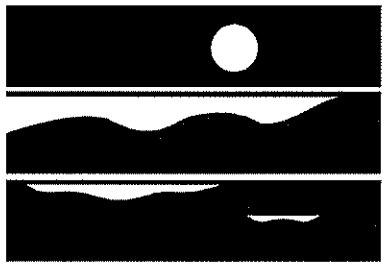

Budd Inlet
Focused Monitoring Report for 1992, 1993 and 1994

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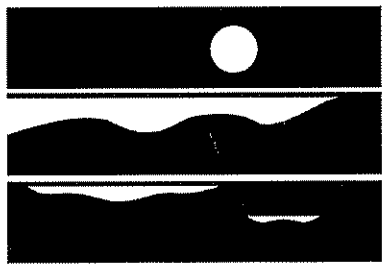

Budd Inlet
Focused Monitoring Report for 1992, 1993, and 1994

by
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Environmental Investigations and Laboratory Services Program
Olympia, Washington 98504-7710

July 1997

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Finally, we would like to acknowledge the Puget Sound Ambient Monitoring Program for providing funding for this project.

Abstract

Budd Inlet is a small semi-enclosed embayment in the southernmost part of Puget Sound. A persistent problem of low near-bottom dissolved oxygen (DO) concentrations in the inner bay has been attributed to the decay of large phytoplankton blooms in combination with stratification during the summer and early fall. Wastewater treatment plant effluent discharged into inner Budd Inlet has been a major source of nutrients. This effluent underwent 90% nitrogen (N)-removal in early 1994. Water properties were monitored biweekly throughout the inlet from 1992 to 1994 to assess the immediate impacts of this change. Following N-removal, surface nitrate+nitrite-N and ammonium-N concentrations showed considerable reductions (~64-86%). However, the concentrations of phytoplankton and near-bottom DO were at levels within the range observed prior to N-removal. Nitrogen may still be available to the system from the sediments and other sources. Weather conditions had an overriding influence on stratification and phytoplankton abundance and hence near-bottom DO concentrations. The high interannual variation and the complexity of multiple forcing mechanisms make conclusions based on only three years of data highly tentative. It is difficult to separate treatment from weather effects. However, evidence of nutrient limitation of phytoplankton growth during 1994 indicates growth would have likely been even higher had N-removal not been implemented.

Executive Summary

Purpose

Budd Inlet is a small semi-enclosed inlet located in the southernmost part of Puget Sound with the City of Olympia at its head. This inlet has a history of water quality problems such as fecal coliform contamination and low dissolved oxygen concentrations in the inner bay during the summer months. The low dissolved oxygen concentrations are thought to be due to poor flushing and strong stratification in the inner bay as well as large phytoplankton blooms which use up oxygen during decay processes. These phytoplankton blooms are fueled by nutrient inputs from the Puget Sound, the Deschutes River/Capital Lake and the Lacey-Olympia-Tumwater-Thurston County Wastewater Treatment Plant (LOTT). Because additional input of nitrogen (N) can cause increased productivity in marine systems and resulting low dissolved oxygen, N-removal was required as a permit condition for LOTT effluent release. In early 1994, LOTT began 90% N-removal from their effluent. Ecology's Marine Waters Monitoring program undertook focused monitoring in Budd Inlet during 1992, 1993 and 1994 funded in part by the Puget Sound Ambient Monitoring Program. The purpose of this study was to assess whether a reduction in nutrient loading to the inlet would result in immediate changes in nutrient, phytoplankton and dissolved oxygen concentrations in the water column. This study covered two years prior and one year following N-removal. The impact of weather and river flow conditions on water quality were also evaluated since these variables are strong determinants of stratification and phytoplankton growth. The data collected in this study can be used for understanding water quality processes in other Puget Sound embayments.

Weather and River Flow

Weather conditions varied substantially over the three-year period. In general, 1992 and 1994 were warmer and sunnier and less stormy than 1993. Compared to historical data (~40 to 50 year averages), 1992, 1993 and 1994 were all warmer, drier (except for spring 1993) and had fairly normal wind speeds and sky cover. Deschutes River flows were much higher in 1993 than in 1992 or 1994 during spring and similar for all three years during summer.

Hydrography

To some extent, hydrographic properties followed the observed weather differences between the years. Salinities were highest in 1994, lowest in 1993 and intermediate in 1992 except for surface data in the inner bay. Surface salinities were much lower and had larger fluctuations in the inner bay than in the central bay. Salinity generally increased from early spring to fall. Higher water temperatures were seen in 1992 and 1994 than in 1993.

Density stratification between surface and bottom was generally strongest in 1994 and weakest in 1993. However, some degree of stratification existed during the sampling season (March to October) for all three years. Stratification was salinity driven. Thus, stratification was strongest in the inner bay which was closest to the major freshwater source, the Deschutes River and weakest near the mouth of Budd Inlet. A reduction in surface salinity from the drainage of Capital Lake during July had a strong influence on stratification and could influence phytoplankton concentration.

Underwater Light Environment

Underwater light values were higher in 1994 than in 1993 since the clear skies in 1994 allowed more light to enter the water column. Overall, light penetrated deeper into the water column in the central bay than in the inner bay (particularly during 1992 and 1994) indicating that less light was available to the phytoplankton population in the inner bay.

Nutrients

LOTT reduced the concentration of nitrogenous nutrients (ammonium plus nitrite and nitrate) in their effluent by 88% for 1994 compared to 1992 and 1993. Subsequently, surface concentrations of nitrate+nitrite-N and ammonium-N in Budd Inlet showed large (64-86% reductions) for 1994 compared to 1992 and 1993. Throughout the bay, surface nutrient concentrations remained at low levels for a longer duration in 1994 than in 1992 or 1993.

During 1992 and 1993 much higher nutrient concentrations (particularly for ammonium-N) were consistently recorded at the inner bay station closest to the primary LOTT outfall than at any other station. Overall, surface nutrient concentrations were higher in the inner bay than in the central bay although the differences were much larger in 1992 and 1993 than in 1994.

Phytoplankton

Phytoplankton chlorophyll *a* concentrations in the inner bay during July through October were lower in 1993 than in 1992 and 1994 likely due to the cloudier skies, cooler water temperatures and weaker stratification seen in 1993. In the central bay, phytoplankton concentrations were similar for all three years. Phytoplankton blooms occurred throughout the bay from March, April or May through October; however, the largest phytoplankton blooms were generally seen in the central bay from July to September. Phytoplankton concentrations were consistently highest in the central bay, although higher nutrient levels were found in the inner bay particularly in 1992 and 1993. Conditions such as lower surface salinity and lower light levels possibly inhibited phytoplankton growth in the inner bay. The phytoplankton population also may have been dispersed or transported out of the inner bay such that an accumulation of the population did not occur.

Phytoplankton growth rate experiments during September 1994 indicated that N was limiting to phytoplankton growth in the central bay. Samples with nutrients added had ~70% more growth than ambient (without nutrients added) samples.

Interannual variation in phytoplankton species composition was seen, some of which may be due to differences in nutrients, salinity, temperature and/or light, although differences are difficult to quantify based on the limited data collected. Potentially harmful phytoplankton species (*Pseudonitzschia* spp., *Heterosigma carterae* and *Alexandrium catenella*) were present at various times during the study period. These species have been associated with harm to humans, fish and invertebrates; however, the necessary concentration for effects to be evident and the conditions that promote toxicity are not presently known.

Dissolved Oxygen

Dissolved oxygen (DO) concentrations less than 5 mg/L are termed low and less than 3 mg/L are termed near-hypoxic since a concentration of 2 mg/L is usually considered hypoxic (Llanso, 1992; Smith et al., 1992). At low concentrations organisms may begin to experience biological stress. At hypoxic concentrations effects such as reduced feeding and growth may begin to occur. Comparing 1993 with 1994, near-hypoxic DO concentrations were observed much more frequently in 1994 (July through October) than in 1993 (early September). However, these differences were likely influenced by changes in stratification (weaker in 1993) and phytoplankton abundance (less in 1993). The data from 1992 were not collected from as deep in the water column (where the lowest DO concentrations are typically observed) as in 1993 and 1994, so comparisons are difficult. Low DO concentrations were observed all three years from July through October, but covered a larger portion of the water column in 1993 than in 1994. The majority of the low and all of the near-hypoxic DO occurrences were in the inner bay at bottom depths.

Conclusions

Budd Inlet has a persistent problem of low dissolved oxygen (DO) concentrations in the bottom waters of the inner bay. This problem has been attributed to the decay of large phytoplankton blooms in combination with stratification during the summer and early fall. Wastewater treatment plant effluent discharged into inner Budd Inlet has been a major source of nutrients for phytoplankton. The results from water properties monitored every two weeks throughout the inlet from 1992 to 1994 to assess the immediate impacts of the 90% N-removal from WWTP effluent in early 1994 were inconclusive. Following N-removal, surface nitrate+nitrite-N and ammonium-N concentrations showed considerable reductions (~64-86%). However, the concentrations of phytoplankton and bottom DO were at levels within the range observed prior to N-removal. Weather conditions had an overriding influence on stratification and phytoplankton abundance and hence bottom DO concentrations. It is difficult to separate treatment from weather effects based on a three-year sampling of a highly variable system. However, evidence of nutrient limitation of phytoplankton growth during 1994 indicates growth would have likely been even higher had N-removal not been implemented.

Introduction

The Washington State Department of Ecology (Ecology) has monitored the water quality of marine waters, including Puget Sound, Willapa Bay and Grays Harbor since 1973, in response to the Federal Clean Water Act. Ecology's Marine Waters Monitoring, one of the components of the Puget Sound Ambient Monitoring Program established in 1988, has focused on maintaining long-term data records of marine water quality throughout the state as well as on conducting focused projects on water quality issues of concern. One such focused project was the Budd Inlet Seasonal Monitoring Study, conducted in spring through fall months of 1992 through 1994. The goal of the study was to assess whether a reduction in nutrient loading to the inlet resulted in immediate changes in nutrient concentrations, phytoplankton dynamics, and dissolved oxygen (DO) concentrations in the water column. The reduction in nutrient loading to Budd Inlet resulted from the removal of dissolved nitrogenous compounds from the Lacey-Olympia-Tumwater-Thurston County Wastewater Treatment Plant (LOTT) effluent. Implementation of N-removal by LOTT occurred in early 1994. Ecology's monitoring spanned two years of pre N-removal conditions and one year of post N-removal conditions.

Study Area

Budd Inlet, within the South Puget Sound Basin, is a semi-enclosed inlet with substantial urban development in its watershed (Figure 1). The inlet is a small (2.6 km x 11.1 km), shallow (average depth = 8.2 m at mean lower-low water) embayment without an entrance sill (Tetra Tech, 1988a), and has been classified as a stratified, partially mixed estuary (URS, 1986). Budd Inlet exhibits a two-layer flow pattern with saltier, generally colder water entering at depth from Puget Sound, and fresher, typically warmer water exiting at the surface (URS, 1986). This slow "conveyor belt" flow is superimposed on a much larger tidal exchange, with complex interactions resulting between the mixed semi-diurnal tidal forcing, salinity-induced stratification, bottom friction (boundary layer) and wind stress. The tidal range in Budd Inlet is close to 4 m (Lavelle et al., 1988).

Flushing rates are lowest near the head of the inlet (URS, 1986) where a variety of point and nonpoint sources of pollution are located. The Deschutes River, the major freshwater source into Budd Inlet (Tetra Tech, 1988a), discharges freshwater into Capitol Lake at the head of Budd Inlet. A control structure at the outlet of Capitol Lake allows the discharge into Budd Inlet (~1% of the total freshwater flow into Puget Sound; Tetra Tech, 1988b) to be adjusted to control water levels in the lake.

Water Quality Problems

Budd Inlet has been an area of known poor water quality (URS, 1986; Tetra Tech, 1988a; Tetra Tech, 1988b; Janzen, 1992, Janzen and Eisner, 1993a; Janzen and Eisner, 1993b; Eisner, et al, 1994; Newton et al., 1994). The DO content of the deep waters, particularly in the inner inlet, seasonally reaches low concentrations known to be deleterious to fish and benthic organisms.

Some of this seasonal cycle is natural, resulting from the oxidation of the large amount of organic production that occurs in the well-lit, stable water column. However, the addition of nutrients (e.g. from wastewater treatment plant effluent) can stimulate even larger amounts of organic production during times when phytoplankton growth would naturally be nutrient-limited. Density stratification is well-maintained in Budd Inlet due to freshwater inputs from the Deschutes River/Capital Lake outflow, and this stratification further contributes to low deep-water DO concentrations by impeding the mixing of oxygenated surface waters downwards. Other factors possibly contributing to low deep-water DO concentrations in Budd Inlet include a low flushing rate for the inlet, vertically migrating dinoflagellates that respire at depth and photosynthesize at the surface, and the sediment oxygen demand (URS, 1986; Tetra Tech, 1988a; Eisner et al., 1994).

Fecal coliform bacteria (fcb) levels in Budd Inlet have been in exceedence of state water quality standards historically (Ecology, 1996) indicating that contamination from anthropogenic sources is likely. Sources of fcb will also be sources of nutrients. Potential anthropogenic sources of fcb and nutrients to Budd Inlet include wastewater treatment plants (LOTT, Tamoshan, Beverly Beach, Seashore Villa), storm drains, leaking septic tanks, agricultural runoff, input via freshwater (primarily Deschutes River/Capital Lake), direct disposal from boat heads, and contributions of certain fcb (*Klebsiella*) that can survive and thrive in wood processing plants. Major sources of bacterial loading identified are Moxlie Creek, LOTT and Capital Lake (URS, 1986).

