Fig. 21). Cell numbers declined to zero in all seasons.

Heterotrophic dinoflagellates four bloom periods with the largest occurring in late-summer (Fig. 22). Cells reached a maximum of 1.1×10^2 c·ml^{-1}. Cells numbers showed many declines throughout all seasons.

Other Phototrophs and Other Heterotrophs

Chlorophyll-dominant phototrophs (> 3 µm) includes centrics, pennates, phototrophic dinoflagellates and other phototrophic organism not recognizable as falling into the other categories (Fig. 23). There were seven blooms throughout the study year. The largest bloom occurred in late-summer/early-fall with cell maximums reaching 1.4×10^4 c·ml^{-1}. Minimum cell abundance occurred in mid-winter (1.5×10^1 c·ml^{-1}).

Heterotrophs (> 3 µm) (heterotrophic dinoflagellates, ciliates and other heterotrophs not falling into the other categories) experienced one major bloom occurring in late-summer with cell abundances reaching 2×10^3 c·ml^{-1} (Fig. 24). Minimum cell abundance occurred in mid-spring (5.3×10^1 c·ml^{-1}).

Temperature and Salinity

   The highest water temperature and salinity occurred in
the summer and early-fall (Fig. 25 & 26). The lowest water
temperature occurred in late-fall. The lowest salinities
occurred in late-fall, winter and spring.

Comparison of the Three Sites

   Synechococcus abundance was highest at the coastal site
(Boat House) and decreased in the middle (South Slough
Pilings) and lower regions (Hinch Road Bridge) of Coos Bay
estuary. The blooms occurred at approximately the same
time. Synechococcus was more variable in the lower regions
of the estuary with a coefficient of variance (CV) of 2.22
as compared to the coastal site with a CV of 1.09.

Synechococcus $c \cdot ml^{-1}$	Mean	SD	CV	Minimum	Maximum
Boat House	5,588	6,113	1.09	664	25,242
S.S. Pilings	2,958	3,957	1.34	215	19,509
Hinch Bridge	1,049	2,332	2.22	9	10,553

   Chlorophyll-dominant eukaryotes < 3 µm abundance
were highest (mean and maximum) in the middle- and lower-
regions of the estuary. In addition, they were more
variable at these sites as compared to the coastal site.
Lowest abundance occurred at the coastal site. Abundance
patterns were similar between sites.

Chlorophyll-dominant Eukaryotes < 3 μm $c \cdot ml^{-1}$	Mean	SD	CV	Minimum	Maximum
Boat House	4,572	4,135	0.9	1,124	17,579
S.S. Pilings	13,073	26,428	2.02	360	136,717
Hinch Bridge	6,731	10,801	1.6	11	45,027

Cryptomonads abundance (mean and maximum) increased in the mid- and lower-regions of the estuary. The lowest abundance occurred at the coastal site which is the inverse of *Synechococcus*. The mid- and lower-regions of the estuary tended to be more variable with larger fluctuations in abundance. The coastal site had the lowest mean and maximum abundance and was less variable.

Cryptomonads $c \cdot ml^{-1}$	Mean	SD	CV	Minimum	Maximum
Boat House	122	67	0.55	44	283
S.S. Pilings	416	239	0.58	74	997
Hinch Bridge	494	460	0.93	0	1,471

Centric diatom abundance was highest at the coastal site and lowest at the mid-estuary site. The coastal site and the lower regions of the estuary were more variable than the mid-estuary. Blooms occurred earliest at the coastal site.

Centric Diatoms $c \cdot ml^{-1}$	Mean	SD	CV	Minimum	Maximum
Boat House	498	1,169	2.33	4	5,890
S.S. Pilings	31	40	1.29	0	148
Hinch Bridge	70	184	2.62	0	752

Pennate diatoms reached their maximum abundance in the mid-region of the estuary. This site was more variable with earlier blooms than the other two sites. The bloom occurred approximately four weeks prior to the smaller blooms at the other two sites. The coastal site was the last to experience the pennate bloom and also had the lowest mean and maximum abundance.

The pennate genus *Pseudo-nitschia* was enumerated separately as an example of seasonal variability in one genus. *Pseudo-nitschia* was of particular interest due to the fact that several species produce domic acid. Four separate peaks of *Pseudo-nitschia* occurred between late-spring and early-fall 1995 at the Boat House (Fig. 27). These four peaks may represent successional blooms of different species of *Pseudo-nitschia* spp. Abundance of *Pseudo-nitschia* spp. at the two estuarine sites were insignificant, indicating a preference for high salinity and a coastal distribution of species in this genus.

Pennate Diatoms	Mean	SD	CV	Minimum	Maximum
Boat House	196	195	0.99	19	836
SS Pilings	306	515	1.69	32	2,059
Hinch Bridge	271	317	1.17	0	960

The largest abundance of phototrophic dinoflagellates occurred in the lower-regions of the estuary and decreased in the mid- and upper-regions. The dino bloom began earlier in the lower areas of the estuary. Abundance patterns

appear to be more variable in the lower regions of South Slough and more constant at the coastal site.

Phototrophic Dinoflagellate $c \cdot ml^{-1}$	Mean	SD	CV	Minimum	Maximum
Boat House	12	13	1.1	0	48
S S Pilings	20	20	0.99	0	81
Hinch Bridge	37	48	1.3	0	159

Heterotrophic dinoflagellates reached their maximum abundance in the lower-estuary. However, their mean abundance was highest at the coastal site. Abundance patterns appear to be more variable in the lower regions of South Slough and less variable at the coastal site.

Heterotrophic Dinoflagellate	Mean	SD	CV	Minimum	Maximum
Boat House	14	13	0.95	0	40
S S Pilings	6	10	1.66	0	41
Hinch Bridge	8	21	2.81	0	108

There were close to twice as many other phototrophs in the lower-estuary as compared to the mid-region. Again, the mid- and lower-regions of the estuare were more variable than the coastal site. Lowest abundance occurred at the coastal site.

Phototrophs	Mean	SD	CV	Minimum	Maximum
Boat House	949	562	0.59	94	2,206
S S Pilings	2,023	1,869	1.12	203	7,320
Hinch Bridge	2,663	3,582	1.57	15	13,908

Other heterotrophic protists were most abundant in the mid- region of the estuary. Their abundance at the coastal

and lower-estuary site was more variable than in the mid-
region of South Slough.

Other Heterotrophs	Mean	SD	CV	Minimum	Maximum
Boat House	537	590	1.1	55	2,910
S S Pilings	1,848	386	0.89	245	8,419
Hinch Bridge	407	458	1.15	53	2,001

Water temperature was more variable in the mid- and
lower-regions of the estuary. The largest temperature
fluctuations occurred in the lower-estuary.

Temperature	Mean	SD	CV	Minimum	Maximum
Boat House	12.2	1.4	0.11	9.1	15.5
S S Pilings	13.9	3.6	0.26	8.3	20.6
Hinch Bridge	13.1	4.1	0.31	6.5	20.1

Salinity was also more variable in the mid- and lower-
regions of the estuary and the largest salinity fluctuations
occurred in the lower areas of the estuary. Since salinity
was always measured at high tide it appears less variable
than what might be seen if measured at low tide.

Salinity	Mean	SD	CV	Minimum	Maximum
Boat House	31.4	1.65	0.05	28.0	35.0
S S Pilings	25.5	6.05	0.25	8.0	34.0
Hinch Bridge	9.9	10.04	1.02	0.0	26.0
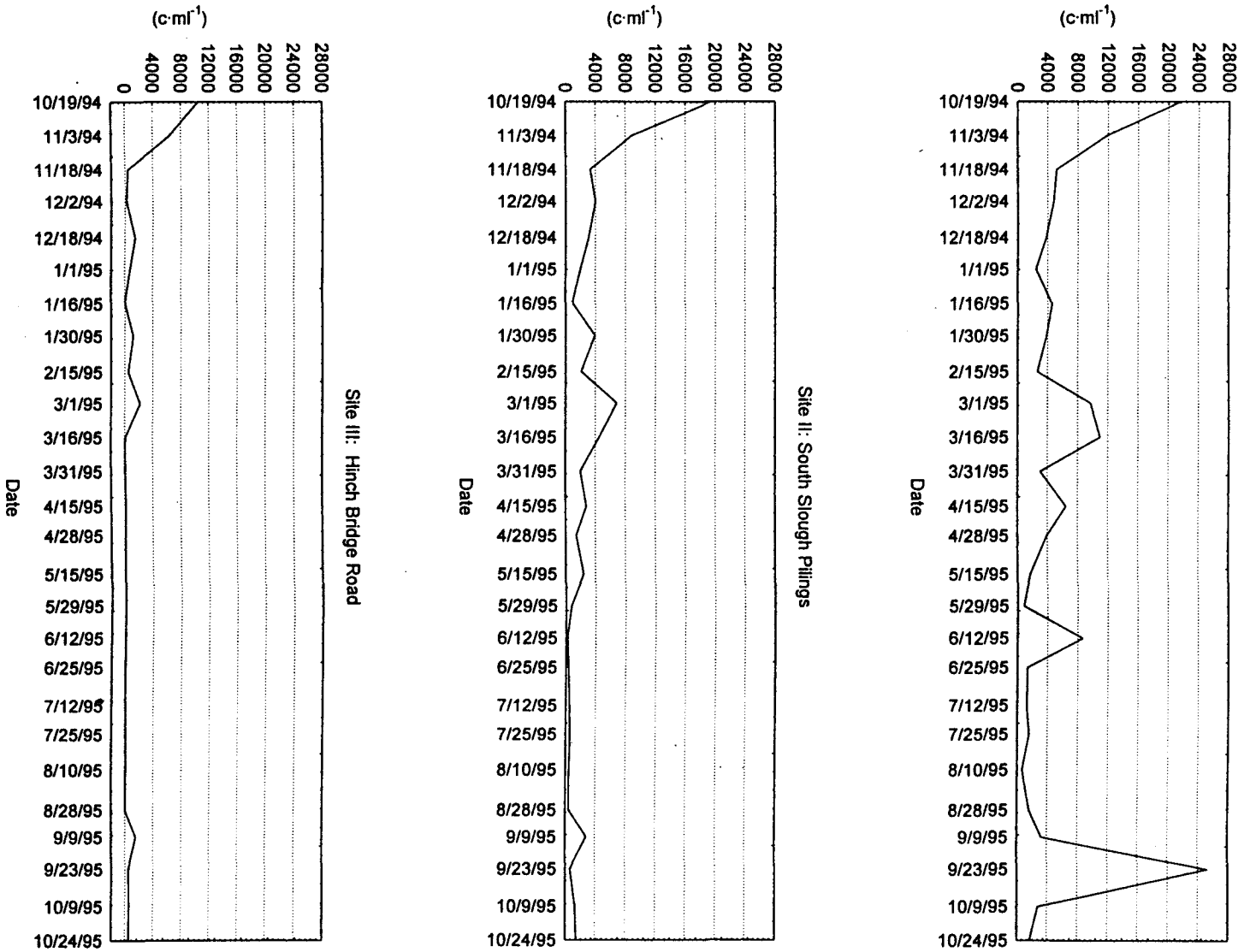
FIGURE 16: *Synechococcus at sites 1, 2, and 3.*

Site III: Hinch Bridge Road

Site II: South Slough Pilings

Site I: Boat House

Synechococcus

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Chlorophyll-Dominant Eukaryotes < 3 µm

Site I: Boat House

Site I: Boat House chart with y-axis (c·ml⁻¹) labeled 20000, 40000, 60000, 80000, 1e5, 1.2e5, 1.4e5, 1.6e5 and x-axis Date from 10/19/94 to 10/24/95.