Focus and Approach

Although other sources exist, a major anthropogenic source of nutrients to Budd Inlet has been from the LOTT effluent. The focus of the Budd Inlet Seasonal Monitoring Study was to document whether the reduction in N content of this source resulted in any immediate changes in nutrient concentrations, phytoplankton dynamics, and DO concentrations in the water column. Additionally, important aspects of the study were to determine how weather and physical conditions vary temporally and spatially and to develop background and comparative information to relate this study site to other estuaries.

Phytoplankton growth is dependent on physical conditions of the water column (e.g., mixing, light availability) as well as on nutrient availability. In order to ascertain the impact of N-removal on the water quality, it was necessary to quantify how physical conditions may have varied temporally and spatially. The build-up and maintenance of low DO concentrations in deep waters is also influenced by physical conditions (density stratification, mixing processes). Physical conditions within the water column are related to weather conditions and freshwater flow, particularly in estuaries such as Budd Inlet that are relatively small in scale. Thus, it is important to consider the role of weather conditions in forcing variation of physical factors in Budd Inlet. Assessing these processes in Budd Inlet is worthwhile because several other South Puget Sound inlets will be facing similar scenarios as population increases.

The approach taken in this analysis was to assess whether the values of water quality data from 1994, the post N-removal year, are within the ranges observed in 1992 and 1993, two years when weather conditions were quite different. The sampling period in 1992 was characterized by warm,

clear weather, whereas, 1993 had cooler, cloudier conditions. Weather conditions from the post N-removal year (1994) were more similar to 1992 than 1993.

In order to interpret whether a significant reduction in nutrient loading resulted in immediate changes in nutrient, phytoplankton, and DO concentrations (based on interannual comparisons of 1992-1994 data), analyses were conducted to:

- determine the spatial and seasonal variation in stratification, nutrient concentration, phytoplankton dynamics, and low DO concentrations (with reference to Eisner et al., 1994);

- assess the degree to which weather conditions determine water column characteristics such as stratification, chlorophyll concentration, and low DO;

- assess the degree to which nutrient removal affected water column characteristics such as stratification, chlorophyll concentration, and low DO in Budd Inlet.

Methods

The analyses in this report are based primarily on the focused monitoring data collected in the spring through fall months of 1992 through 1994. Two other data sets used are Ecology's long-term monitoring data from two stations in Budd Inlet and LOTT's receiving water monitoring data. A more detailed account of Ecology's focused monitoring for 1992 is in the 1992 Budd Inlet Seasonal Monitoring Report (Eisner et al., 1994). The station locations and most of the methods for the 1993 and 1994 data collection and analysis were the same as those in 1992. The long-term monitoring program is described in Janzen (1992) and in several annual reports (Janzen and Eisner, 1993a; Janzen and Eisner, 1993b; Newton et al., 1994). LOTT's station locations (similar to those used in this study) and monitoring methods are described in LOTT's NPDES (National Pollutant Discharge Elimination) Waste Discharge Permit No. WA-003706-1, 1994. Data from the LOTT stations are shown in the City of Olympia, Department of Public Works, Final Effluent Year Reports for 1986 to 1995.

Budd Inlet Focused Monitoring Surveys

Field surveys occurred every two to three weeks between spring and fall. Up to 25 stations were monitored in Budd Inlet and adjacent waters during each survey. Stations were sampled during low, high, ebb and flood tides. However, to best compare data from the three years, only the low tide data were evaluated in this report. Station locations for the low tide transects were the same as during 1992 (Figure 1). The two long-term monitoring stations in Budd Inlet, BUD002 and BUD005 (Figure 1), were sampled once a month on an ongoing basis. Data from the long-term monitoring stations are from various tidal stages due to logistical constraints.

Table 1 lists the latitude and longitude, and parameters sampled at low tide transect stations in 1992, 1993 and 1994 and at long-term monitoring stations.

Monitoring Approach and Design

Low tide sampling strategies included:

- Twice a month sampling in the inner bay focused on physical, biological, and chemical parameters at stations at the head of the inlet. These stations were nearest to the LOTT outfalls and Deschutes River/Capitol Lake discharge;

- Twice a month sampling along longitudinal transects from the inner to outer bay, conducted to detect gradients in many of these same parameters emanating outward from the head of the inlet;

- Field experiments to determine phytoplankton production and nutrient limitation at one inner and one central bay station during a large dinoflagellate bloom in mid-September, 1994.

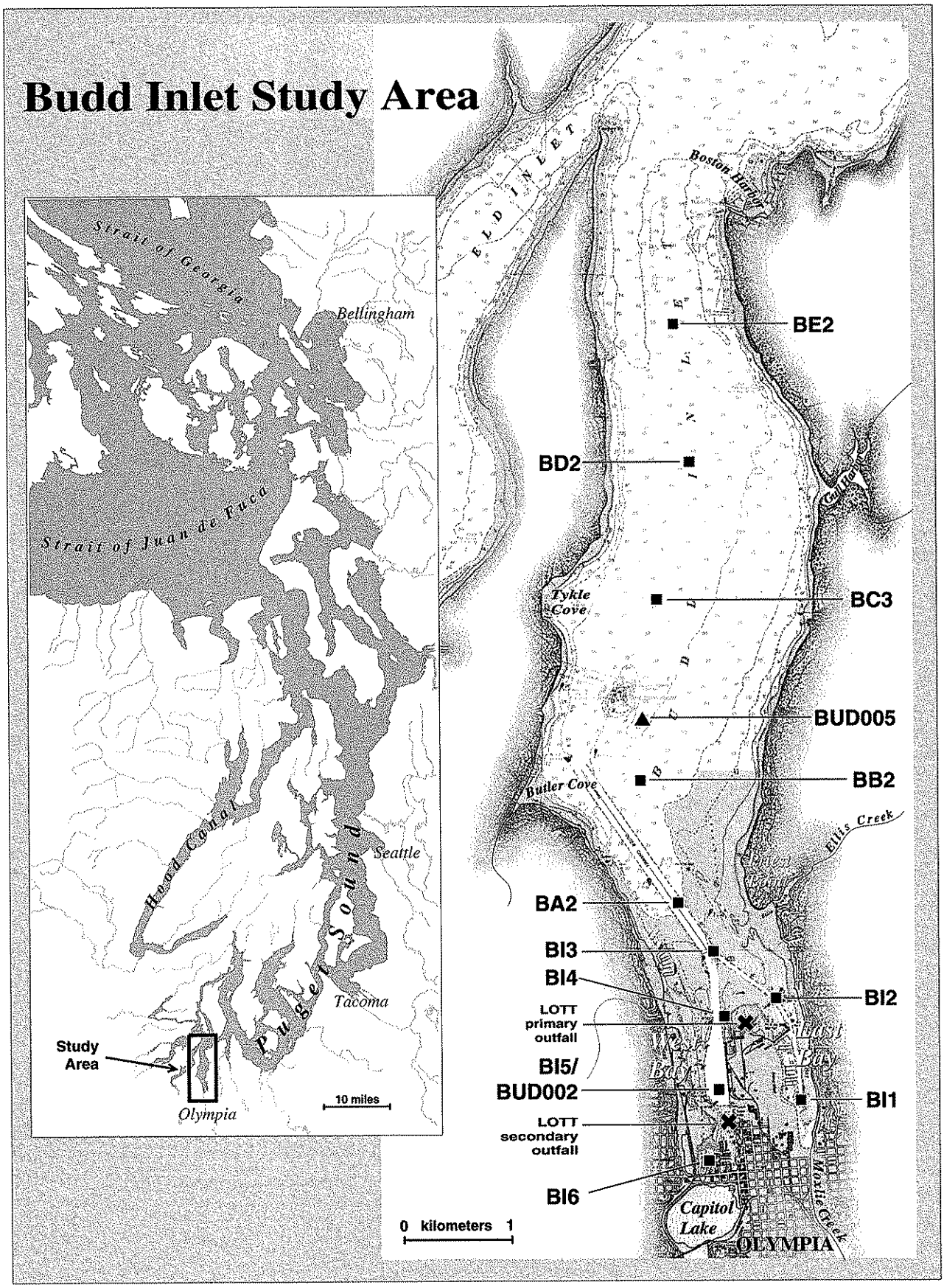


Figure 1. Budd Inlet study area: station locations for low tide transects during 1992, 1993, and 1994. Station BI1 was not sampled during 1993. Stations BUD002 and BUD005 are from a separate Ecology long-term monitoring program.

Table 1. Budd Inlet station locations and parameters sampled during low tide transects in 1992, 1993 and 1994. Station BI1 was not sampled in 1993. Longterm monitoring stations (BUD002 and BUD005) sampled on an ongoing basis are also included. "CTD" indicates a continuous depth profile of conductivity, temperature, dissolved oxygen, fluorometer (or transmissometer for March -June 1992), and PAR (1993 and 1994 only) readings.

Station	Latitude deg-min-hundreds	Longitude (deg-min-hundreds)	Parameters Sampled
BI1	47-03-08	122-53-69	CTD, Secchi
BI2	47-03-74	122-53-85	CTD, Secchi, Nutrients
BI3	47-03-94	122-54-38	CTD, Secchi
BI4	47-03-64	122-54-31	CTD, Secchi, Nutrients, Phytoplankton species
BI5	47-03-09	122-54-27	CTD, Secchi, Nutrients
BI6	47-02-71	122-54-48	CTD, Secchi, Nutrients
BA2	47-04-32	122-54-65	CTD, Secchi
BB2	47-04-98	122-55-12	CTD, Secchi, Nutrients
BC3	47-06-03	122-55-00	CTD, Secchi, Nutrients
BD2	47-06-87	122-54-72	CTD, Secchi
BE2	47-07-70	122-54-85	CTD, Secchi
BUD002	47-03-09	122-54-27	CTD, Secchi, Nutrients, Chlorophyll a, Fecal coliform bacteria
BUD005	47-05-30	122-55-00	CTD, Secchi, Nutrients, Chlorophyll a, Phytoplankton species, Fecal coliform bacteria

Inner Bay Sampling

Sampling was concentrated on inner Budd Inlet at stations adjacent to the LOTT outfall and Deschutes River/Capitol Lake discharge. Inner Budd Inlet encompasses the area south of Priest Point Park including both East Bay and West Bay (Figure 1). Six stations (BI1 through BI6) were sampled approximately every two weeks in the inner bay during low slack tides (primarily during lower low spring tides). Low slack tide periods were considered to encompass the hour before and the hour after the peak low tide time. The slack tide was sampled in order to minimize the influence of dynamic conditions resulting from the tidal mixing and movement of water in and out of the bay. The low slack tide was sampled consistently in order to compare seasonal and interannual variability.

At all inner bay stations, profiles of conductivity-temperature-with-depth (CTD) were conducted, with sensors also measuring DO, *in situ* fluorescence, and photosynthetically active radiation (PAR). Secchi disk depth was also recorded. Stations BI2, BI4, and BI6 were sampled for dissolved nutrients (nitrate+nitrite-N, ammonium-N, and orthophosphate-P) chlorophyll *a*, and phaeopigment. During each survey, a sample for phytoplankton species composition was collected at station BI4.

Longitudinal Transect Sampling

To assess possible head-to-mouth gradients in the inlet, longitudinal transects were also conducted every two weeks. These consisted of five stations (BA2, BB2, BC3, BD2, BE2) from the head of the inlet to the mouth along the central axis of the bay (Figure 1). The transect was sampled immediately prior to or following the inner bay sampling, thus during the same low slack tidal period. CTD profiling casts and Secchi disk measurements were conducted at each station along the longitudinal transect. Stations BB2 and BC3 were also sampled for nutrients, chlorophyll *a*, and phaeopigment. This design allowed a view of the distribution of physical, chemical and biological parameters from inner to outer bay with minimal dynamic influences from tides.

Primary Production Experiments

Productivity experiments were conducted at two stations: BI5 and BB2. These two stations were chosen because they are representative of two very different conditions within Budd Inlet. Station BB2 is located in the central bay, where the phytoplankton biomass is typically the highest. Station BI5 is located in the inner bay, near the LOTT overflow outfall, where nutrient concentrations are typically high, yet phytoplankton biomass is typically low. The low phytoplankton biomass in spite of high nutrient content in the inner bay had been hypothesized to be due to low growth rates or high loss rates for these phytoplankton populations (Eisner et al., 1994). On 19-20 September 1994, determination of primary production with and without nutrient spiking was conducted at these two stations.

Materials and Procedures

Materials and procedures used during 1993 and 1994 were nearly identical to those used during 1992 (Eisner et al., 1994). Sampling was conducted from a 6-m (20-ft) Boston Whaler. A Magellan Global Positioning System (GPS) unit as well as landmarks and navigational aids were used to locate stations.

A Sea-Bird Electronics Sealogger SBE-25 CTD profiler was the primary CTD for collecting continuous water column profile data. Real-time observation of the profiles was obtained with a data link to a lap-top computer. Parameters measured by the SBE-25 included conductivity (used to compute salinity), temperature, pressure (used to calculate depth), DO, *in situ* fluorescence (to estimate chlorophyll *a* concentration) and PAR (to measure underwater light). PAR data were collected only in 1993 and 1994. Density was derived from salinity and *in situ* temperature. The SBE-25 was deployed to the bottom in 1993 and 1994 and within ~ 1.5 m of the bottom in 1992. A Sea-Bird Electronics Seacat SBE-19 CTD profiler was used as a backup instrument when the SBE-25 was unavailable. The Seacat-19 also served as the primary CTD for the Budd Inlet seasonal project from March to June 1992 and was used for long-term monitoring at stations BUD002 and BUD005 starting in 1989. The SBE-19 CTD lacked fluorescence and PAR sensors, but measured light transmission and pH. Sampling procedures followed the manufacturer's instructions (Sea-Bird Electronics, 1990 and 1992a), and are described in the Marine Water Column Ambient Monitoring Plan (Janzen, 1992).