Site II: South Slough Pilings

Site II: South Slough Pilings chart with y-axis (c·ml⁻¹) labeled 20000, 40000, 60000, 80000, 1e5, 1.2e5, 1.4e5, 1.6e5 and x-axis Date from 10/19/94 to 10/24/95.

Site III: Hinch Bridge Road

Site III: Hinch Bridge Road chart with y-axis (c·ml-1) labeled 20000, 40000, 60000, 80000, 1e5, 1.2e5, 1.4e5, 1.6e5 and x-axis Date from 10/19/94 to 10/24/95.

FIGURE 17: Chlorophyll-dominant eukaryotes < 3 m at sites 1, 2, and 3.

Cryptomonads

Site I: Boat House

(c·ml⁻¹)
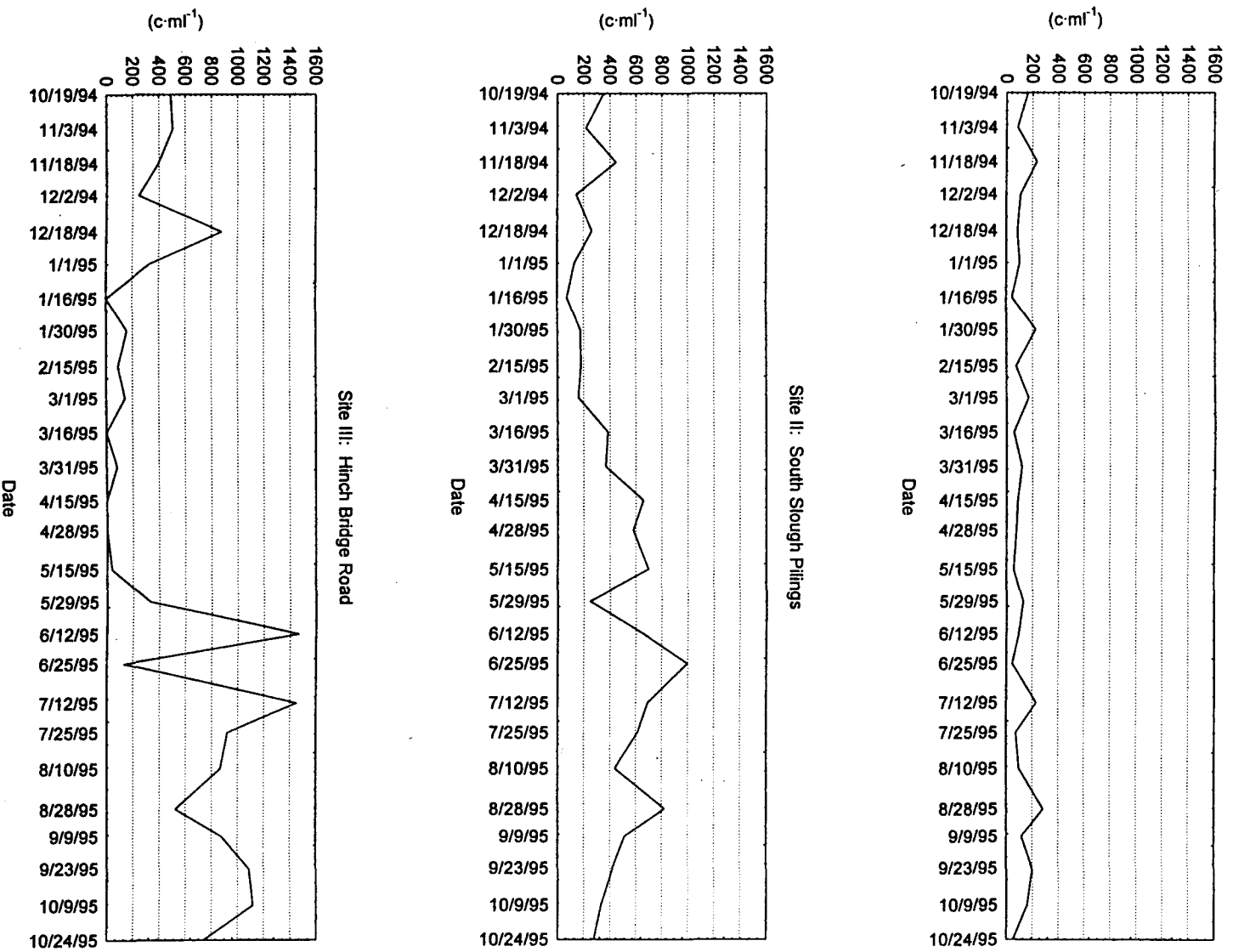
FIGURE 18: Cryptomonads at sites 1, 2, and 3.

Site III: Hinch Bridge Road

Site II: South Slough Pilings

Date

FIGURE 19: Centric diatoms at sites 1, 2, and 3.

Centric Diatoms

Site I: Boat House

Site II: South Slough Pilings

Site III: Hinch Bridge Road

Pennate Diatoms

Site I: Boat House

Site II: South Slough Pilings
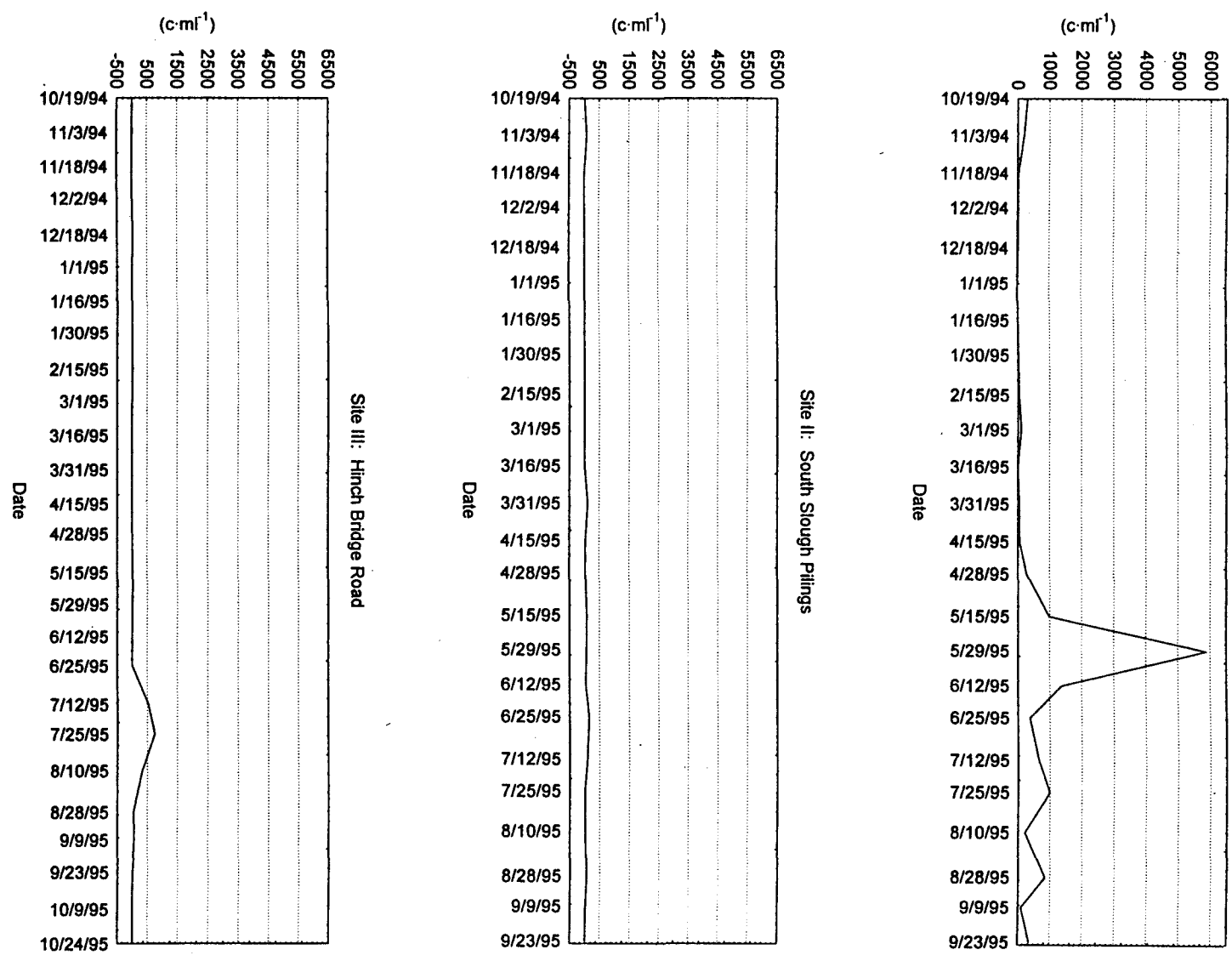
Site III: Hinch Bridge Road

FIGURE 20: Pennate diatoms at sites 1, 2, and 3.

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Autotrophic Dinoflagellates

FIGURE 21: Autotrophic dinoflagellates at sites 1, 2, and 3.