Secchi disk measurements were taken at each station using a solid white, 30-cm disk. Values were recorded to the nearest tenth of a meter.

A 1.2 liter (L) Niskin bottle was manually deployed to collect discrete water samples for dissolved nutrients (ammonium-N, nitrate+nitrite-N, and orthophosphate-P), chlorophyll *a*, phaeopigment, phytoplankton enumeration and taxonomy, DO, and conductivity. Sample collection methods followed the Recommended Protocols and Guidelines for Measuring Conventional Water Column Variables in Puget Sound (PSEP, 1990). Specific details on Ecology's sampling methods are described in the Marine Water Column Ambient Monitoring Plan (Janzen, 1992).

CTD Data Processing and Plotting

Data Processing

CTD data were processed using SEASOFT Software, version 4.024. CTD data were averaged over 0.50-m and 0.25-m depth intervals for 1993 and 1994 data, respectively. During 1992, data were averaged over depth intervals of 0.50 m during March through June and 0.25 m during July through October. Profiles of salinity and density were derived using values of temperature, conductivity, and pressure. Further details on CTD data processing procedures can be found in Sea-Bird Electronics, (1993).

Contour Plots

Contour plots of hydrographic, DO, and chlorophyll *a* CTD data were made using Golden Software's SURFER program. Data were first gridded by Kriging with the quadrant search method which allows data from a minimum of four different directions to be included in the interpolation process. The search radius was set to 10 km, which is much greater than the distance between stations. This forced the algorithm to search adjacent downcasts for intermediate interpolations at gridpoint locations. Gradient spacing was kept constant for all plots to facilitate comparison. The bottom depths for vertical contour plots vary slightly among survey dates due to tide height variations and station location variation caused by fluctuations in the GPS signal.

Sampling Protocols and Data Analyses

Sampling protocols and analyses for 1993 and 1994 data were generally similar to those used for 1992 data (Eisner et al., 1994). Any changes in sampling procedures between years are described below.

Weather and River Flow Data

Weather data were obtained from the National Weather Service (NWS), for Olympia, Washington. The weather station is located at the Olympia Airport, 10 km south of Budd Inlet. The NWS mean daily air temperature represents the mean of the daily minimum and maximum temperatures recorded. NWS mean daily wind speeds were based on 21 or more observations at hourly intervals. Hourly data were not available from June to December 1994 from NWS. During this period, mean daily wind speeds were calculated from observations done once every three hours from 0400 or 0700 until 1900. NWS mean daily percent sky cover was calculated from observations taken hourly from sunrise to sunset. However, during June, July and August 1994 means were based on observations made once every three hours from 0400 or 0700 until 1900 only (not necessarily sunrise to sunset). Monthly means for temperature, wind speed and percent sky cover were based on these daily means. The total precipitation for each day was summed to determine the total monthly precipitation. Historic data (NOAA, 1994) covering 53 years (air temperature and precipitation), 50 years (percent sky cover) or 42 years (wind speed) were averaged to determine means for yearly, April through June, and July through October periods.

Deschutes River flow data were obtained from the United States Geological Survey. Flow rates were measured near the E street bridge south and upstream of the Olympia Brewery at mile 0.6 along the Deschutes River. Although the river flows into Capitol Lake initially, freshwater is released into Budd Inlet when the lake flood gates are opened.

Hydrography Data

Data analysis of salinity, temperature and density primarily focused on two depths: a) 1 m, which is representative of the surface layer and is above the pycnocline; and b) near-bottom, which was

generally 1 m above the bottom, and representative of the bottom water mass (Eisner et al., 1994). Depths were slightly different at long-term stations BUD002 and BUD005, with 0.5 m used to represent the surface layer and 10 m used to represent the bottom water mass. Most of the data represent daytime and light wind (less than 13 km/h) conditions. Vertical density data were used to calculate the relative stratification of the water column by subtracting the 1-m density (sigma-t) values from the near-bottom density (sigma-t) values. Salinity samples collected for comparison to CTD values were analyzed by the University of Washington Routine Chemistry Lab with a Guildline Instruments, Inc. "Autosal" salinometer, using standard seawater as a reference.

Underwater Light Environment

The extinction coefficient of light can be calculated from the Secchi disk depth (the depth at which the disk disappears), and then used to derive the depth of the euphotic zone (the depth to which light penetrates in the water column). In temperate zones the depth of the euphotic zone is typically defined as the depth at which 1% of the incident radiation is available (e.g., Steemann Nielsen, 1975), and is considered the portion of the water column where there is sufficient light for photosynthesis to occur.

To calculate the euphotic zone depth, the extinction coefficient, k, was determined by:

$$k = 1.6/\text{Secchi disk reading (m)}$$

This equation was originally derived by Poole and Atkins (1929) for the English Channel, but has been modified for Puget Sound waters by substituting a value of 1.6 for 1.7. This adjustment reflects the observation that this coefficient is smaller in estuaries (~1.4; Holmes, 1970) and empirical data from Puget Sound (1.6, Ecology unpublished data).

The euphotic zone depth (1% light level) was derived using the formula for light extinction in water:

$$I_z/I_0 = e^{-kz}$$

substituting 0.01 (i.e., 1%) for I_z/I_0 and solving for z, the depth (m) at which 1% of the surface light (I_0) is found.

Nutrients

In order to obtain data within and below the mixed layer, nutrient samples were collected at both 1-m and near-bottom depths. The near-bottom collection occurred at 10 m or at 1 m above the bottom in waters less than 10 m. Subsamples of ~ 50 mL were immediately filtered using a syringe and Nalgene cellulose acetate membrane filters (0.45-µm pore size). The samples were stored on ice until the end of the field survey, and then were frozen for preservation. Frozen samples were delivered to Ecology's Manchester Environmental Laboratory (MEL) for analysis. MEL used an Alpkem series 300 autoanalyzer for analyses of dissolved nitrate+nitrite-N,

ammonium-N and orthophosphate-P following method numbers 353.2, 350.1 and 365.3, respectively, (EPA, 1984).

Phytoplankton

Phytoplankton Biomass

Chlorophyll *a* was used to measure phytoplankton biomass. Fluorometric determination of chlorophyll *a* was conducted both *in situ* and by laboratory analysis of extracts from discrete water samples. Chlorophyll *a* is the most direct indicator of phytoplankton biomass since it is specific to all phytoplankton. However, because this pigment can vary in content per cell in response to cell size, and light, nutrient and physiological conditions (Parsons et al., 1984b), chlorophyll *a* concentration cannot be considered a precise estimate of phytoplankton biomass.

Samples for pigment analysis were collected at the depth of the fluorescence maximum as determined from the real-time CTD observations. Samples were stored in the dark on ice until filtration at the field laboratory at the end of the survey day. Subsamples of 50 or 30 ml were filtered onto Whatman GF/F glass fiber filters (0.70 μm nominal pore size), previously moistened with aqueous magnesium carbonate solution. The filters were placed in centrifuge tubes, stored in the dark, and frozen for preservation. The filters were stored in 90% acetone during 1994, but were stored in air only (without acetone) during 1993 and 1992. Storage in air results in chlorophyll *a* pigment degradation by ~22% (Eisner, 1994). MEL conducted fluorometric analysis using a Sequoia-Turner model 112 fluorometer for detection of chlorophyll *a* and phaeopigment concentrations following method number SM17-10200 H-3 (APHA-AWWA-WPCF, 1989). Prior to September 1994, an incorrect bulb was used in the fluorometer; values determined before this date are underestimates. While these data are not used for quantitative analysis in this report, values are referred to for relative patterns of phytoplankton biomass.

In situ fluorometer data were primarily used to evaluate chlorophyll *a* concentration and distribution. These *in situ* values were calibrated by regression with the reliable laboratory determinations of chlorophyll *a* from discrete water samples (*in situ* concentration = 1.06 * lab concentration + 2.70; $r^2 = 0.89$).

Phytoplankton biomass at inner bay stations BI6, BI5, BI4 and BI3, was estimated from the chlorophyll *a* concentrations integrated over the entire water column based on *in situ* fluorometer data. The "mean chlorophyll *a* concentration" was calculated by dividing the integrated chlorophyll *a* concentration by the bottom depth. These calculations could not be done for central bay data since during 1992 and 1993 the range of the *in situ* fluorometer was set at 30 μg/L (mg/m^3), which was lower than the maximum chlorophyll *a* concentrations seen at these stations. In order to estimate phytoplankton biomass in the central bay data, the vertical extent (number of meters) of the water column that exceeded 30 μg/L chlorophyll *a* was compared for central bay stations BA2, BB2, BC3 and BD2. For both inner and central bay stations only data collected from July through October were evaluated since these were the months with the highest phytoplankton concentrations. The maximum chlorophyll *a* concentration for a given survey was

the highest chlorophyll *a* concentration seen in the water column at a particular station based on *in situ* fluorometer data.

Primary Production

Samples for 24-h simulated *in situ* ^{14}C uptake experiments were obtained from stations BI5 and BB2 on the morning of 19 September 1994 at six depths representing 1%, 7%, 15%, 30%, 50% and 96% of surface light. These depths were determined using a Secchi disk to calculate the light extinction coefficient, as described above ("Euphotic zone calculations"). A Niskin bottle with silicone tubing and washers was deployed to each of the six depths and samples obtained for chlorophyll *a* and nutrient determinations and for productivity, as follows: two 125-mL aliquots for incubation in clear glass bottles ("light" bottles) and one 125-mL aliquot for incubation in an opaque glass bottle ("dark" bottle). All glassware used for the productivity experiments was previously rinsed with a 10% hydrochloric acid aqueous solution and further rinsed with Milli-Q water three times. At each depth, a set composed of two light and one dark bottles was obtained in duplicate, with one set for the "ambient" treatment and the other for the "nutrient spike" treatment. Once filled, all productivity sample bottles were kept out of direct sunlight in darkened boxes.

For the ambient treatment, all bottles were inoculated with 18 μCi ^{14}C sodium bicarbonate (microfiltered, buffered aqueous solution). For each depth, the two light bottles were placed in a Plexiglas tube that was screened (neutral density perforated nickel screening) to the appropriate light level. All light bottle tubes and dark bottles were then submerged in an incubation chamber plumbed with running seawater. For the nutrient spike treatment, all bottles were given a spike of NH_4Cl and KH_2PO_4 for an initial concentration of 10 μM N and 2 μM P at the time of the ^{14}C inoculation, then processed identically to the ambient treatment. Two additional 125-mL clear glass bottles were filled at each station for determination of nutrients at the end (24 h) of the incubation for both treatments. These samples, taken at the 100% light level only, were incubated in clear glass bottles but not inoculated with ^{14}C.

After 24 h, all productivity sample bottles were transported, cold and dark, to a lab for filtration onto Whatman GF/F filters. The damp filters were fumed over HCl fumes for ~2 minutes to drive off inorganic ^{14}C, then immersed in EcoLume scintillation cocktail in 25 mL vials. The specific activity of the samples was determined in a Beckman scintillation counter (Packard Tricarb 2250CA), yielding disintegrations per minute (DPM's) using an internal quench correction. Primary productivity (mg C m^{-3} d^{-1}) was calculated subtracting dark from light DPM's using the equation of Parsons et al. (1984a) with the known total specific activity and incubation time. Carbonate carbon was estimated from salinity.

Productivity rates were integrated down to the 1% light level depth to obtain daily euphotic zone primary production (mg C m^{-2} d^{-1}). Also, primary productivity rates (mg C m^{-3} d^{-1}) were normalized to phytoplankton biomass (as estimated by chlorophyll *a*, mg chl *a* m^{-3}), to obtain the P:B ratio (mg C mg chl a^{-1} d^{-1}), an index of the phytoplankton specific growth rate (μ). P:B will not correlate with μ, however, when cellular C:chl *a* ratios are not consistent throughout the water column (e.g., from photoadaptation).

Phytoplankton Species

Inner bay phytoplankton samples were taken at the depth of the fluorescence maximum. These depths are shown in Table 2. Near-surface (0.5 m) phytoplankton samples were also collected monthly in central Budd Inlet at station BUD005 (Figure 1), as part of the long-term monitoring program conducted by Ecology, and thus followed that program's sampling dates. Samples were collected in glass jars and stored preserved with a final concentration of ~ 0.4 percent formaldehyde buffered with sodium acetate (Throndsen, 1978). Taxonomic identification and enumeration using an inverted light microscope (Hasle, 1981) were conducted by Dr. Rita Horner, University of Washington.

Since the duration of a bloom can be a few days to a week, phytoplankton blooms may be missed by two week or monthly sampling frequencies. In addition, only one depth was sampled for each survey. In order to consider as much species abundance data as possible, evaluations were based on data from both inner bay station BI4 and central bay long-term station BUD005, however phytoplankton species were substantially under sampled.

Dissolved Oxygen

Dissolved oxygen was measured using a polarographic DO probe attached to the CTD profiling unit. A YSI sensor measured DO on the SBE-25 CTD and a Beckman sensor measured DO on the SBE-19 CTD. An integral pump kept a continual flush of sample water washing over the sensor membrane surface. Dissolved oxygen samples collected for comparison to CTD values were analyzed at Ecology using the Winkler Method with the azide modification (APHA-AWWA-WPCF, 1989).

Comparison of CTD and Winkler estimates of DO showed that the DO sensors on both CTDs have a lag time of several minutes when deployed through a steep gradient in DO. Since the CTD was lowered at a rate of 0.25m/s, there may not have been enough time for the DO sensor to equilibrate and record values as low (or as high) as may have existed. Thus, CTD sensor determinations of DO may be inaccurate, particularly at the low (< 6 mg/L) and high (> 9 mg/L) extremes. The DO results in this report are used as relative measures for comparing stations, tidal stages, surveys and years, but cannot be considered as absolute values.

In this report, DO concentrations less than 5 mg/L are termed low, and DO concentrations less than 3 mg/L are termed near-hypoxic, since a concentration of 2 mg/L is usually considered hypoxic (Llanso, 1992; Smith, et al., 1992). Low DO concentrations may begin to produce biological stress. Hypoxic concentrations are associated with detrimental effects to organisms in the water column, causing reduced feeding and growth, and mortality as oxygen decreases to 0 mg/L (Harding et al., 1992).

Depths used to represent the DO concentration in surface and bottom water masses were the same as those used in the analysis of hydrography data. The vertical extent of the water column (meters) with low and near-hypoxic concentrations was compared for 1993 and 1994, but data from 1992 were not generally included for comparison since depths for near-bottom sample

Table 2. Station and depth of phytoplankton species collection in the inner bay during 1992, 1993 and 1994.

Survey Date	Station	Depth (m)
12-Mar-92	BI5	1
25-Mar-92	BI3	1
30-Apr-92	BI5	1
15-May-92	BI4	1
11-Jun-92	BI4	1
2-Jul-92	BI4	1
16-Jul-92	BA2	1
29-Jul-92	BI4	3
26-Aug-92	BI4	2
10-Sep-92	BI4	3.5
7-Oct-92	BI4	5
5-May-93	BI4	3
21-May-93	BI4	3
2-Jun-93	BI4	2.5
16-Jun-93	BI4	3
30-Jun-93	BI4	2
15-Jul-93	BI4	1
29-Jul-93	BI4	5
16-Aug-93	BI4	1
17-Aug-93	BI4	6
30-Aug-93	BI4	1
7-Sep-93	BI4	1
15-Sep-93	BI4	1.5
29-Sep-93	BI4	1
14-Oct-93	BI4	1
26-Oct-93	BI4	3.5
17-Nov-93	BI4	1
31-Mar-94	BI4	1
25-Apr-94	BI4	10
10-May-94	BI4	5
9-Jun-94	BI4	2
22-Jun-94	BI4	4
7-Jul-94	BI4	4
21-Jul-94	BI4	2
18-Aug-94	BI4	2.5
19-Sep-94	BI5	0.5
3-Oct-94	BI4	2

collection were ~1.5 meters shallower in 1992 than in 1993 and 1994. Shallower sampling depths were used in 1992 as a precaution against damage of the CTD; a protective cage built prior to the 1993 field season eliminated this need.

Quality Assurance

The data quality objectives for this study are listed in Table 3.

Laboratory Quality Control (QC) Procedures and Results

Laboratory QC Procedures

The MEL QC procedures are described in the *Marine Water Column Ambient Monitoring Plan* (Janzen, 1992) and in the *Manchester Quality Assurance Manual* (Ecology, 1988).

Approximately 2 samples per survey were analyzed in duplicate for dissolved nutrients. The precision of the nutrient data was estimated by calculating the Relative Standard Deviation (RSD; Coefficient of Variation) of laboratory duplicate results for data from 1992, 1993 and 1994. The RSD was calculated as 100 * (standard deviation/mean). Results that fell below reporting limits (BRL) were not included in the precision estimates. The reporting limit, the minimum concentration at which a pre-determined level of precision is attainable, is 0.01 mg/L for all nutrients. Reporting limits were chosen by determining the minimum control standard concentration that yielded less than a 10% RSD during repeat analyses. A similar precision estimate for chlorophyll *a* results was not calculated due to changing methods and inaccuracies.

Laboratory QC Results

The mean concentration of replicate samples plotted against RSD for nitrate+nitrite-N, ammonium-N and orthophosphate-P for 1992, 1993 and 1994 (Figure 2) shows that the estimated precision of laboratory replication was good. Values greater than 10% RSD were seen for only 8%, 9% and 4% of the data for nitrate+nitrite-N, ammonium-N and orthophosphate-P, respectively. Higher RSDs were seen at concentrations closer to reporting limits for nitrate+nitrite-N and ammonium-N. The highest RSDs observed for all three nutrients were from samples collected during summer or early fall 1994. Freshwater instead of saltwater standards were used for autoanalyzer nutrient analysis during all three years. This likely introduced some error into these analyses.

CTD Calibration Procedures and Results

CTD calibration procedures are described in detail in the *Marine Water Column Ambient Monitoring Plan* (Janzen, 1992), and in the Sealogger SBE-25 and Seacat SBE-19 CTD operator's manuals (Sea-Bird Electronics, 1990 and 1992a). Monthly laboratory calibrations conducted in a stable, aerated water bath were used to generate calibration coefficients for the DO sensor on the CTD. Calibration coefficients for temperature, conductivity and pressure sensors were determined at Seabird Electronics during routine annual factory calibrations. These coefficients were applied during data processing.

Table 3. Marine water column quality assurance/quality control objectives. For nutrients micrograms-atoms/L can be computed with the following equations: ((mg/L x 1000) /14.01) for nitrogen; ((mg/L x 1000)/30.97)) for phosphorus.

Analytical Parameters	Ecology's Reporting Units	Ecology Reporting Limit	Relative Standard Deviation (RSD)
Laboratory Sample Parameters:			
Ammonium-N	mg/L	0.01	*10%
Nitrite+Nitrate-N	mg/L	0.01	*10%
Orthophosphate-P	mg/L	0.01	*10%
Chlorophyll a and Phaeopigment	mg/m^3	0.05	20%
CTD Parameters:			
Salinity	ppt	0.01	8%
Temperature	degrees C	0.1	5%
pH	pH units	0.1	0.1 pH unit
Dissolved Oxygen	mg/L	0.1	8%
Light Transmissivity	% light	0.1	5%
Fluorometry	mg/m^3 (chl a)	Not Determined	Not Determined

* maximum RSD expected near the reporting limit

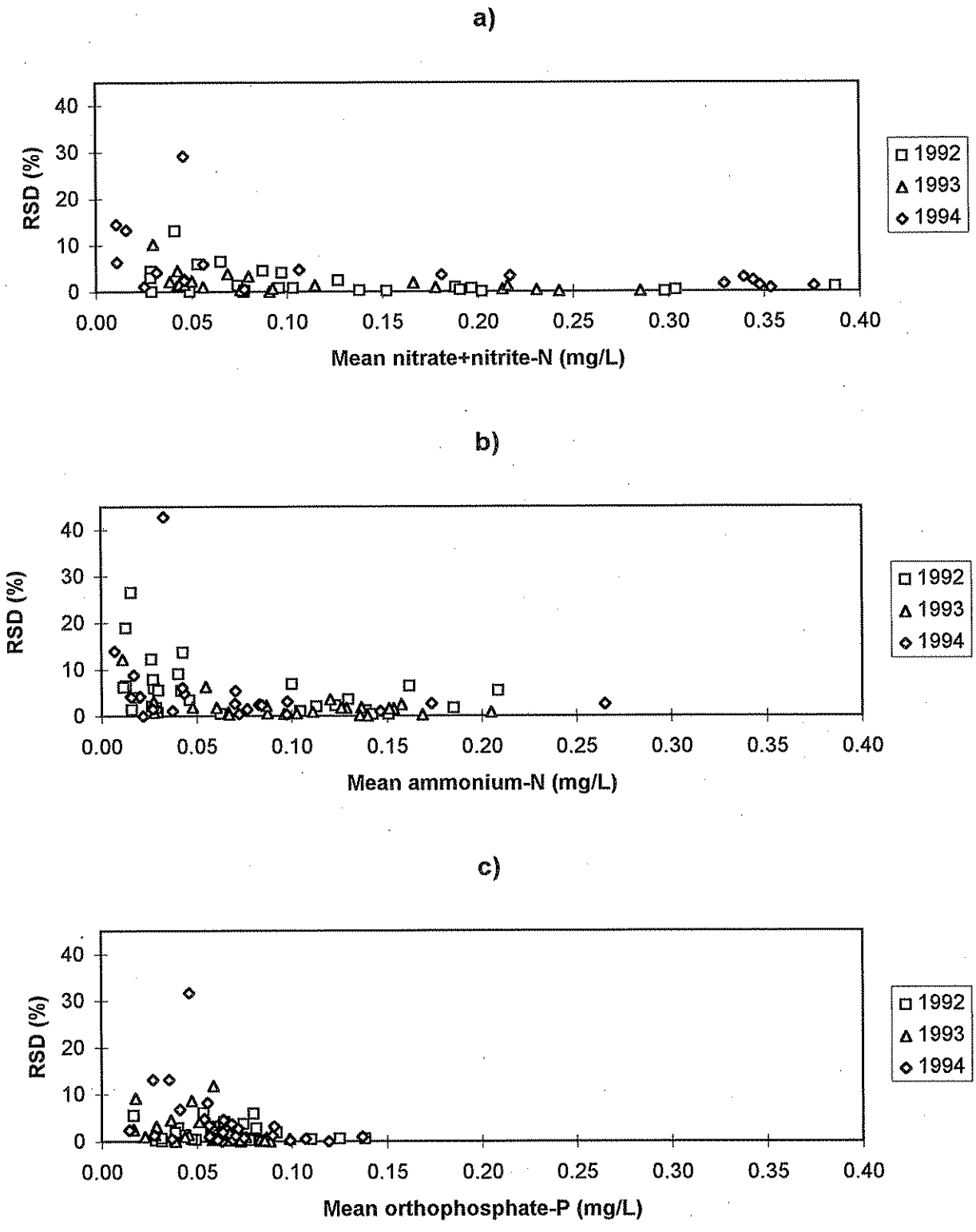
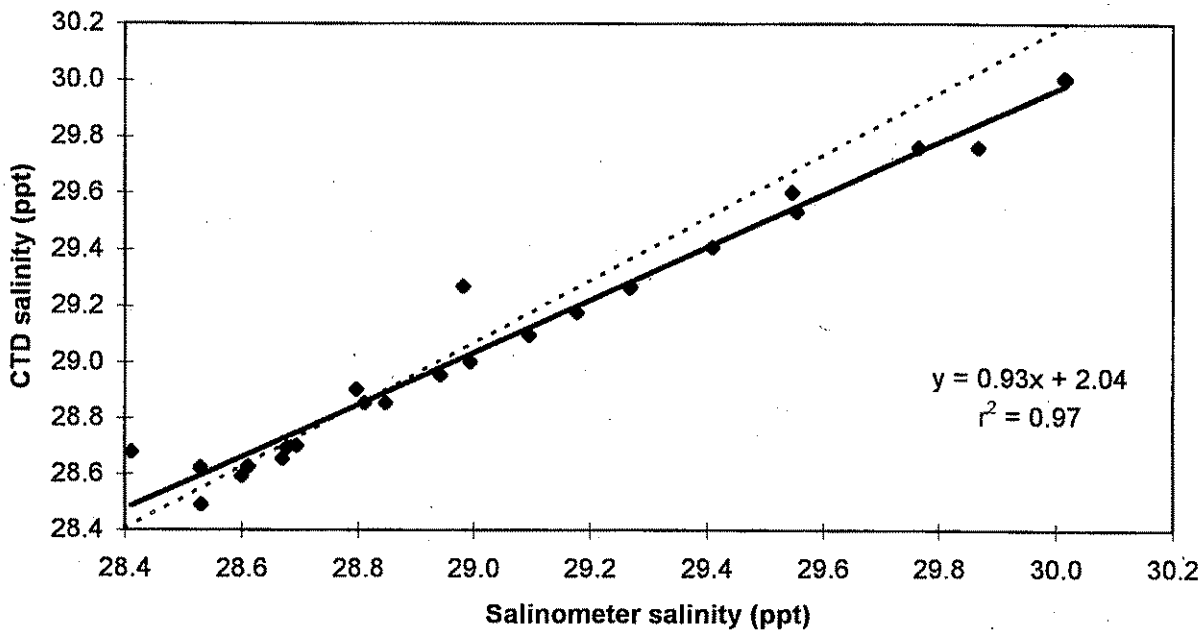


Figure 2. Mean concentration of lab replicate samples plotted against RSD (relative standard deviation) for a) nitrate+nitrite-N, b) ammonium-N and c) orthophosphate-P. Samples were collected in Budd Inlet during 1992, 1993 and 1994.

Discrete water samples for salinity and DO analyses were collected during the surveys as part of the quality assurance checks conducted on the CTD sensors. Salinity determinations by the SBE-25 CTD (calculated from conductivity) and by salinometer analysis of discrete water samples had a very strong correlation ($r^2 = 0.97$, Figure 3a). These comparisons also verified that the conductivity sensor on the CTD was performing to the needed resolution (the RSDs for these between method comparisons were < 0.7%, much less than the precision objective of 8% in Table 3).