Heterotrophic Dinoflagellates

Site I: Boat House

(c·ml⁻¹)

Date

Site II: South Slough Pilings

(c·ml⁻¹)

Date

Site III: Hinch Bridge Road

(c·ml⁻¹)

Date
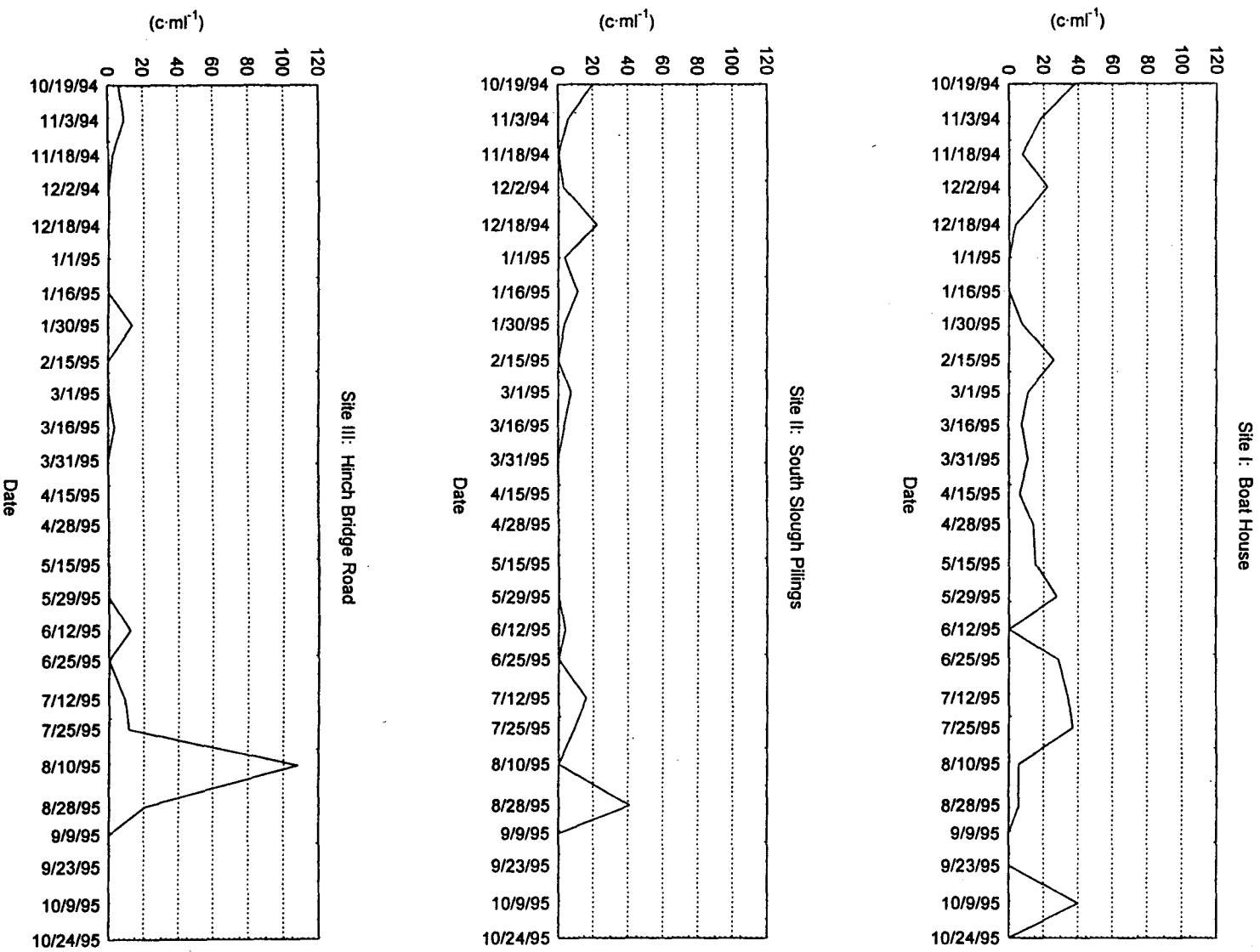
FIGURE 22: Heterotrophic dinoflagellates at sites 1, 2, and 3.

Other Autotrophs

Site I: Boat House

(c·ml⁻¹)

16000
14000
12000
10000
8000
6000
4000
2000
0

10/19/94
11/3/94
11/18/94
12/2/94
12/18/94
1/1/95
1/16/95
1/30/95
2/15/95
3/1/95
3/16/95
3/31/95
4/15/95
4/28/95
5/15/95
5/29/95
6/12/95
6/25/95
7/12/95
7/25/95
8/10/95
8/28/95
9/9/95
9/23/95
10/9/95
10/24/95

Date

Site II: South Slough Pilings

(c·ml⁻¹)

16000
14000
12000
10000
8000
6000
4000
2000
0

Date

Site III: Hinch Bridge Road

(c·ml⁻¹)

16000
14000
12000
10000
8000
6000
4000
2000
0

Date

FIGURE 23:   Other autotrophs at sites 1, 2, and 3.

Site I: Boat House

Site II: South Slough Pilings

Site III: Hinch Bridge Road

(c·ml⁻¹)

$(c \cdot ml^{-1})$

Date
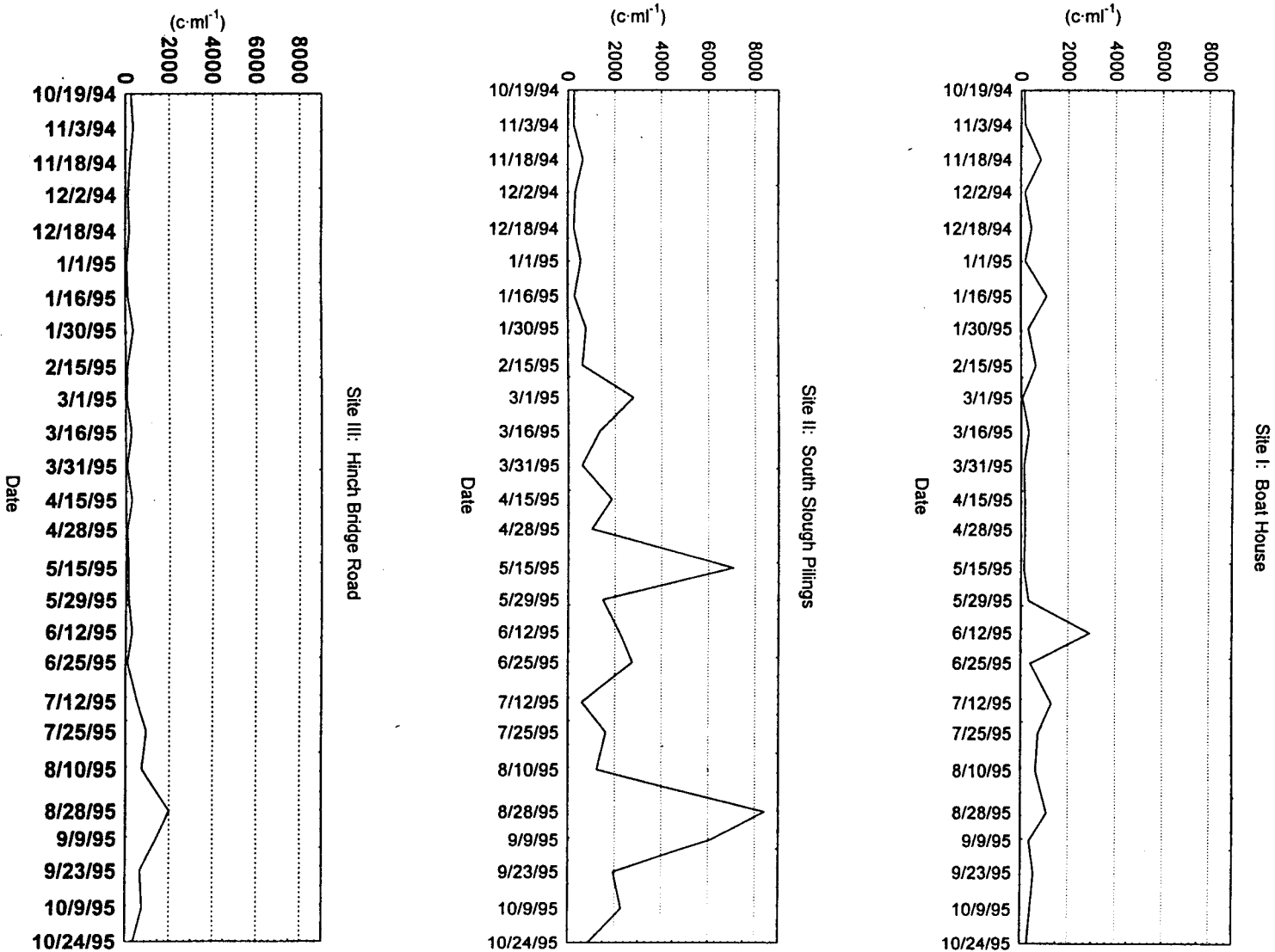
FIGURE 24: Other heterotrophs at sites 1, 2, and 3.
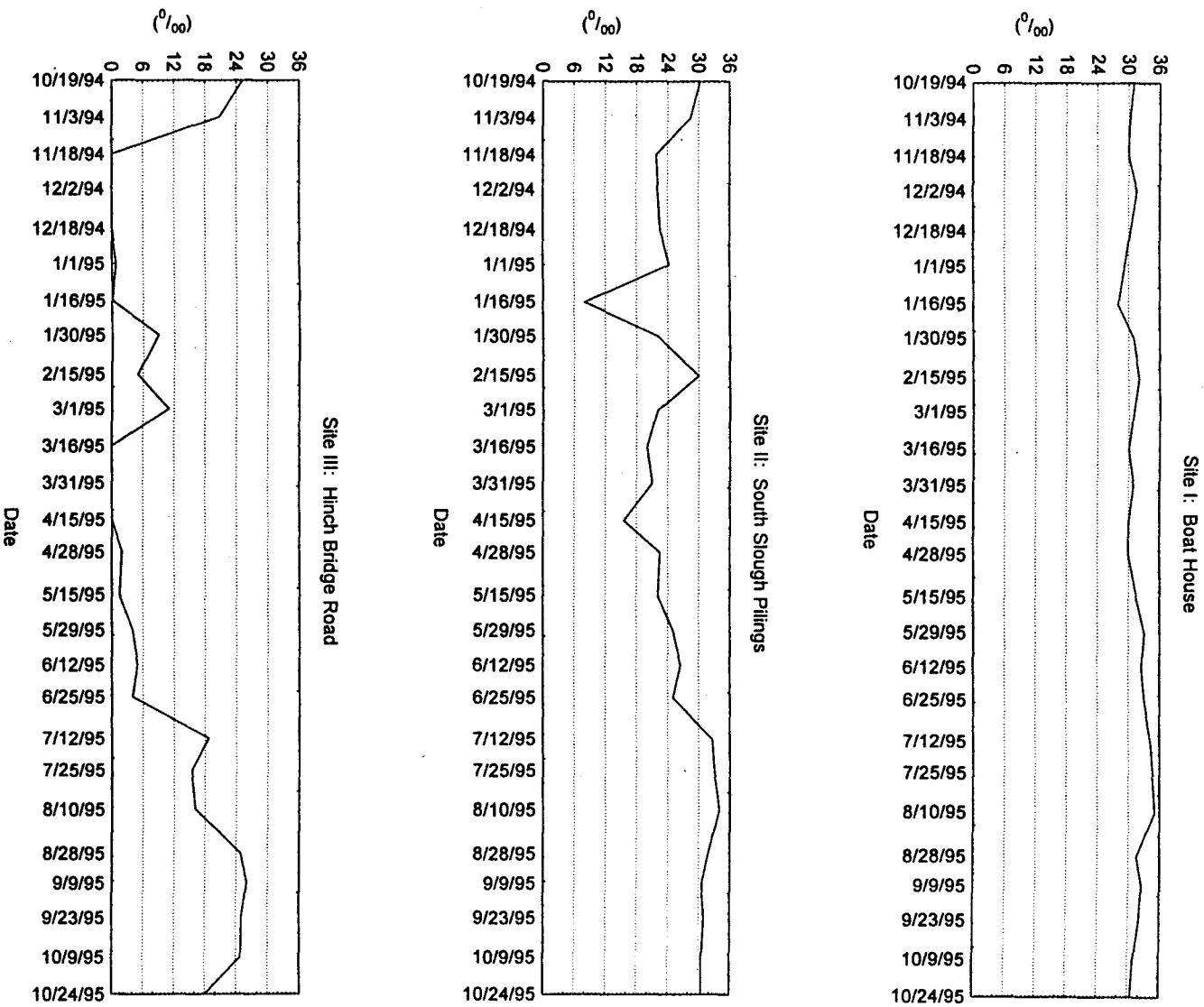
FIGURE 25: Temperature data from sites 1, 2, and 3.