Dissolved oxygen determinations by the SBE-25 CTD sensor and by Winkler titration of discrete water samples had a strong correlation ($r^2 = 0.88$, Figure 3b), however, a one to one correlation was seen only for intermediate DO concentrations (6 to 9 mg/L). For DO concentrations below 6 mg/L, Winkler values were lower than CTD values by ~ 0.5 mg/L. Conversely, for concentrations above 9 mg/L, Winkler values were higher than CTD values by ~ 0.5 to 2 mg/L with the error increasing as DO increased. These results reflect the lag in response of the CTD sensor as it passes through DO gradients. The mean RSD for all DO data was 6.8% with 29% of the values greater than the precision objective of 8% (Table 3). However, the precision for DO concentrations from 6 to 9 mg/L was much better with a mean RSD of 3.5% with only 9% of the values above the objective of 8%.

a)



b)

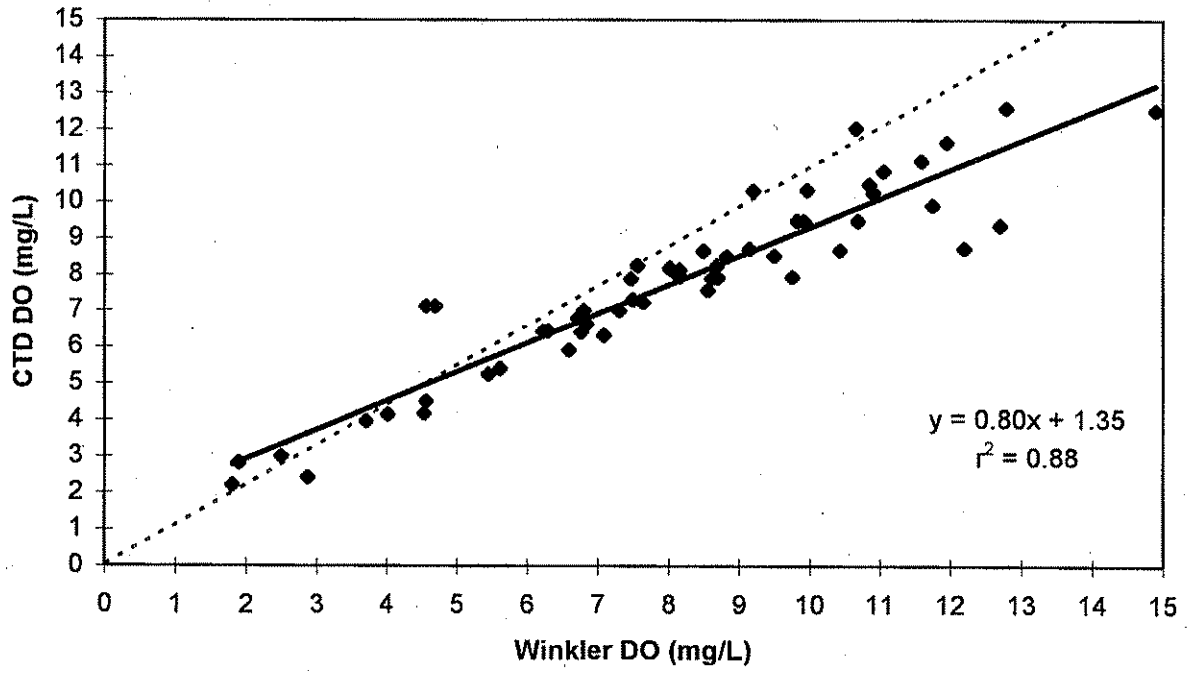


Figure 3. Linear regressions between lab analysis of discrete water samples and determinations with the Sealogger CTD for a) salinity and b) dissolved oxygen.

Results And Discussion

Weather and River Flow Conditions

The interannual variation of air temperature, precipitation, wind, sky cover and Deschutes River flow data was substantial (Figure 4). Averages or totals for yearly, early growing season (April through June), late growing season (July through October) and long-term time periods (1940s to 1994) are shown in Table 4. The anomalies in weather data relative to long-term means for 1992, 1993 and 1994 are shown in Figure 5.

Compared to historical data (~40 to 50 year averages), 1992, 1993 and 1994 were all warmer, drier (except for spring 1993) and had fairly normal wind speeds and sky cover. On a yearly basis, 1993 was cooler, drier and had lower river flows than 1994 and 1992. 1994 had higher precipitation, river flows and winds than 1992 largely due to the late fall/winter storm conditions in 1994. For April through June, 1992 was fair (warmest, calmest, least sky cover), 1993 was stormy (wet and windy, highest percent sky cover, highest river flow), and 1994 was intermediate (colder, cloudier and slightly more windy than 1992, but drier). For July through October, 1992 was intermediate, 1993 was cool, dry and had the most sky cover, and 1994 was warm, calm, and clear (except for October which was cool, wet and windy).

Air Temperature

Based on yearly average air temperatures, 1992 was the overall warmest of the three years (11.2 degrees C) and 1993 was the coldest (10.1 degrees C) with 1994 intermediate (10.7 degrees C). For April through June, 1992 was the warmest and for July through October, 1994 was the warmest of the three years. All years exhibited highest air temperatures during July and August and lowest in November to February. Of the three years, the highest average temperature observed was during July 1994. For April through October all three years were warmer than the 53-year mean temperature for these months.

Precipitation

Based on yearly total precipitation, 1993 was the driest of the three years (30.6 inches), and 1994 was the wettest (49.7 inches) with 1992 intermediate (40.2 inches). For April through June, however, 1993 had over twice as much precipitation as 1992 and 1994. For July through October, 1994 had higher precipitation than 1992 followed by 1993 (very dry), although these results were strongly influenced by the heavy rainfall during October 1994. Within an annual cycle, precipitation tended to vary inversely with air temperature. Precipitation was highest each year in the spring, and in late fall/early winter and generally lowest during the summer/early fall months. 1994 was drier earlier in the year than 1992 or 1993. Rainfall averages remained below 2 inches per month for 4 months in 1992 (May through August), 5 months in 1993 (June to October) and

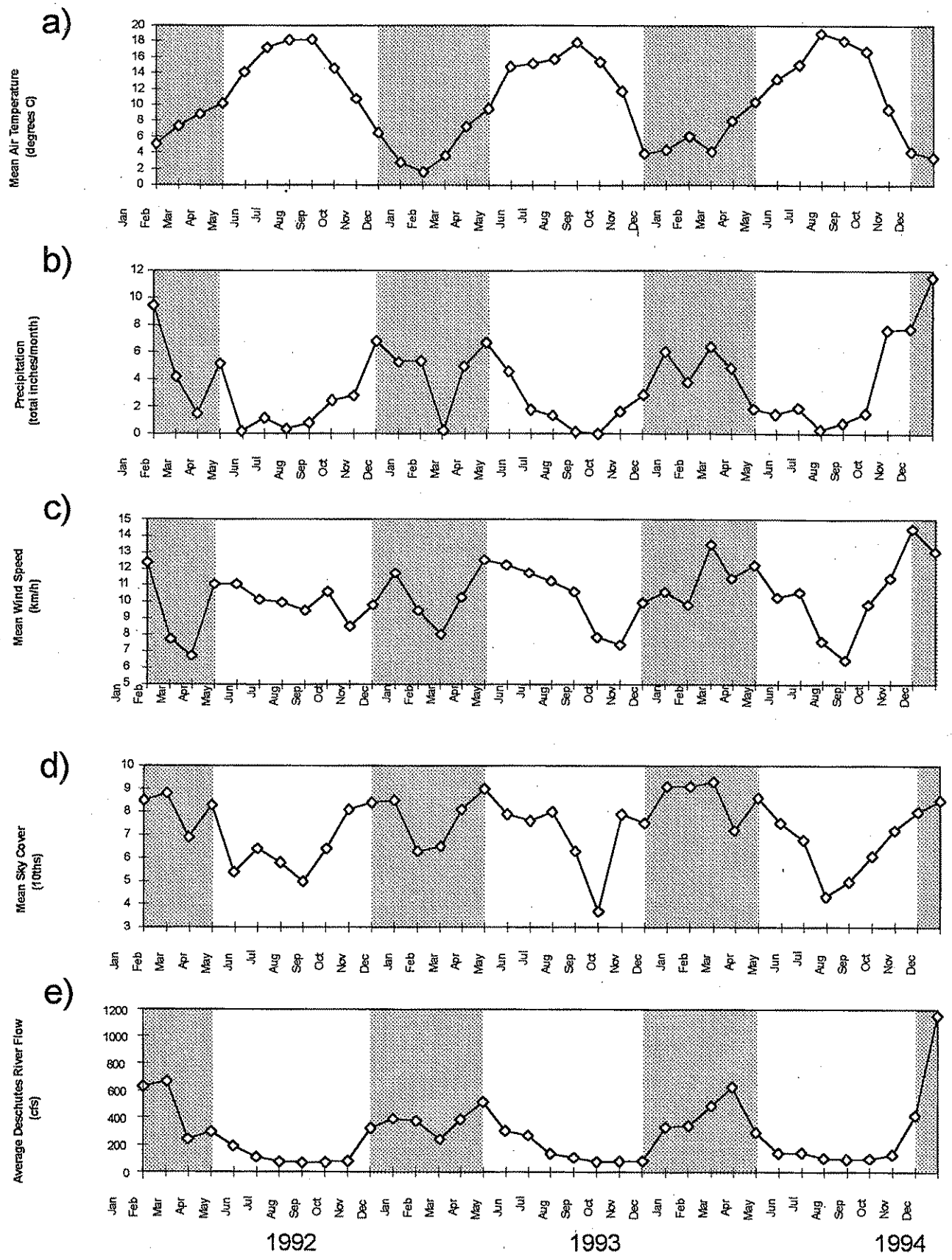


Figure 4. Monthly means or totals for Olympia weather and river flow data of a) air temperature, b) precipitation, c)wind speed, d) sky cover, and e) Deschutes River flow. Unshaded areas correspond to water sampling periods.

Table 4. Means or totals for yearly (January-December), early growing season (April -June) and late growing season (July-October) weather and Deschutes River flow data. Weather data were collected at Olympia airport. Historic data was averaged for 42, 50 or 53 years depending on the parameter. Mean air temperature and total precipitation were averaged for 53 years from 1942 through 1994, mean wind speed was averaged for 42 years from 1951 through 1994 (no data for 1970-1971), and mean sky cover was averaged for 50 years from 1945 through 1994.

	January-December				April-June				July-October			
	1992	1993	1994	Historic	1992	1993	1994	Historic	1992	1993	1994	Historic
Mean Air Temp (deg C)	11.2	10.1	10.7	**9.9**	13.9	13.2	12.9	**11.9**	15.4	15.2	15.9	**14.9**
Total Precip (in)	40.2	35.6	49.7	**50.1**	6.5	13.0	5.2	**7.0**	6.4	3.1	10.3	**8.7**
Mean Wind Speed (km/h)	10.0	10.1	10.9	**10.8**	10.8	12.2	11.1	**11.3**	9.7	9.3	8.8	**9.5**
Mean Sky Cover (tenths)	7.2	7.3	7.3	**7.5**	6.7	8.2	7.6	**7.3**	6.3	6.5	5.6	**6.2**
Mean River Flow (cfs)	264	243	338		199	366	193		75	100	107	

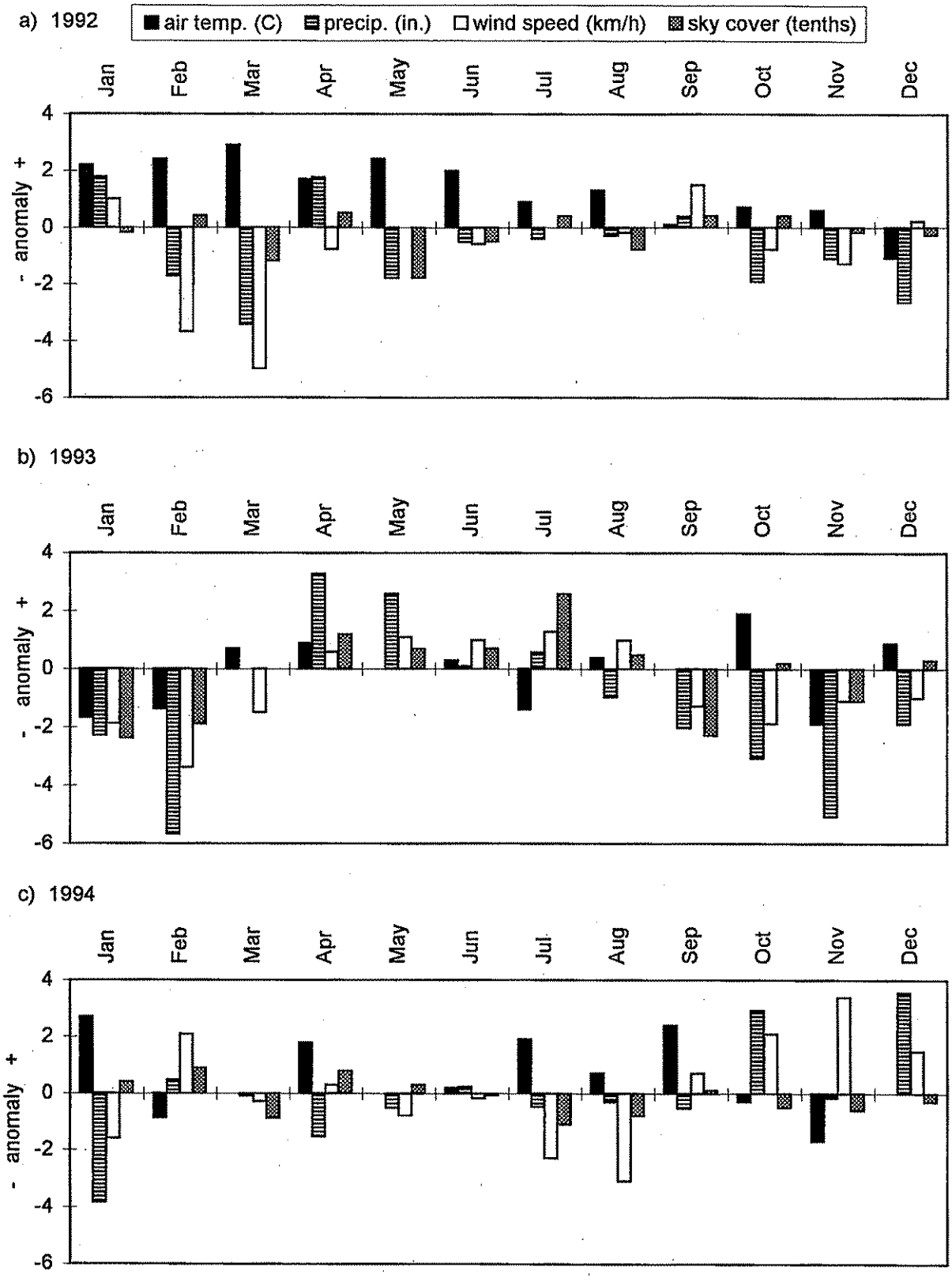


Figure 5. Weather anomalies relative to long-term means for a) 1992, b)1993, and c)1994. Anomaly units are degrees C for air temp., inches for precip., km/h for wind speed and tenths for sky cover. Data are from National Weather Service. See Table 4 for years used to determine long-term means.

6 months in 1994 (April through September). 1992 was drier than normal for April through October. 1993 was much wetter than normal for April through June and much drier than normal for July through October periods. 1994 was slightly drier than normal for April through June and slightly wetter than normal for July through October periods.

Wind

Yearly average wind speeds were higher in 1994 than in 1993 and 1992. However, for April through June, wind speeds were much higher in 1993 than in 1992 and 1994. For July through October average wind speeds were highest in 1992 and lowest in 1994. Winds were strongest (>11 km/h) during January and December 1992, April through July 1993, and February through April and October through December 1994. Overall, for all three years, wind speeds were lower in the summer than in the winter and spring. 1992 had slightly lower wind speeds than normal for April through June and slightly higher wind speeds than normal for July through October periods. 1993 had much higher wind speeds than normal for April through June and similar to normal wind speeds for July through October periods. 1994 had similar to normal wind speeds for April through June and lower than normal speeds for July through October periods.

Sky Cover

Yearly average percent sky cover (tenths covered, maximum =10) was similar for all three years. For April through October, percent sky cover was higher and there were fewer extended periods of sunshine (less than 50% sky cover for three or more days in a row) in 1993 than in 1992 or 1994 (Figure 6). In addition, these periods of sunshine occurred much later in the growing season in 1993 than in the other two years. The clearest skies were during 1992 for April through June and during 1994 for July through October (Table 4). Sky cover was greatest in the winter and spring and lowest in summer and early fall. Percent sky cover and wind speed were somewhat positively correlated during 1993 and 1994 ($r^2 = 0.46$). 1992 had lower than normal percent sky cover for April through June and similar to normal percent sky cover for July through October periods. 1993 had much higher percent sky cover than normal for April through June and slightly higher percent sky cover for July through October periods. 1994 had slightly higher than normal percent sky cover for April through June and much lower than normal percent sky cover for July through October periods.

Freshwater Runoff

Yearly average river flow was higher in 1994 (338 cubic feet/second (cfs)/day) than in 1992 (264 cfs/day) and 1993 (243 cfs/day). For April through June, however, river flows were much higher in 1993 than in 1992 or 1994. For July through October, river flows were similar for all three years with values close to 100 cfs typically seen. The peaks of river flow occurred during or shortly after periods of high precipitation. River flow and precipitation were positively correlated with an r^2 value of 0.61 (Figure 7). Highest river

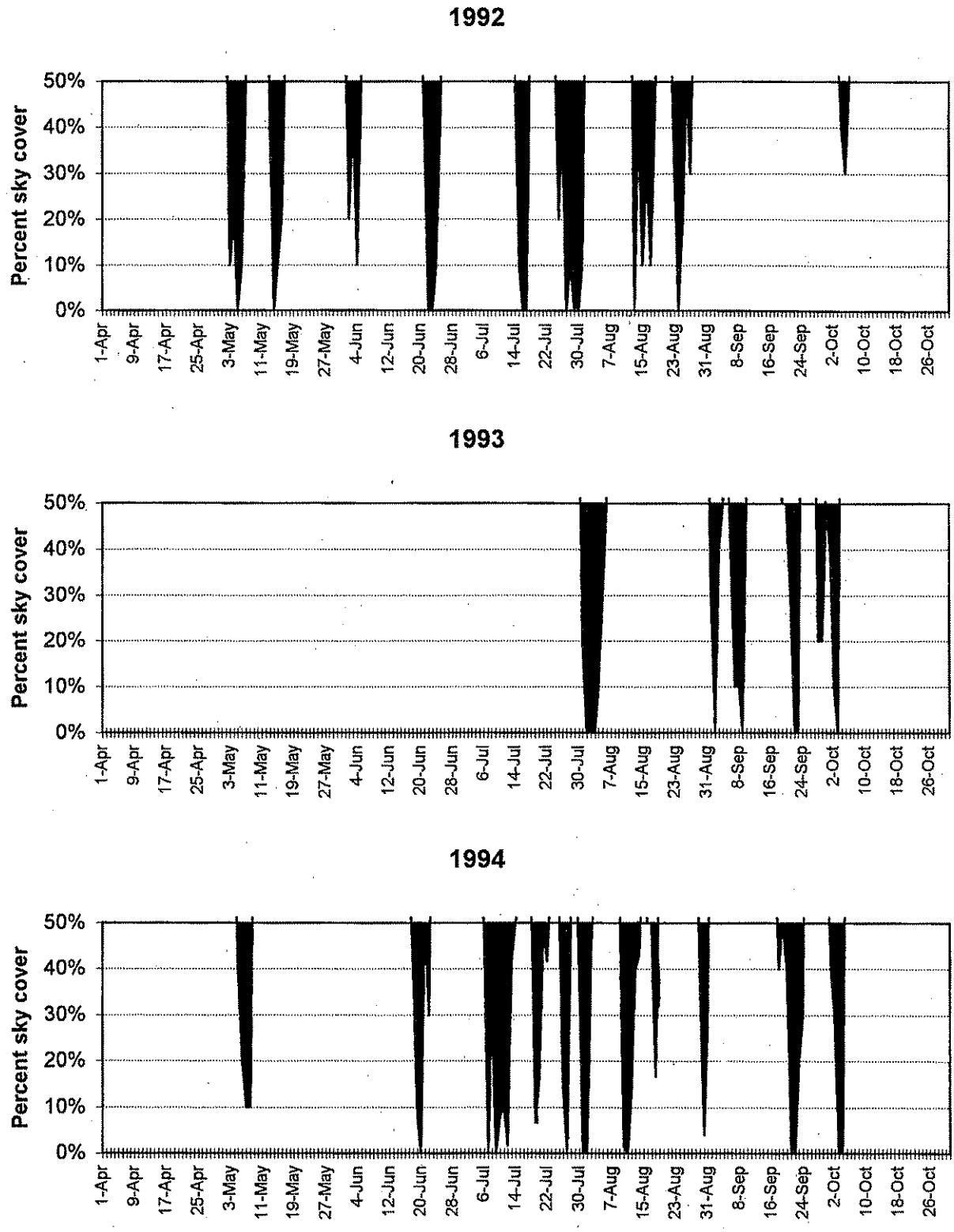


Figure 6. Periods of sun for 3 or more days as indicated by mean daily sky cover values of 50% or less. Mean daily sky cover was determined from observations made from sunrise to sunset at hourly intervals except for June to October 1994 when observations were made every 3 hours.

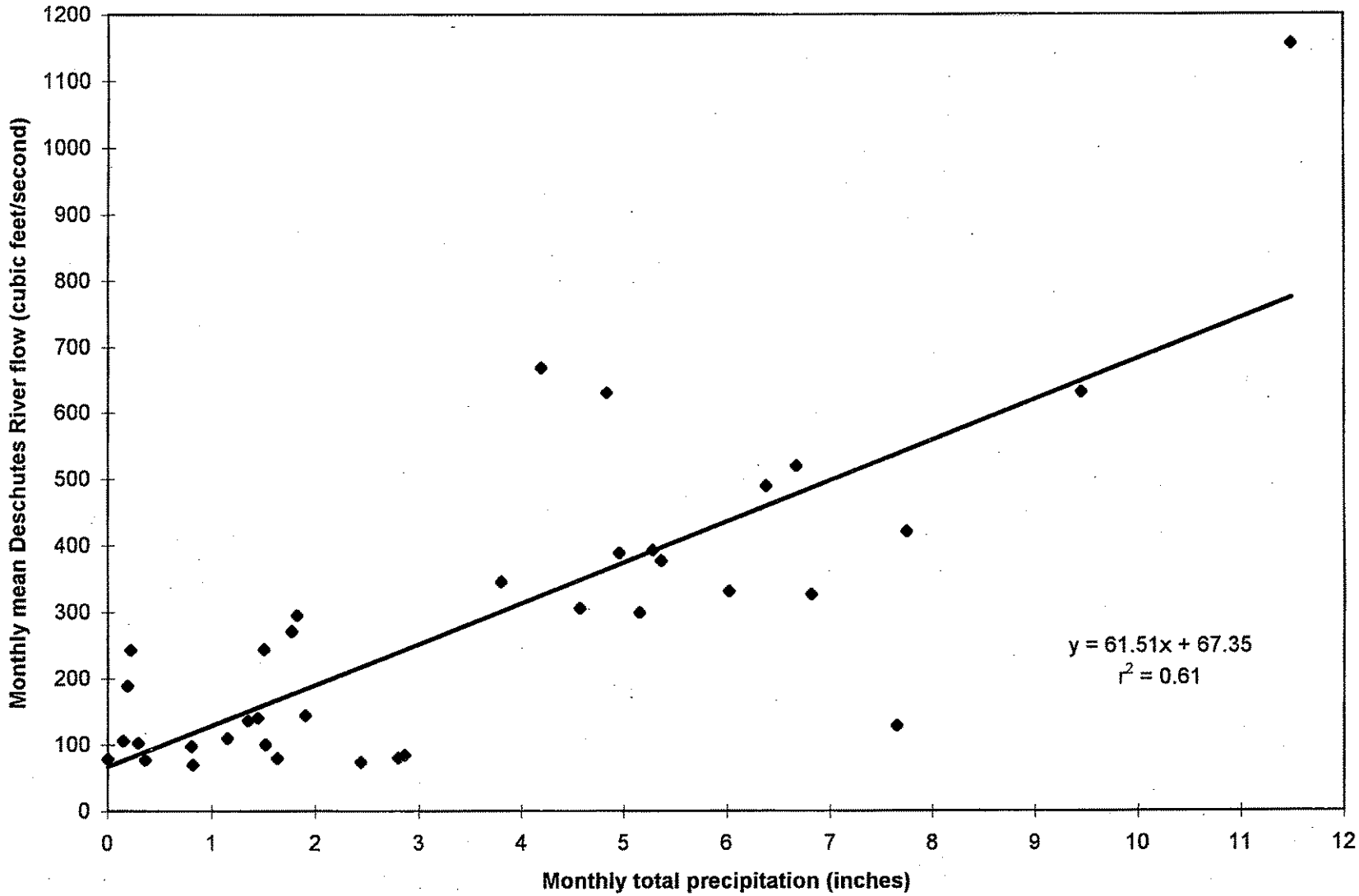


Figure 7. Linear regression between monthly total precipitation and monthly mean Deschutes River flow for 1992, 1993 and 1994.

flows occurred during winter and early spring of each year. The lowest flows were in late summer/early fall of each year, as by this time precipitation was also low.

Hydrography

Salinities at 1-m and near-bottom depths were highest in 1994, lowest in 1993 and intermediate in 1992 except for 1-m data in the inner bay. In the inner bay the highest 1-m salinities during spring were in 1992 and the highest in summer were in 1993 due to weaker stratification during these periods. A seasonal increase in salinity was seen from early spring to fall at both 1-m and near-bottom depths. Surface salinities were much lower and had larger fluctuations in the inner bay than in the central bay.

Water temperature correlated with air temperature, with higher values recorded in 1992 and 1994 than in 1993. The warmest temperatures were observed during July and August for all three years. The 1-m temperatures showed larger fluctuations than near-bottom temperatures.

Density stratification between 1 m and near-bottom was generally strongest in 1994 and weakest in 1993. Stratification was strongest in the inner bay and decreased from the head to the mouth of Budd Inlet. Stratification was predominantly salinity driven. A large reduction in surface salinity and increase in stratification was observed in 1992 and 1994 following the drainage of Capital Lake in mid-July. Throughout the inlet, some degree of stratification existed during the sampling season (March to October), as indicated by changes in sigma-t with depth. Typically the major pycnocline was above 3 m.