Salinity

Site I: Boat House

Site II: South Slough Pilings

Site III: Hinch Bridge Road

64

Temperature
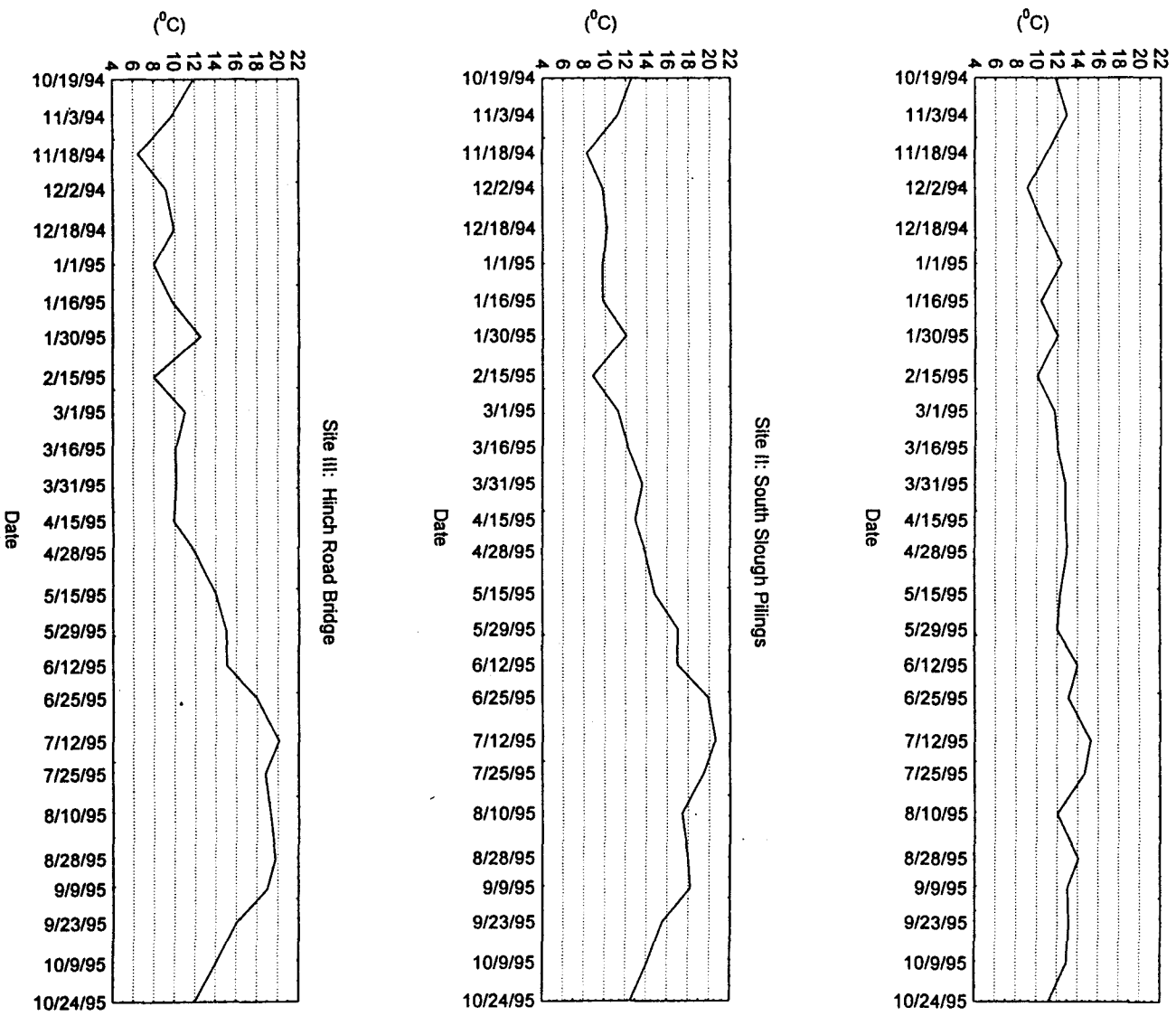
FIGURE 26: Salinity data from sites 1, 2, and 3.

Pseudo-nitschia sp.

66
99
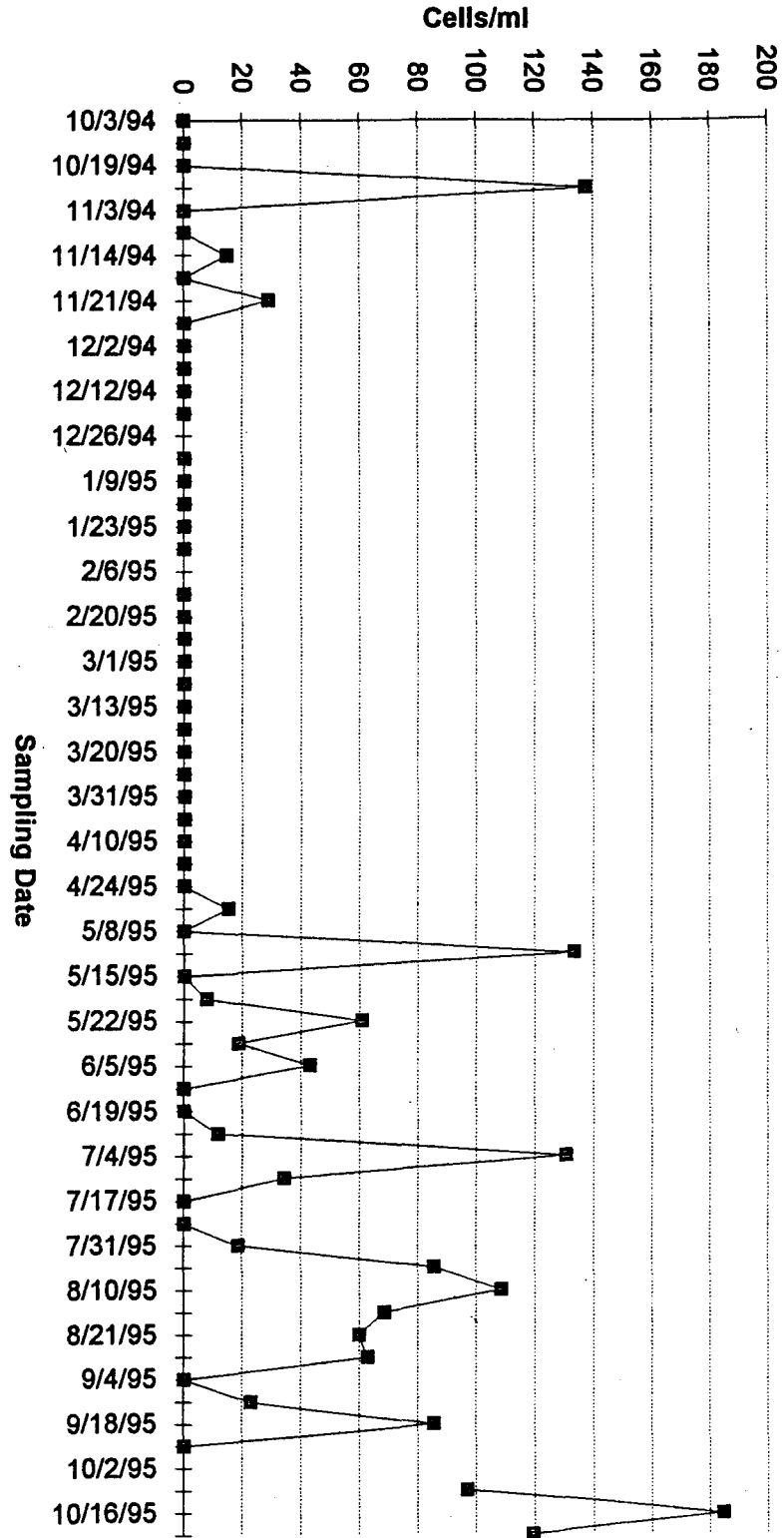
Figure 28: Heterotroph abundance at OIMB's Boat House.
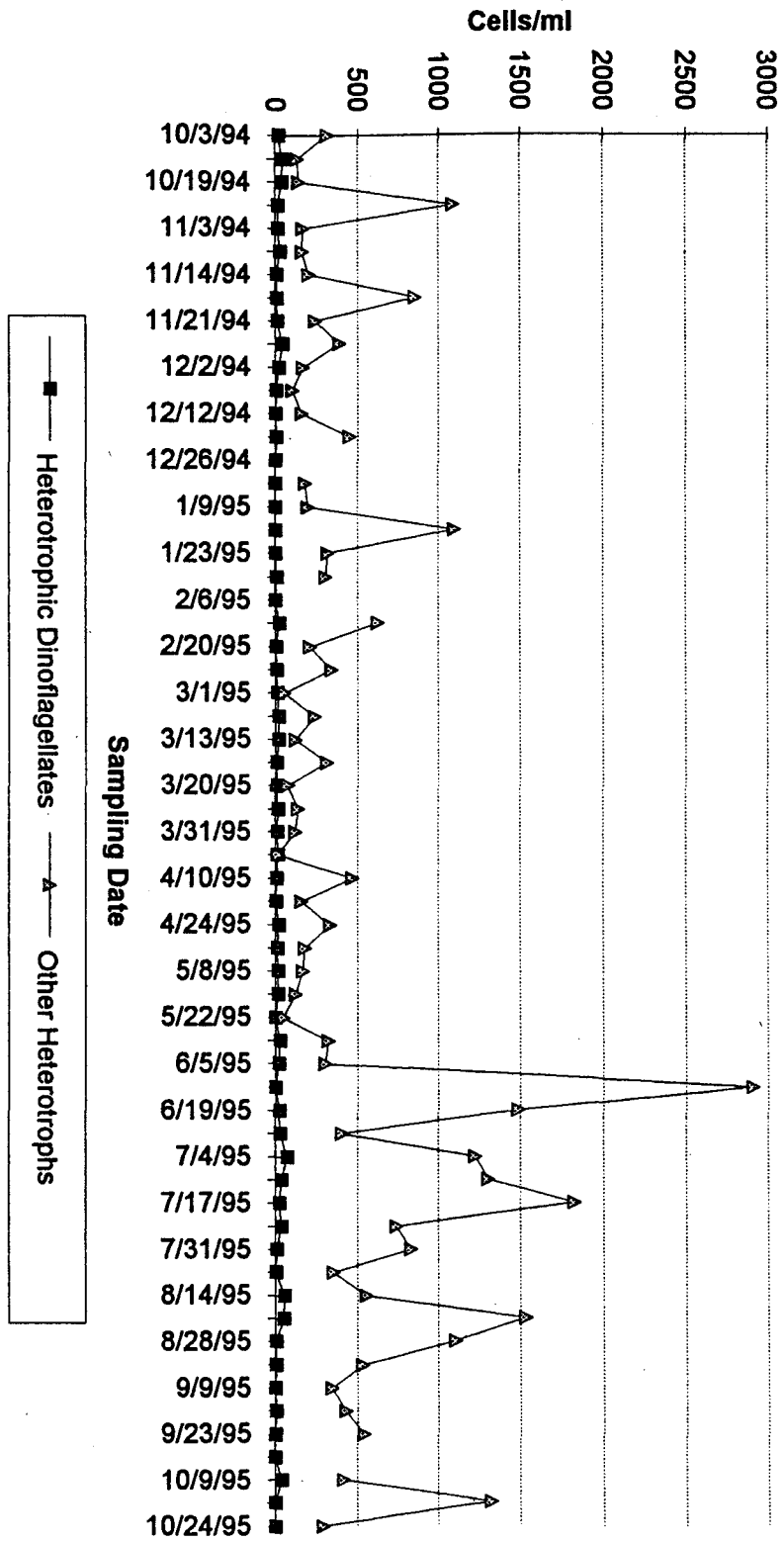
CHAPTER IV

DISCUSSION

Seasonal trends of phytoplankton abundance were similar to seasonal patterns found in northern temperate waters with blooms occurring in the spring and fall and low abundance in both summer and winter months (Gran 1931 and 1935; Sverdrup 1953; Colebrook and Robinson 1965; Margalef 1968). In this study, the fall bloom (cell abundance) was of equal or greater magnitude than the spring bloom in both study years. Therefore, it seems reasonable to assume that even though the general 2-peak patterns found in this study were similar to those found elsewhere, the processes regulating primary production in the South Slough may be different particularly for the fall bloom.

Solar radiation (photoperiod and total incident photosynthetically available radiation) and nutrients are of primary importance in determining the daily phytoplankton division rate. Therefore, low winter abundances are expected to have been due to a decline in day length (8.2 hours winter solstice vs. 16.1 hours at summer solstice) even though nutrients may be high (Perry et al. 1989). Additional contributing factors to low winter abundances may

be lower water temperature and salinity and increased turbidity from winter storms.

Unlike winter, low cell abundance in the summer is not necessarily an indication of low primary production. Since light is not a limiting factor in summer months, other factors such as limited nutrients or increased grazing pressure may be regulating phytoplankton abundance. Upwelling is a major process adding nutrients to coastal waters mainly in summer months. Distinct upwelling signatures (cold and saline water) were not seen in either study year. However, these signatures may have been masked by other processes such as heating and evaporation in the summer. On the other hand, the period 1993-1994 is considered an El Niño Southern Oscillation (ENSO) warm phase and therefore it is possible that no significant upwelling occurred . Since nutrient information was not a part of this study, limited nutrients cannot be totally ruled out. Heterotrophs were not enumerated during year 1. Data for year 2 indicates that heterotrophs did increase in abundance through the summer and therefore predation by heterotrophs may have contributed at least in part to low autotrophic cell numbers.

Not all autotrophic organisms decreased during the summer months. Large chlorophyll-dominant eukaryotes increased in abundance throughout the summer of the second study year (samples for summer 1994 were not available so a comparison of the two summers cannot be made) and remained

above winter abundance levels. It is possible that these large chlorophyll-dominant eukaryotes were not evident in the 1st year due to the ENSO-warm phase. Large diatoms are a major component of this assemblage and these large diatoms require high nutrients (especially Si and N) for growth. In addition, cryptomonads experienced a short bloom in mid-summer. *Synechococcus* and chlorophyll-dominant eukaryotes < 3μm experience seasonal blooms during the fall. However, chlorophyll-dominant eukaryotes < 3μm maintained their abundance throughout the second spring and summer while *Synechococcus* declined after the spring bloom.

The fall blooms of pico- and nanoplankton (e.g., *Synechococcus*, cryptomonads and small chlorophyll dominant eukaryotes) may be an indication of a change in community structure from one dominated by larger phytoplankton (i.e., diatoms) to one dominated by picoplankton and flagellates. This change in community structure may be due to a decline in heterotrophs. Heterotrophic dinoflagellates and other heterotrophs sharply decline at about the same time that pico- and nanoplankton abundance increases indicating a possible release from grazing pressure (Fig. 28). Small flagellates, due to their surface:volume ratio and ability for locomotion, may be better suited for environments with lower nutrients. Additionally, lower light levels, depleted nutrients, decreased sinking rates or other factors may contribute to fall dominance of pico- and nanoplankton. Prior research has indicated that picoplankton are adapted

to photosynthesis at low light levels (Platt et al., 1983). Specifically, in laboratory experiments and in the water column *Synechococcus* grew best at low light levels (Morris and Glover 1981; Glover et al. 1985). Both *Synechococcus* and eukaryotic picoplankton are abundant in oligotrophic water where nutrient concentrations are low (Murphy and Haugen 1985). Other studies have shown that picoplankton biomass is relatively greater at times of nutrient limitation in temperate, subtropical and tropical waters. Picoplankton are able to absorb nutrients at very low concentrations due to their small size and large surface-to-volume ratio giving them a competitive edge over larger organisms (Vaccaro et al. 1977; Albright et al. 1980).

The increase in biomass seen in the spring is usually due to longer day length, turbulent mixing which brings nutrients to surface waters, and stratification which holds the phytoplankton in the euphotic zone. Shapiro et al. (1988), found that the increase in biomass in a coastal ecosystem was due to the addition of large cells (usually diatom dominated) to a base level of small cells. Picoplankton numbers don't change that much - but relative to the big cells, they become important in oligotrophic waters. This study found that all size classes of phytoplankton experience blooms at certain times of the year. Biomass and carbon were not calculated and therefore it is impossible to determine exact biomass contribution

levels of different size classes of organisms. However, an extrapolation can be made using established biovolume formulas and assuming equivalent spherical diameters of cells. This calculation indicates that an increase of 125,000 small 1 m cells (e.g., *Synechococcus* sp.) is equivalent to an increase of one 50 m microplankton (e.g., *Coscinodiscus* sp.) when biomass is considered. In support of prior work (Murphy and Haugen, 1985), extrapolating to biovolume analyses suggests that spring blooms are due to the addition of large cells to a base level of small cells. However, the coefficient of variance showed that picoplankton were more variable than large chlorophyll-dominant eukaryotes (CV's of 1.3 and .97 respectively).

An anomalous trend observed in both years of the study involves the bloom pattern of cryptomonads. In January 1994 and January 1995, when all other organisms were at their lowest abundance, cryptomonads experienced distinct blooms. At those times both salinity and water temperature were low (Figures 9 and 10). Cryptomonads may be adapted to these low light, low salinity, fluctuating conditions and low temperature conditions but do not compete successfully with other large chlorophyll-dominant organisms of spring and summer.

Phytoplankton abundance patterns varied between year 1 and year 2. Year 1 was more variable than year 2 across all categories. This may simply be due to lost samples in the summer of the first study year; therefore CV's were based on

fewer observations in year 1. In order to determine the significance of differences, a much larger data set, covering many years, would be required. Here, differences are noted in order to suggest possible trends and to point the way for future research when a larger data set is compiled. Statistical analysis was not done due to the small data set and lost samples in study year 1.

Seasonal changes of phytoplankton abundance patterns do occur in the upper, middle and lower-regions of Coos Bay estuary. These areas experience low abundance through the winter months and seasonal blooms, mainly in the spring and fall, for most organisms. However, the waxing and waning pattern of each category of organism changes with location except for *Synechococcus* and small chlorophyll dominant eukaryotes. Their peaks and troughs differ somewhat but the timing was more similar than the other categories of organisms.

The coastal (Boat House) and mid-estuarine (South Slough Pilings) sites tended to be more similar in abundance patterns (coefficient of variance) for *Synechococcus*, cryptomonads, autotrophic dinoflagelles, heterotrophic dinoflagellates, other autotrophs, other heterotrophs, and temperature and salinity. Hinch Bridge Road tended to be the most variable site for these categories having the highest coefficient of variance. However, for small chlorophyll-dominant eukaryotes and pennate diatoms, the

Boat House and Hinch Bridge Road were more similar and the mid-estuarine site (South Slough Pilings) was more variable.

The mean abundance of *Synechococcus* and other heterotrophs decreased with increasing distance from the coastal site. Cryptomonads, autotrophic dinoflagellates, and other autotrophs increased in mean abundance with increasing distance from the Boat House.

Water temperature and salinity tended to be the most variable in the upper-regions of the estuary and the least variable at the coastal site. The variability in water temperature and salinity may be influencing the composition pattern of phytoplankton between sites. Organisms more tolerant of large changes in temperature and salinity may do better in the lower-regions of the estuary. However, my study indicates that all categories of organisms tend to be the least variable in the upper regions (Boat House and South Slough) of the estuary and most variable in the lower regions (South Slough and Hinch Bridge Road).

Cryptomonads and other autotrophs were the only two categories of organisms whose coefficient of variance, mean, and standard deviation increased with increasing distance from the Boat House. Cryptomonads maintain a stable presence in coastal areas but may not be able to thrive because of competition from other organisms. Whereas, in areas where there is a wide temperature and salinity range such as in the mid- and lower-regions of Coos Bay estuary, cryptomonads may be able to out-compete other organisms due

to their tolerance of fluctuations in temperature and salinity.

"Other autotrophs" like cryptomonads may also be more tolerant of fluctuations in temperature and salinity. On the other hand, their increase in mean abundance, standard deviation, and coefficient of variance may be and indication of a change in dominance from marine flora to freshwater flora. In order to determine this - taxonomic work would need to be done.