Salinity

Freshwater flow from the Deschutes River/Capitol Lake outlet is regulated by a controlled dam at the head of Budd Inlet. The flood gates on this dam open when the height of Capitol Lake exceeds a predetermined level (~4 m); typically this results in freshwater flow into Budd Inlet nearly every day (personal comm., Cliff Ikerd, Department of General Administration). This flow would be strongest in times of high river flow. The flood gates are closed during periods when the tide height is equal to or greater than the lake height, in order to reduce the amount of salt water intrusion into the lake. Each year, during July, Capitol Lake is completely drained and then backflushed with salt water from Budd Inlet. This event occurred during July 14-16 in 1992, between July 19-23 in 1993 and during July 18-21 in 1994.

Interannual Variation

For April through October, 1-m and near-bottom salinities were saltiest in 1994, freshest in 1993 and intermediate in 1992, except for 1-m data in the inner bay (Table 5). In the inner bay, the saltiest 1-m salinities occurred in 1992 for April to June and in 1993 for July through October. 1994 was the year with the largest observed fluctuation in salinity, with

Table 5. Mean salinity and temperature in the inner bay (stations BI6, BI5 and BI4 combined) and in the central and outer bay (stations BA2, BB2, BC3, BD2 and BE2 combined) for 1-m and near-bottom depths. Means computed for April-October, April-June, and July-October for 1992, 1993 and 1994.

Salinity		1-m		near-bottom	
		inner	central/outer	inner	central/outer
Apr-Oct	1992	26.75	28.43	29.11	29.19
	1993	27.19	28.17	28.72	28.92
	1994	26.75	28.60	29.28	29.35
Apr-Jun	1992	27.15	27.85	28.49	28.58
	1993	25.91	27.61	28.26	28.57
	1994	25.95	27.94	28.77	28.85
Jul-Oct	1992	26.55	28.76	29.43	29.52
	1993	28.23	28.64	29.10	29.21
	1994	27.12	29.00	29.54	29.65

Temperature		1-m		near-bottom	
		inner	central/outer	inner	central/outer
Apr-Oct	1992	16.62	16.49	14.23	14.16
	1993	14.43	14.86	13.30	13.08
	1994	16.54	15.96	13.88	13.58
Apr-Jun	1992	14.27	14.26	12.17	12.06
	1993	13.18	13.35	11.83	11.49
	1994	14.76	14.27	11.66	11.55
Jul-Oct	1992	17.85	17.71	15.30	15.31
	1993	15.41	16.07	14.44	14.36
	1994	17.41	16.96	14.98	14.79

1 meter values ranging from 15 to 31 ppt at inner bay stations (Figure 8a). Generally inner bay 1-m salinities fluctuated less during 1993 than during 1992 and 1994.

Seasonal Variation

A seasonal increase in salinity was seen at both 1-m and near-bottom depths with lowest values typically seen in early spring and highest values in fall (Figure 8). Data collected at 0.5 and 10 m depths at long-term station BUD005 also show this seasonal pattern (Figure 9). This steady increase in salinity most likely reflects the reduced freshwater input to the inlet during the summer months, and the effect of saltier waters entering from Puget Sound. At all stations, 1-m salinities had larger fluctuations throughout the sampling period than near-bottom salinities. Low 1-m salinities were also seen at inner bay stations following the drainage of Capital Lake during July of 1992 and 1994 (Figure 8a). During July 1993, a survey did not immediately follow the drainage of Capital Lake.

Spatial Variation

The range of salinities at 1-m depths was smaller at central and outer bay stations than at inner bay stations for all three years (Figure 8 a, b). The gradient in 1-m salinity from the head of the inlet outward was less pronounced during ebb and low tides, than during flood and high tides (Eisner et al., 1994). This was likely a result of freshwater from the Deschutes River/Capitol Lake outlet, the major influence on salinity stratification in the inlet, spreading out during an ebb or low tide and remaining nearer the head of the inlet during a flood or high tide. LOTT is also a freshwater source in the inner bay. There are two minor sources of freshwater on the eastern shore located at Gull Harbor and Priest Point (Ellis Creek) and one on the southern end of East Bay (Moxlie Creek) (Figure 1); however, their impact on surface salinity is probably low.

Degree of Correlation with River Flow

River flow had only a weak influence on 1-m salinity in the inner bay ($r^2 = 0.17$ and 0.08 at stations BI6 and BI5, respectively, Figure 10 a, b) possibly due to fluctuations from the opening of the Deschutes River/Capitol Lake flood gate. In the central and outer bay correlations were higher ($r^2 = 0.50$ at both stations BD2 and BE2, Figure 10 c, d). Weak regressions ($r^2 = 0.22$) between river flow and 0.5 m salinity were also seen at long-term central bay station BUD005 for data from various tidal stages collected during January 1992 to December 1994.

Degree of Correlation with Precipitation

Salinity at 1 m for April through October data was not directly correlated with precipitation ($r^2 = 0.002$) in Budd Inlet. However, as mentioned in the weather section, peak river flows occurred during or shortly after periods of high precipitation (Figure 4) and showed a positive correlation with precipitation ($r^2 = 0.61$, Figure 7). Therefore, surface salinity was likely indirectly influenced by precipitation events. The lack of

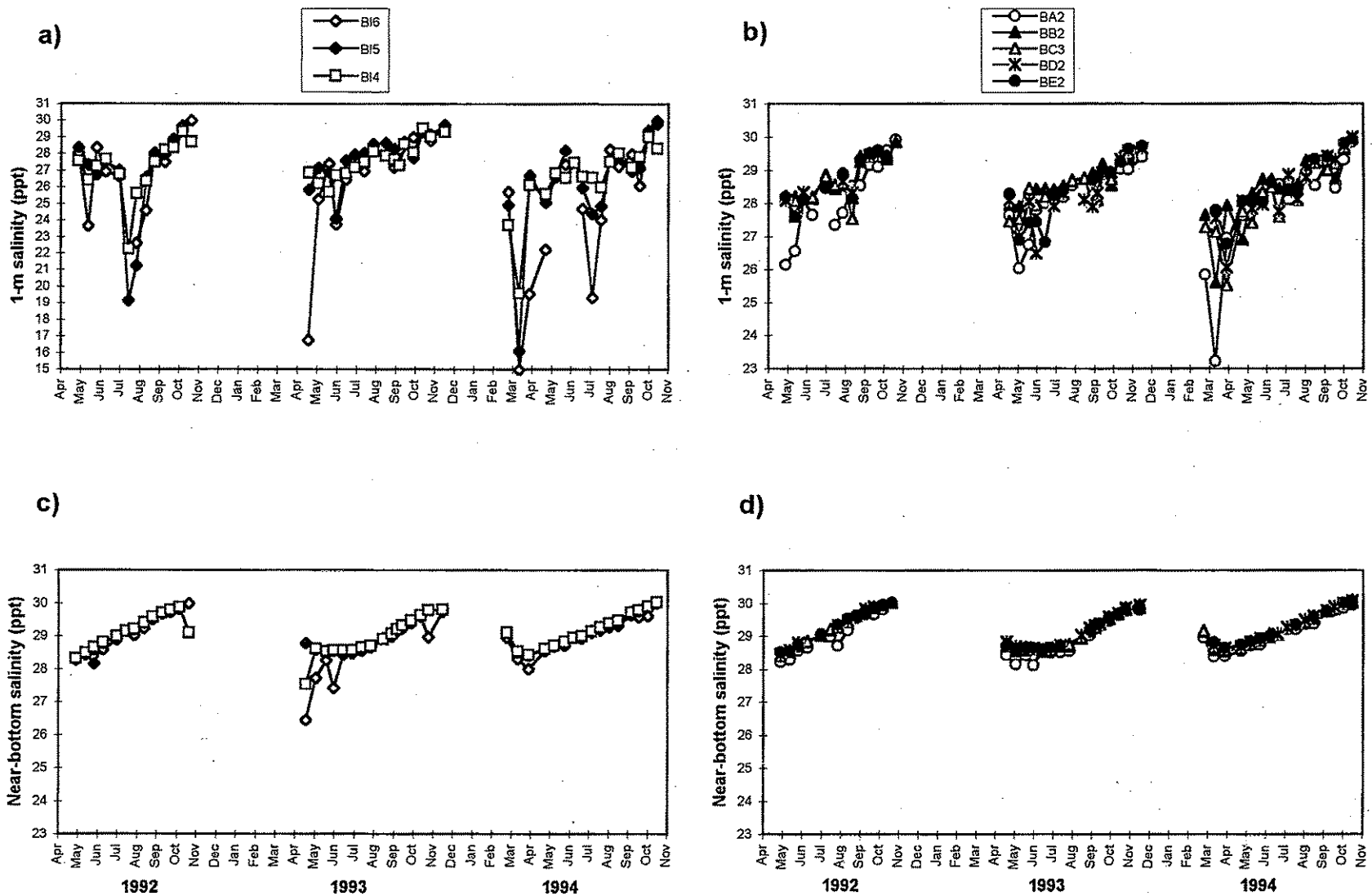


Figure 8. Salinity in Budd Inlet during 1992, 1993 and 1994 at a) 1-m in the inner bay, b) 1-m in the central and outer bay, c) near-bottom in the inner bay, and d) near-bottom in the central and outer bay. Note the range of salinity shown in a) is twice that of b), c) and d).

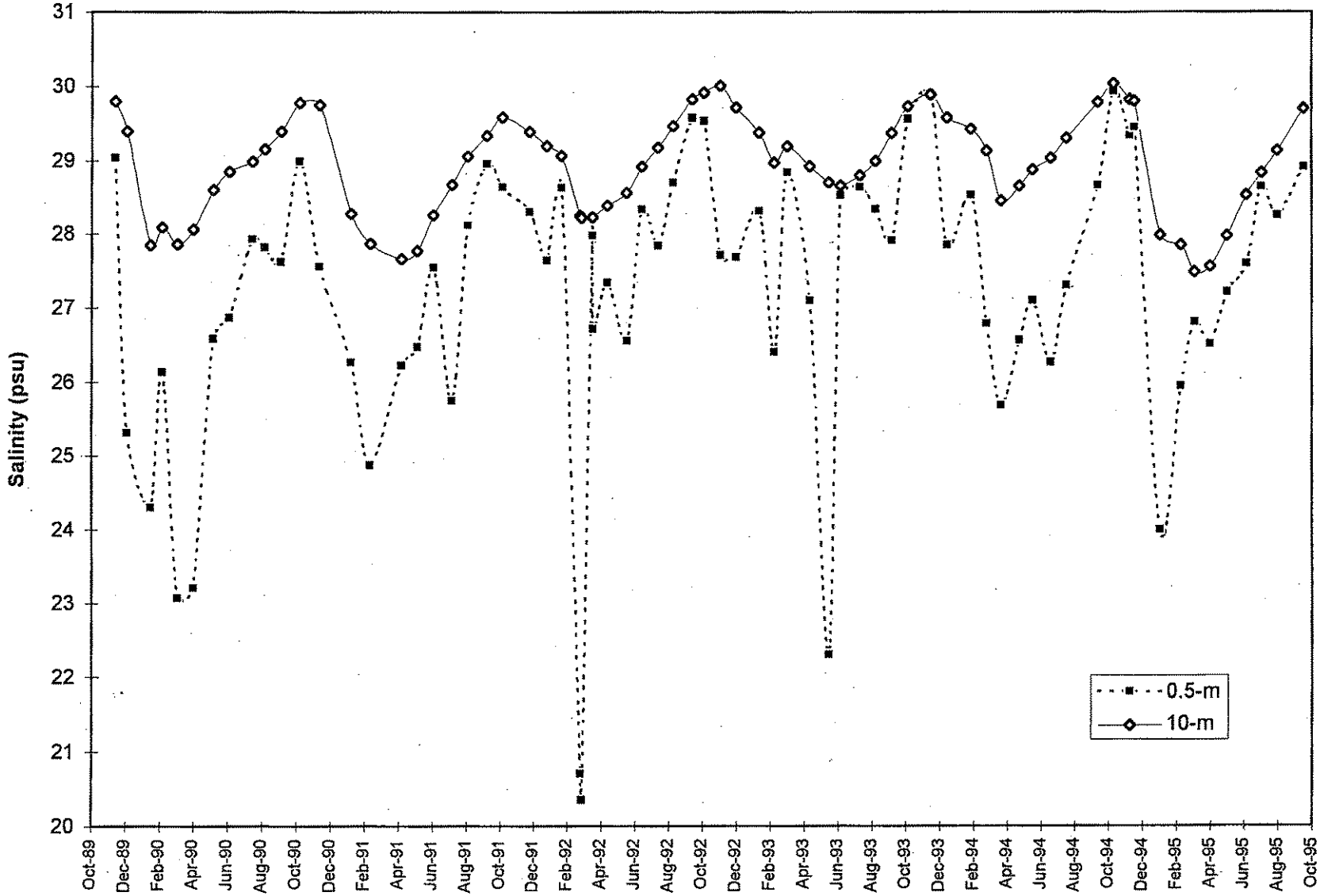


Figure 9. Salinity data at long-term central bay station BUD005 for 0.5 and 10-m depths. Data collected with Seabird Electronics Seacat-19 CTD.