Diatoms had similar abundance patterns at all locations (lower abundance in the winter and increasing in the spring, summer and fall). However, centric diatoms were more prevalent in coastal areas whereas pennates dominate in the mid- and lower-areas of the estuary. The pennates in the mid- and lower-regions of the estuary may have been benthic organisms that had been re-suspended and mixed in the water column rather than pelagic diatoms.

In conclusion:

1. The abundance and dominance pattern of phytoplankton changed seasonally at all three locations. Increases in cell abundance occurred across all categories of organisms. But increases in biomass were due primarily to the addition of larger cells to a base level of small cells - as has been observed elsewhere.

2. The mean abundance of phycoerythrin containing cyanobacteria was greater than the mean abundance of small chlorophyll-dominant eukaryotes at all locations.

3. Cryptomonad abundance varied between sites; they were more abundant in estuarine than coastal environments at any given time.

4. Phytoplankton assemblages varied within the different temperature and salinity regimes. Assemblages tended to be least variable at sites with the lowest variation in temperature and salinity.

Benefits of Research

It is my intention that this study will be used as base line information for a long range study of the seasonal abundance and species composition of phytoplankton in this locality. There is a paucity of information available pertaining to phytoplankton dynamics in Oregon's coastal areas. However, the ecological importance of this highly productive coastal areas has been widely recognized by many scientists as well as commercial and recreational industries. High rates of primary production have been linked with increased fish catches and increased fish and invertebrate larval survival. In addition, current studies suggest that primary production data can be used to estimate pelagic fish production in healthy marine ecosystems (Parsons and Chen 1994).

Lately there has been a lot of concern regarding the effects of El Nino Southern Oscillation (ENSO) and other periodic events. These events cause global changes in

climate and may lead to fundamentally different habitat and ecosystem changes. ENSO events are associated with reductions in fish production caused by a decrease in primary productivity in the eastern equatorial Pacific (Barber and Chavez 1983). In the North Pacific subtropical gyre ENSO events are associated with a decrease in upper-ocean mixing and changes in ocean circulation. These changes resulted in an increase in primary production, particularly of *Trichodesminium* spp. (a nitrogen-fixing organism), leading to a shift from a nitrogen-limited system to a phosphorus-limited system (Karl et al. 1995). The biological and physical changes associated with ENSO affect the entire food web. In order to understand fully the long term effects of anomalous events we must first have a grasp on the distribution and abundance patterns of the primary producers. Long term investigations are needed to quantify "normal" seasonal patterns of phytoplankton succession and abundance. This information is pertinent to food chain considerations. Until then we will not be able to draw logical conclusions regarding the effects of periodicity events on primary production.

APPENDIX A

TEMPORAL STUDY RAW DATA

Sampling Date	Synechococcus (c/ml)	Chlorophyll-dominant Eukaryotes < 3 m (c/ml)	Cryptomonads (c/ml)
9/27/93	3533	3905	94
10/4/93	10839	3047	61
10/11/93	12895	12279	626
10/18/93	41355	3711	117
10/25/93	40540	1347	121
11/1/93	15097	8893	134
11/8/93	11711	1390	126
11/15/93	10155	4072	134
11/22/93	5351	4964	111
11/29/93	6684	7282	111
12/6/93	10413	859	123
12/14/93	3882	217	39
12/20/93	4210	1138	63
12/27/93	–	–	–
1/3/94	9349	2500	49
1/10/94	8008	2395	59
1/17/94	5250	4372	88
1/24/94	10451	1202	194
1/31/94	6176	159	97
2/7/94	4589	18	129
2/14/94	14068	106	108
2/21/94	–	–	–
2/28/94	11448	92	188
3/14/94	4249	308	80
3/21/94	3632	46	107
3/28/94	18852	35	106
4/4/94	10579	282	67
4/11/94	5635	176	92
4/18/94	16407	100	124
4/25/94	19805	370	95
5/2/94	8183	97	62
5/9/94	10959	1157	59
5/16/94	–	–	–
5/23/94	–	–	–
5/30/94	–	–	–
6/6/94	–	62	77
6/13/94	–	–	–
6/20/94	–	–	–
6/27/94	–	–	–
7/4/94	–	–	–
7/11/94	–	–	–

Sampling Date	*Synechococcus* (c/ml)	Chlorophyll-dominant Eukaryotes < 3 m (c/ml)	Cryptomonads (c/ml)
7/18/94	37	1339	–
7/25/94	4875	55	–
8/1/94	996	4010	18
8/8/94	3339	507	89
8/15/94	19002	6844	540
8/22/94	37901	5133	900
8/29/94	67220	14795	222
9/5/94	67272	4494	455
9/12/94	98858	3959	80
9/19/94	47337	11473	89
9/26/94	27268	9804	167
10/3/94	11130	567	565
10/10/94	26794	11272	1009
10/19/94	21669	13057	162
10/24/94	23528	9342	248
11/3/94	11815	6852	85
11/7/94	4069	2313	68
11/14/94	4760	3250	75
11/18/94	5163	2844	235
11/21/94	2088	1197	51
11/28/94	4029	2131	224
12/2/94	4776	2918	108
12/5/94	4817	5176	49
12/12/94	6421	4012	106
12/18/94	3769	4709	85
12/26/94	–	–	–
1/1/95	2417	3434	103
1/9/95	2369	2133	63
1/16/95	4583	1486	44
1/23/95	2916	2927	251
1/30/95	3867	2151	225
2/6/95	–	–	–
2/15/95	2661	2419	74
2/20/95	10396	4210	100
2/27/95	13786	4801	196
3/1/95	9690	5244	170
3/6/95	25647	5460	284
3/13/95	22974	2480	111
3/16/95	–	2031	55
3/20/95	–	2650	118
3/27/95	3370	1256	55
3/31/95	3028	2447	118
4/3/95	798	–	15
4/10/95	4182	1514	56
4/15/95	6537	3582	86

Sampling Date	*Synechococcus* (c/ml)	Chlorophyll-dominant Eukaryotes < 3 m (c/ml)	Cryptomonads (c/ml)
4/24/95	3468	5909	41
4/28/95	3871	14249	76
5/8/95	3972	2077	23
5/15/95	1697	1293	53
5/22/95	1297	5239	52
5/29/95	823	1331	127
6/5/95	1055	545	62
6/12/95	8642	4192	94
6/19/95	7381	916	87
6/25/95	1346	1570	46
7/4/95	1015	1579	80
7/12/95	1251	1124	230
7/17/95	364	309	114
7/25/95	1597	2280	74
7/31/95	118	4099	102
8/7/95	388	582	9
8/14/95	1932	4611	80
8/21/95	1452	716	236
8/28/95	1590	3988	283
9/4/95	16065	12630	236
9/9/95	3243	5516	116
9/18/95	1805	3799	48
9/23/95	25242	17579	198
10/2/95	-	-	-
10/9/95	2812	5370	160
10/16/95	1433	1274	21
10/24/95	1698	2807	52

Sampling Date	Chlorophyll-dominant Eukaryotes > 3 m (c/ml)	Temperature (^{0}C)	Salinity ($^0/_{00}$)
9/27/93	2348	10.8	33.0
10/4/93	596	10.7	32.8
10/11/93	4011	11.3	32.4
10/18/93	224	13.7	32.0
10/25/93	1013	12.4	32.2
11/1/93	1238	11.2	32.8
11/8/93	1493	10.9	33.1
11/15/93	1210	8.9	32.7
11/22/93	847	9.0	32.8
11/29/93	1412	9.4	32.7
12/6/93	697	10.2	31.5
12/14/93	388	10.6	31.5
12/20/93	569	9.3	28.6
12/27/93	−	−	−
1/3/94	1240	11.5	32.0
1/10/94	1240	10.6	31.8
1/17/94	1226	10.9	29.9
1/24/94	1462	10.9	31.5
1/31/94	842	10.7	31.7
2/7/94	988	9.9	31.9
2/14/94	1484	10.6	32.3
2/21/94	−	−	−
2/28/94	1497	11.2	30.2
3/7/94	1018	10.0	30.1
3/14/94	4035	11.6	32.1
3/21/94	1057	10.4	32.8
3/28/94	1226	11.4	32.1
4/4/94	1096	9.9	32.5
4/11/94	687	11.6	32.5
4/18/94	1717	11.9	30.9
4/25/94	1359	11.8	31.5
5/2/94	2869	11.3	31.9
5/9/94	−	13.5	32.4
5/16/94	−	13.0	31.6
5/23/94	−	12.4	31.5
5/30/94	−	11.9	33.0
6/6/94	659	13.2	30.7
6/13/94	−	14.2	31.6
6/20/94	−	13.5	31.4
6/27/94	−	16.8	−
7/4/94	−	10.6	31.8
7/11/94	−	10.0	34.0

Sampling Date	Chlorophyll-dominant Eukaryotes > 3 m (c/ml)	Temperature (^{0}C)	Salinity ($^0/_{00}$)
7/18/94	–	–	–
7/25/94	–	–	–
8/1/94	7007	11.7	33.0
8/8/94	1318	14.6	32.6
8/15/94	7045	15.6	32.5
8/22/94	9186	16.2	–
8/29/94	4986	12.6	32.9
9/5/94	1832	13.9	32.7
9/12/94	788	15.1	–
9/19/94	872	12.6	32.8
9/26/94	514	10.6	33.6
10/3/94	583	11.1	33.5
10/10/94	2520	11.0	33.3
10/19/94	903	11.8	31.0
10/24/94	2368	12.3	33.3
11/3/94	435	12.9	30.2
11/7/94	1047	12.3	32.7
11/14/94	1071	10.9	32.0
11/18/94	191	11.0	30.0
11/21/94	907	9.8	31.1
11/28/94	1686	9.7	32.4
12/2/94	192	9.1	31.6
12/5/94	289	9.7	32.0
12/12/94	586	9.1	31.6
12/18/94	753	10.7	30.3
12/26/94	–	–	–
1/1/95	643	–	–
1/9/95	960	14.5	27.9
1/16/95	716	–	–
1/23/95	846	11.1	22.5
1/30/95	750	12.0	31.0
2/6/95	–	–	–
2/15/95	1706	10.0	32.0
2/20/95	1300	11.4	29.5
2/27/95	1259	11.1	31.7
3/1/95	864	11.7	31.0
3/6/95	979	11.3	31.3
3/13/95	447	11.2	31.5
3/16/95	750	12.2	30.0
3/20/95	1636	11.9	31.2
3/27/95	628	11.0	29.3
3/31/95	1618	12.8	31.0
4/3/95	351	12.8	32.1
4/10/95	1784	11.0	30.4
4/15/95	948	12.8	30.0

Sampling Date	Chlorophyll-dominant Eukaryotes > 3 m (c/ml)	Temperature (^{0}C)	Salinity ($^0/_{00}$)
4/24/95	2194	11.8	28.5
4/28/95	2592	13.0	30.0
5/8/95	2660	10.9	32.2
5/15/95	1965	12.3	31.5
5/22/95	1480	12.2	32.2
5/29/95	6952	12.0	33.0
6/5/95	7066	11.5	32.8
6/12/95	2602	14.0	32.5
6/19/95	1502	13.4	31.5
6/25/95	1818	13.1	33.0
7/4/95	4171	12.0	32.3
7/12/95	2509	15.3	34.2
7/17/95	8865	11.9	33.7
7/25/95	2696	14.7	34.6
7/31/95	2557	14.1	33.5
8/7/95	2077	11.3	33.4
8/14/95	1494	12.3	33.3
8/21/95	1968	12.2	33.8
8/28/95	2673	14.1	31.5
9/4/95	1363	16.1	31.0
9/9/95	1363	13.0	32.5
9/18/95	2645	12.0	32.5
9/23/95	2061	13.1	32.0
10/2/95	-	-	-
10/9/95	2719	12.9	31.0
10/16/95	814	14.9	31.0
10/24/95	717	11.2	30.5

APPENDIX B

SPATIAL STUDY RAW DATA

Synechococcus

Sampling Date	Boat House (c/ml)	Pilings (c/ml)	Hinch Road (c/ml)
10/19/94	21669	19509	10553
11/3/94	11815	8840	6386
11/18/94	5163	3265	423
12/2/94	4776	3986	198
12/18/94	3769	3076	1433
1/1/95	2417	1962	736
1/16/95	4583	914	9
1/30/95	3867	3922	1191
2/15/95	2661	2085	499
3/1/95	9690	6810	2160
3/16/95	10922	4498	63
3/31/95	3028	1986	55
4/15/95	6455	2770	129
4/28/95	3880	1391	48
5/15/95	1697	2382	19
5/29/95	823	742	32
6/12/95	8642	215	20
6/25/95	1346	366	10
7/12/95	1252	511	18
7/25/95	1597	602	52
8/10/95	664	459	91
8/28/95	1590	419	18
9/9/95	3243	2804	1532
9/23/95	25242	630	450
10/9/95	2812	1301	577
10/24/95	1698	1458	570

Chlorophyll-dominant Eukaryotes < 3 μm

Sampling Date	Boat House (c/ml)	Pilings (c/ml)	Hinch Road (c/ml)
10/19/94	13057	15452	14724
11/3/94	6852	9032	7476
11/18/94	2844	3712	273
12/2/94	2918	1588	273
12/18/94	4709	3361	485
1/1/95	3435	3513	1026
1/16/95	1486	360	19
1/30/95	2151	2096	720
2/15/95	2419	2188	803
3/1/95	5244	2105	2401
3/16/95	2031	702	129
3/31/95	4078	3665	19
4/15/95	3582	1302	55
4/28/95	14249	10488	12
5/15/95	1293	136717	133
5/29/95	1332	3122	622
6/12/95	4192	10004	6199
6/25/95	1570	12920	3845
7/12/95	1124	5393	3466
7/25/95	2281	10081	9611
8/10/95	4420	4866	4838
8/28/95	3988	23427	25376
9/9/95	3862	34306	46027
9/23/95	17579	11965	24386
10/9/95	5370	17913	7122
10/24/95	2807	9624	14963

Cryptomonads

Sampling Date	Boat House (c/ml)	Pilings (c/ml)	Hinch Road (c/ml)
10/19/94	162	351	489
11/3/94	85	215	505
11/18/94	235	447	395
12/2/94	111	143	247
12/18/94	85	262	875
1/1/95	103	129	329
1/16/95	44	74	0
1/30/95	225	174	157
2/15/95	74	177	89
3/1/95	170	159	144
3/16/95	55	384	0
3/31/95	118	366	81
4/15/95	86	656	0
4/28/95	86	578	0
5/15/95	53	698	37
5/29/95	127	244	332
6/12/95	95	657	1471
6/25/95	46	997	130
7/12/95	230	691	1451
7/25/95	74	612	918
8/10/95	98	438	864
8/28/95	283	821	522
9/9/95	117	515	873
9/23/95	198	421	1085
10/9/95	160	332	1117
10/24/95	52	277	739

Centric Diatoms

Sampling Date	Boat House (c/ml)	Pilings (c/ml)	Hinch Road (c/ml)
10/19/94	296	3	2
11/3/94	197	75	9
11/18/94	31	4	5
12/2/94	27	2	1
12/18/94	19	22	37
1/1/95	4	22	0
1/16/95	4	0	0
1/30/95	22	0	5
2/15/95	41	0	15
3/1/95	107	7	0
3/16/95	4	4	0
3/31/95	44	111	0
4/15/95	55	28	0
4/28/95	268	27	0
5/15/95	977	75	25
5/29/95	5890	63	0
6/12/95	1357	34	7
6/25/95	365	148	0
7/12/95	650	88	536
7/25/95	988	6	752
8/10/95	211	17	331
8/28/95	832	51	40
9/9/95	86	11	570
9/23/95	353	0	0
10/9/95	91	0	0
10/24/95	36	0	0

Pennate Diatoms

Sampling Date	Boat House (c/ml)	Pilings (c/ml)	Hinch Road (c/ml)
10/19/94	112	32	41
11/3/94	121	160	119
11/18/94	51	122	21
12/2/94	49	86	31
12/18/94	107	163	22
1/1/95	33	59	67
1/16/95	22	81	0
1/30/95	26	170	65
2/15/95	103	85	41
3/1/95	19	103	55
3/16/95	41	218	41
3/31/95	63	1994	33
4/15/95	123	2059	194
4/28/95	393	419	289
5/15/95	277	350	757
5/29/95	352	190	712
6/12/95	60	142	835
6/25/95	160	185	960
7/12/95	194	125	741
7/25/95	536	178	372
8/10/95	836	115	838
8/28/95	319	82	297
9/9/95	322	280	222
9/23/95	87	140	165
10/9/95	410	73	64
10/24/95	287	332	63

Autotrophic Dinoflagellates

Sampling Date	Boat House (c/ml)	Pilings (c/ml)	Hinch Road (c/ml)
10/19/94	0	3	2
11/3/94	0	0	28
11/18/94	12	11	10
12/2/94	22	32	60
12/18/94	4	30	133
1/1/95	11	7	140
1/16/95	0	4	0
1/30/95	30	26	74
2/15/95	7	37	22
3/1/95	15	37	89
3/16/95	4	63	4
3/31/95	15	81	0
4/15/95	6	28	0
4/28/95	8	35	0
5/15/95	8	10	6
5/29/95	19	13	0
6/12/95	9	19	159
6/25/95	0	19	0
7/12/95	49	13	86
7/25/95	9	6	43
8/10/95	6	0	40
8/28/95	6	41	6
9/9/95	6	6	6
9/23/95	46	11	41
10/9/95	11	0	0
10/24/95	0	0	17

Heterotrophic Dinoflagellates

Sampling Date	Boat House (c/ml)	Pilings (c/ml)	Hinch Road (c/ml)
10/19/94	39	20	6
11/3/94	18	6	9
11/18/94	7	0	3
12/2/94	22	3	0
12/18/94	4	22	0
1/1/95	0	4	0
1/16/95	0	11	0
1/30/95	7	4	14
2/15/95	26	0	0
3/1/95	11	7	0
3/16/95	7	4	4
3/31/95	11	0	0
4/15/95	6	0	0
4/28/95	14	0	0
5/15/95	15	0	0
5/29/95	28	0	0
6/12/95	0	4	12
6/25/95	29	0	0
7/12/95	34	16	9
7/25/95	37	9	11
8/10/95	6	0	108
8/28/95	6	41	21
9/9/95	0	0	0
9/23/95	0	0	0
10/9/95	40	0	0
10/24/95	0	0	0

Other Autotrophs

Sampling Date	Boat House (c/ml)	Pilings (c/ml)	Hinch Road (c/ml)
10/19/94	495	239	1263
11/3/94	118	360	1192
11/18/94	97	539	302
12/2/94	94	175	245
12/18/94	624	185	521
1/1/95	595	569	813
1/16/95	691	118	15
1/30/95	672	1053	406
2/15/95	1555	776	1234
3/1/95	724	2493	2223
3/16/95	702	1429	26
3/31/95	1496	606	26
4/15/95	763	2336	92
4/28/95	1923	815	38
5/15/95	703	6885	662
5/29/95	692	1016	518
6/12/95	1176	1926	5052
6/25/95	1294	2724	1629
7/12/95	1626	446	3629
7/25/95	1163	1440	1530
8/10/95	831	1010	1959
8/28/95	1516	6812	13565
9/9/95	951	5145	13557
9/23/95	1575	1429	3793
10/9/95	2206	1910	3596
10/24/95	394	896	1519

Other Heterotrophs

Sampling Date	Boat House (c/ml)	Pilings (c/ml)	Hinch Road (c/ml)
10/19/94	128	137	251
11/3/94	168	104	353
11/18/94	854	222	207
12/2/94	167	148	115
12/18/94	451	225	188
1/1/95	185	126	74
1/16/95	1097	259	126
1/30/95	307	344	337
2/15/95	624	137	81
3/1/95	55	443	59
3/16/95	314	137	266
3/31/95	126	70	55
4/15/95	160	286	286
4/28/95	177	280	53
5/15/95	125	269	111
5/29/95	322	535	125
6/12/95	2910	970	284
6/25/95	405	600	82
7/12/95	1302	459	539
7/25/95	739	642	943
8/10/95	636	382	638
8/28/95	1106	1765	1980
9/9/95	348	1235	1412
9/23/95	542	673	671
10/9/95	416	477	783
10/24/95	294	388	367

Temperature

(^0C)

Sampling Date	Boat House	Pilings	Hinch Road
10/19/94	11.8	12.6	11.9
11/3/94	12.9	11.2	9.7
11/18/94	11.0	8.3	6.5
12/2/94	9.1	9.8	9.2
12/18/94	10.7	10.2	9.9
1/1/95	12.4	9.8	8.0
1/16/95	10.4	9.8	9.8
1/30/95	12.0	12.0	12.5
2/15/95	10.0	8.8	8.0
3/1/95	11.7	11.2	11.0
3/16/95	12.0	12.2	10.1
3/31/95	12.8	13.6	10.2
4/15/95	12.8	12.9	9.9
4/28/95	13.0	13.9	12.0
5/15/95	12.3	14.8	14.0
5/29/95	12.0	17.0	15.0
6/12/95	14.0	17.0	15.1
6/25/95	13.1	19.9	18.0
7/12/95	15.3	20.6	20.1
7/25/95	14.7	19.5	18.8
8/10/95	12.0	17.4	19.3
8/28/95	14.1	18.0	19.8
9/9/95	13.0	18.2	19.0
9/23/95	13.1	15.5	16.0
10/9/95	12.9	14.1	14.0
10/24/95	11.2	12.5	12.0

Salinity

$(^0/_{00})$

Sampling Date	Boat House	Pilings	Hinch Road
10/19/94	31.0	30.3	25.3
11/3/94	30.2	18.3	20.7
11/18/94	30.0	21.8	0.0
12/2/94	31.6	22.1	0.0
12/18/94	30.3	22.5	0.0
1/1/95	29.2	24.3	0.8
1/16/95	28.0	8.0	0.0
1/30/95	31.0	22.0	9.0
2/15/95	32.0	30.0	5.0
3/1/95	31.0	22.0	11.0
3/16/95	30.0	20.0	0.0
3/31/95	31.0	21.0	0.0
4/15/95	30.0	15.5	0.0
4/28/95	30.0	22.5	2.0
5/15/95	31.5	22.0	1.5
5/29/95	33.0	25.0	4.0
6/12/95	32.5	26.5	5.0
6/25/95	33.0	25.0	4.0
7/12/95	34.2	32.6	18.7
7/25/95	34.6	33.0	15.4
8/10/95	35.0	34.0	16.1
8/28/95	31.5	31.8	24.8
9/9/95	32.5	30.5	26.0
9/23/95	32.0	31.0	25.0
10/9/95	31.0	30.5	24.8
10/24/95	30.5	30.5	18.0

REFERENCES

Albright, L.J., J. Chocair, K. Masuda, and D.M. Valdes. 1980. In situ degradation of the kelp *Macrocystis integrifolia* and *Nereocystis laetkeana* in British Columbia waters. *Nat. Can.* 107:3-10.

Barber, R.T. and F.P. Chavez. 1983. Biological consequesnces of El Niño. *Sci.* 222:1203-1210.

Barber, R.T. and R.L. Smith. 1981. Coastal Upwelling Ecosystems, pp. 31-68. In: A.R. Longhurst (Ed.), *Analysis of Marine Ecosystems*. Academic Press, New York, 741 pp.

Begon, M., J.L. Harper and C.R. Townsend. 1990. Ecology: individuals, populations and communities, 2nd ed. Blackwell, Boston.

Boney, A.D. 1989. Successions and associations, pp. 51-71. In: Arnold, E. (Ed.) *Phytoplankton*. Camelot Press Ltd, Southampton.

Booth, B.C. 1988. Size classes and major taxonomic groups of phytoplankton at two locations in the subarctic Pacific Ocean in May and August, 1984. *Marine Biology* 97:275-286.

Booth, B.C. 1987. The use of autofluorescence for analyzing oceanic phytoplankton communities. *Botanica mar.* 30:101-108.

Clemons, M.J. and C. B. Miller. 1984. Blooms of large diatoms in the oceanic, subarctic Pacific. *Deep-Sea Research.* 31(1):85-95.

Cloern, J.E. 1991. Tidal stirring and phytoplankton bloom dynamics in an estuary. *Journal of Marine Research.* 49:203-221.

Cloern, J.E. and A.D. Jassby. 1995. Year-to-year fluctuation of the spring phytoplankton bloom in south San Francisco Bay: an example of ecological variability at the land-sea interface. In: Powell, T.M and J.H. Steele (Eds.) *Ecological Time Series*. Chapman & Hall, New York.

Colebrook, J.M. and G.A. Robinson. 1965. Continuous plankton records: seasonal cycles of phytoplankton and copepods in the North-Eastern Atlantic and the North Sea. *Bull. Mar. Ecol.* 6:123-139.

Glover, H.E., D.A. Phinney, and C.S. Yentsch. 1988. Photosynthetic characteristics of picoplankton compared with those of larger phytoplankton populations, in various water masses in the Gulf of Maine. *Biol. Oceanogr.* 3:223-248.

Glover, H.E., A.E. Smith, and L. Shapiro. 1985. Diurnal variations in photosynthetic rates: comparisons of ultraphytoplankton size fraction. *Journal of Plankton Res.* 7(4):519-535.

Gran, H.H. 1931. On the conditions for the production of plankton in the sea. Rapp. P.-v. *Rénu. Cons. Int. Explor. Mer.* 75:37-46.

Gran, H.H. and T. Braarud. 1935. A quantitative study of the phytoplankton in the Bay of Fundy and the Gulf of Maine (including observations on hydrography, chemistry and turbidity). *J. Biol. Bd. Canada.* 1:279-433.

Huyer, Adriana. 1977. Seasonal variation in temperature, salinity, and density over the continental shelf off Oregon. *Limnol. Oceanogr.* 22(3):442-453.

Johnson, P.W. and J. McN. Sieburth. 1979. Chroococcoid cyanobacteria in the sea: a ubiquitous and diverse phototrophic biomass. *Limnol. Oceanogr.* 24:928-935.

Joint, I.R. 1986. Physiological ecology of picoplankton in various oceanographic provinces. *Can. Bull. Fish. aquat. Sci.* 214:287-309.

Karl, D.M., R. Leteller, D. Hebel, L.Tupas, J. Dore, J. Christian and C. Winn. 1995. Ecosystem changes in the North Pacific subtropical gyre attributed to the 1991-92 El Nino. *Nature.* 373(6511):230-234.

Kovala, P.E. and J.D. Larrance. 1966. Computation of phytoplankton cell numbers, cell volume, cell surface and plasma volume per liter, from microscopical counts, p. 1-91. Seattle, Department of Oceanography, University of Washington, Special Report # 38.

Lalli, C.M. and T.R. Parsons. 1995. Phytoplankton and primary production. In: *Biological Oceanography: An Introduction.* BPC Wheatons Ltd, Exeter. pp. 45-79.

Mann, K.H. and J.R.N. Lazier. 1991. Vertical structure in coastal waters: coastal upwelling regions. In: *Dynamics of Marine Ecosystems Biological-Physical Interactions in the Oceans,* Blackwell Scientific Publications, Boston.

Margalef, R. 1968. Temporal succession and spatial heterogeneity in phytoplankton. In: Buzzati-Traverso, A.A. (Ed.) *Perspectives in Marine Biology,* University of Chicage Press, Chicago.

Miller, C.B., B.W. Frost, B. Booth, P. A. Wheeler, M.R. Landry, and N. Welschmeyer. 1991. Ecological processes in the subarctic Pacific: iron limitation cannot be the whole story. *Oceanography.* 4(2):232-239.

Morris, I. and Glover. 1981. Physiology of photosynthesis by marine coccoid cyanobacteria-some ecological implications. *Limnol. Oceanogr.* 26:957-961.

Murphy, L.S. and E.M. Haugen. 1985. The distribution and abundance of phototrophic ultraplankton in the North Atlantic. *Limnol. Oceanogr.* 30:47-58.

Nybakken, J.W. 1993. Estuaries and salt marshes. In: Marine Biology: *An Ecological Approach,* Third Edition, Harper Collins College Publishers, pp. 302-324.

Olson, R.J., S.W. Chisholm, E.R. Zettler, M.A. Altabet, and J.A. Dusenberry. 1990. Spatial and temporal distributions of prochlorophyte picoplankton in the North Atlantic ocean. *Deep-Sea Research.* 37(6):1033-1051.

Parsons, T.R. and Y-L.L. Chen. 1994. Estimates of trophic efficiency, based on the size distribution of phytoplankton and fish in different environments. *Zoological Studies.* 33(4):296-301.

Parsons, T.R. and C.M. Lalli. 1988. Comparative oceanic ecology of the plankton communities of the subarctic Atlantic and Pacific oceans. *Oceanogr. Mar. Biol. Annu. Rev.* 26:317-359.

Platt, T., D.V. Subba Rao, and B. Irwin. 1983. Photosynthesis of picoplankton in the oligotrophic ocean. *Nature* (Lond.) 301:702-704.

Pattullo, J. and W. Denner. 1965. Processes affecting seawater characteristics along the Oregon coast. *Limnol. Oceanogr.* 10:443-450.

Pearsall, W.H. 1932. Phytoplankton in the English lakes II. the composition of the phytoplankton in relation to dissolved substances. *J. Ecol.* 20(2):241-261.

Perry, M.J., J.P. Bolger and D.C. English. 1989. Primary production in Washington coastal waters. In: Landry, M.R. and B.M. Hickey (Eds.) *Coastal Oceanography of Washington and Oregon.* Elsevier, Amsterdam. pp. 117-138.

Porter, K.G. and Y.S. Feig. 1980. The use of DAPI for identifying and counting aquatic microflora. *Limnol. Oceanogr.* 25:943-948.

Reed, R.K. and W.P. Elliott. 1973. Freshwater imput to coastal waters off the Pacific Northwest. *Limnol. Oceanogr.* 18:683-686.

Shapiro, L.P. and R.L. Gillard. 1985. Physiology and ecology of the marine eukaryotic ultraplankton. *Canadian Bulletin of Fisheries and Aquatic Sciences* 214:371-389.

Shapiro, L.P. and E.M. Haugen. 1988. Seasonal distribution and temperature tolerance of *Synechococcus* in Boothbay Harbor, Maine. *Estuarine, Coastal and Shelf Science.* 26:517-525.

Sieburth, J. McN., V. Smetacek, and J. Lenz. 1978. Pelagic ecosystem structure: heterotrophic compartments of the plankton and their relationship to plankton size. *Limnol. Oceanogr.* 23:1256-1263.

Smayda, T.J. 1980. Phytoplankton species succession. pp. 493-570. In: Morris, I. (Ed.) *The Physiological Ecology of Phytoplankton*. University of California Press.

Stewart, A.J. and R.G. Wetzel. 1986. Cryptophytes and other microflagellates as couplers in planktonic community dynamics. *Arch. Hydrobiol*. 106(1):1-19.

Sverdrup, H.U. 1953. On conditions for the vernal blooming of phytoplankton. J. Cons. Perm. Int. Exp. Mer. 18:287-295.

Uehlinger, V. 1964. Etude statistique des méthodes de dénombrement planctonique. *Arch. Sci. Genève*. 17(2):121-223.

Vaccaro, R.F. F. Azam and R.E. Hodson. 1977. Response of natural marine bacterial populations to copper controlled ecosystem pollution experiment. *Bull. Mar. Sci*. 27:17-22.

Waterbury, J.B., S.W. Watson, R.R.L. Guillard, and L.E. Brand. 1979. Widespread occurrence of a unicellular, marine, planktonic cyanobacterium. *Nature*. 277:293-294.

Wetzel, R.G. and G.E. Kikens. 1991. Composition and biomass of phytoplankton. In: *Limnological Analyses*, Second Edition. Springer-Verlag, New York.