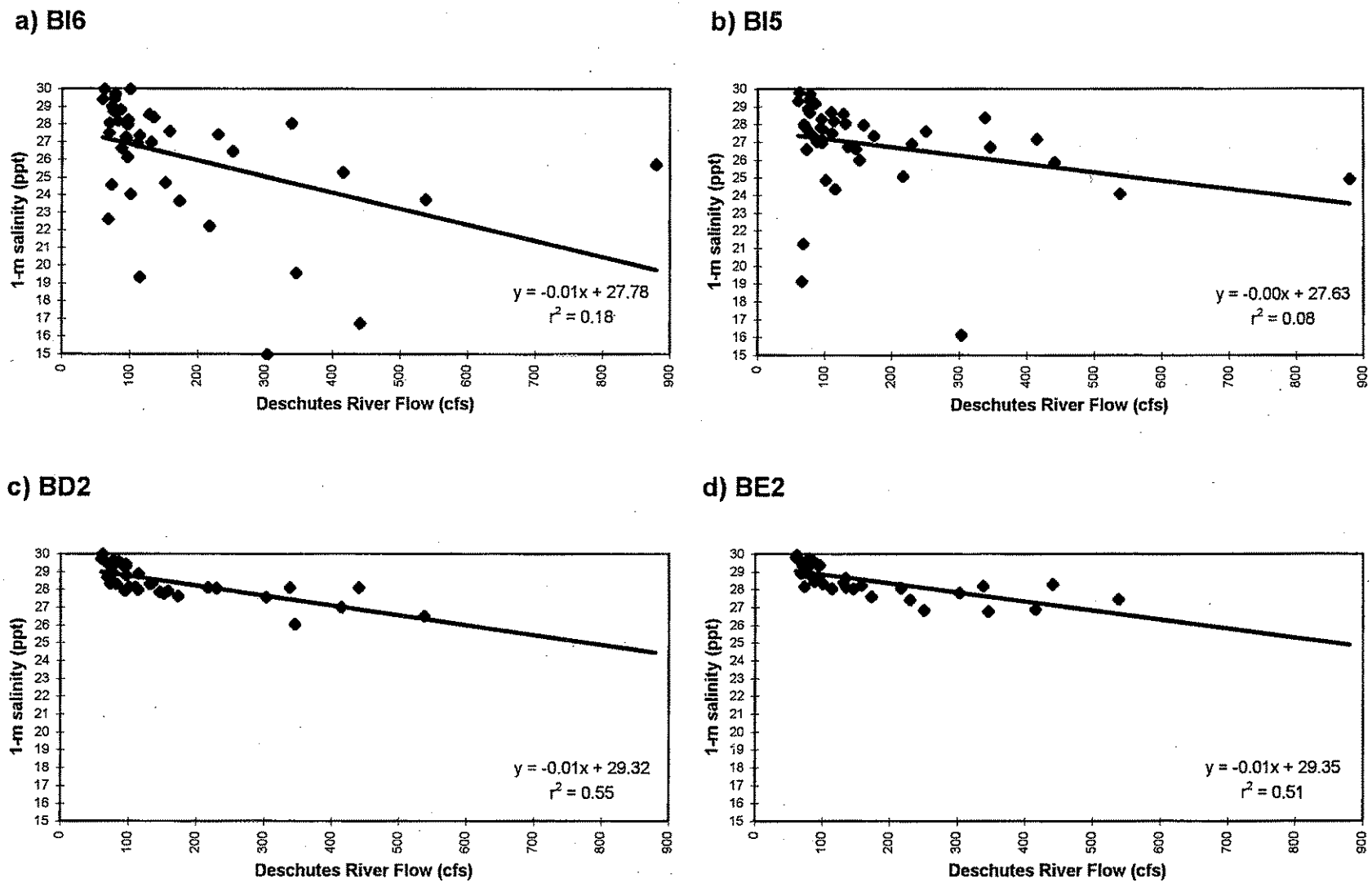


Figure 10. Linear regressions between Deschutes River flow and 1-m salinity in Budd Inlet for inner bay stations a) BI6 and b) BI5, and central/outer bay stations c) BD2 and d) BE2.

correlation between precipitation and 1-m salinity may also be due to the depth used in the comparison. Salinities closer to the surface (i.e. 0.1 m) may have shown a higher correlation with precipitation.

Temperature

Interannual Variation

Overall, 1992 and 1994 had warmer water temperatures than 1993 during the growing season (Figure 11). Temperatures at both 1-m and near-bottom depths were warmest in 1992, coolest in 1993 and intermediate in 1994, except for some differences during April through June. These differences include warmer 1-m temperatures in 1994 than in 1992 for the entire bay and warmer near-bottom temperatures in 1993 than in 1994 in the inner bay (Table 5). In the inner bay larger thermoclines (based on differences in temperature at 1-m and near-bottom depths) were seen in 1992 and 1994 than in 1993 (Figures 11 a, c).

Seasonal Variation

At both 1-m and near-bottom depths, the warmest water temperatures observed were during July, August and September (Figure 11) and the coldest in February and March. Temperature data from long-term station BUD005 shows similar patterns (Figure 12); however, note that the water at 0.5 m often warmed up a month or two earlier than the water at 10 m. The thermoclines were strongest during the summer according to both seasonal and long-term data (Figures 11 and 12).

Spatial Variation

Temperature variation was greater at 1 m than at near-bottom at all stations. The variation at 1 m was similar throughout the bay, although warmer temperatures were seen in the central and outer bay than in the inner bay during August 1992 and 1993. Data from cross-bay transects were not analyzed for 1993-1994, however in 1992, thermal stratification was greatest in West Bay out to station BI3 and along the eastern shore of the central bay (Figure 4c in Eisner et al., 1994). In general, surface temperatures at stations on the east shore were warmer than those on the west shore (Figure 4a, b in Eisner et al., 1994).

Degree of Correlation with Air Temperature

The temperature of the surface water in Budd Inlet was correlated with air temperature (r^2 = 0.64 and 0.69 at stations BI5 and BE2, respectively, Figure 13). Air temperature was often higher than or similar to water temperature in the summer (Figure 13a). Looking at these correlations over an annual cycle at station BUD005, air temperatures were generally lower than 0.5-m water temperatures in the fall and winter (Figure 14).

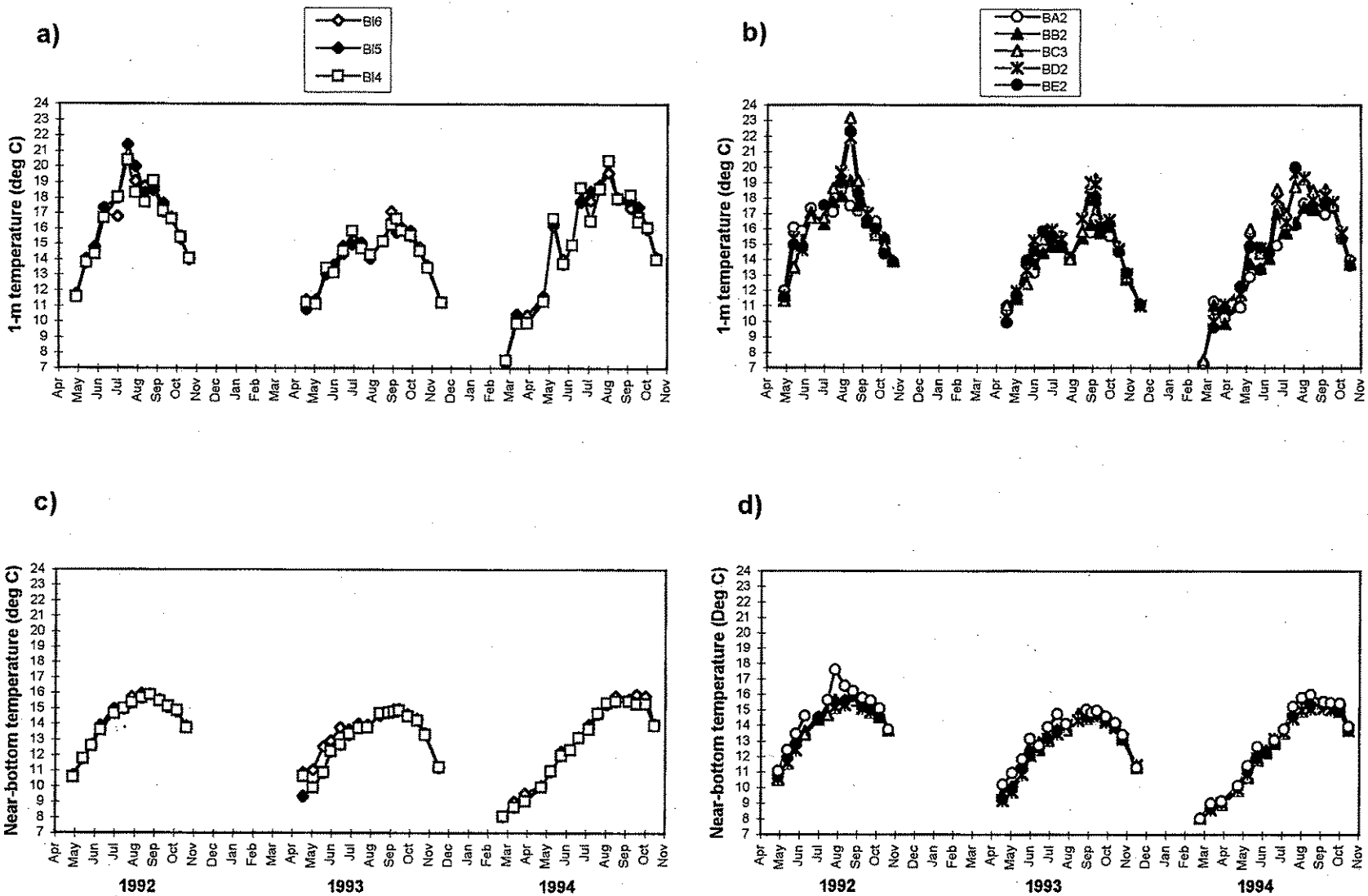


Figure 11. Temperature (water) in Budd Inlet during 1992, 1993 and 1994 at a) 1-m in the inner bay, b) 1-m in the central and outer bay, c) near-bottom in the inner bay, and d) near-bottom in the central and outer bay.

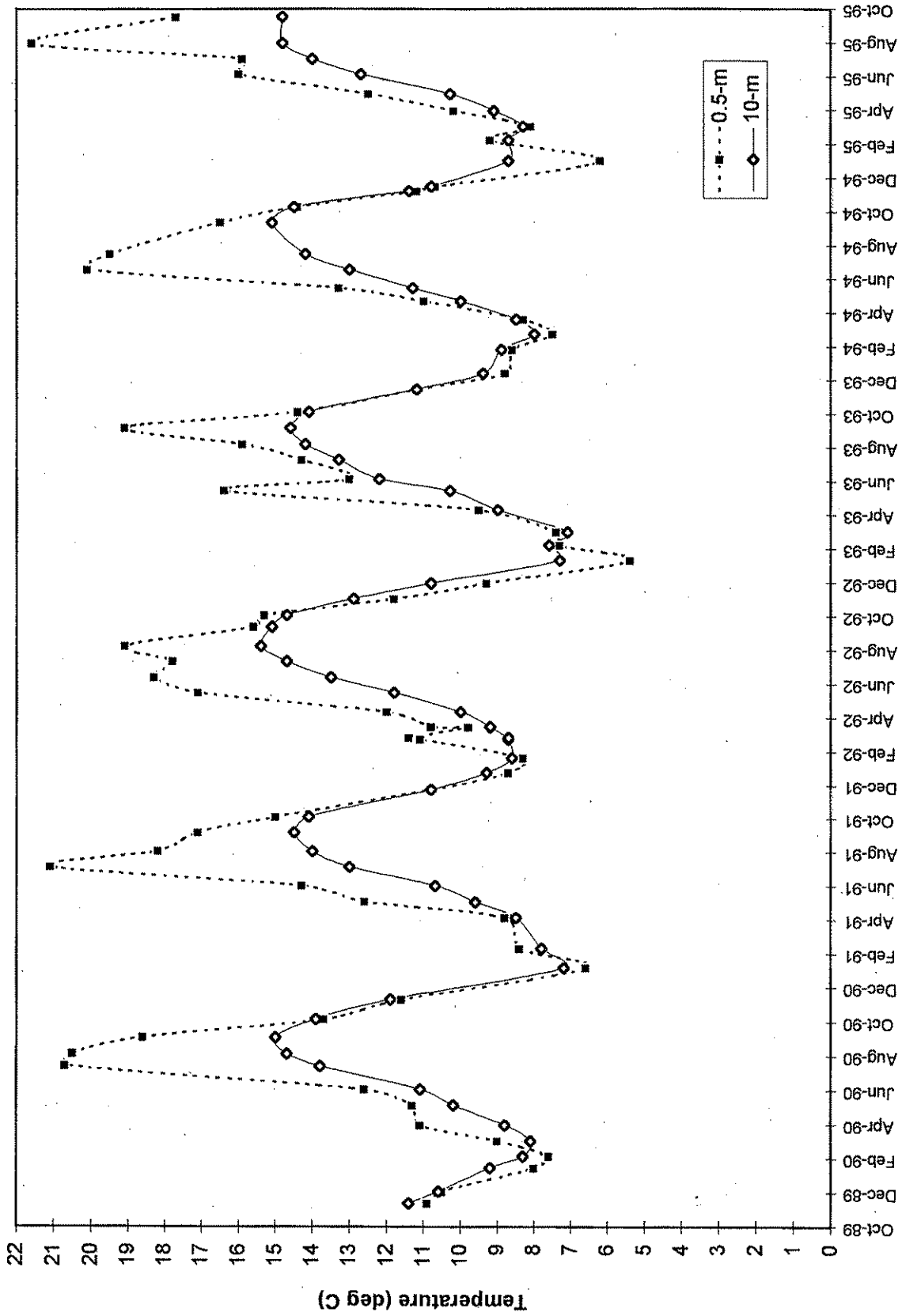


Figure 12. Temperature data from long-term central bay station BUD005 for 0.5 and 10-m depths. Data collected with Seabird Electronics Seacat-19 CTD.

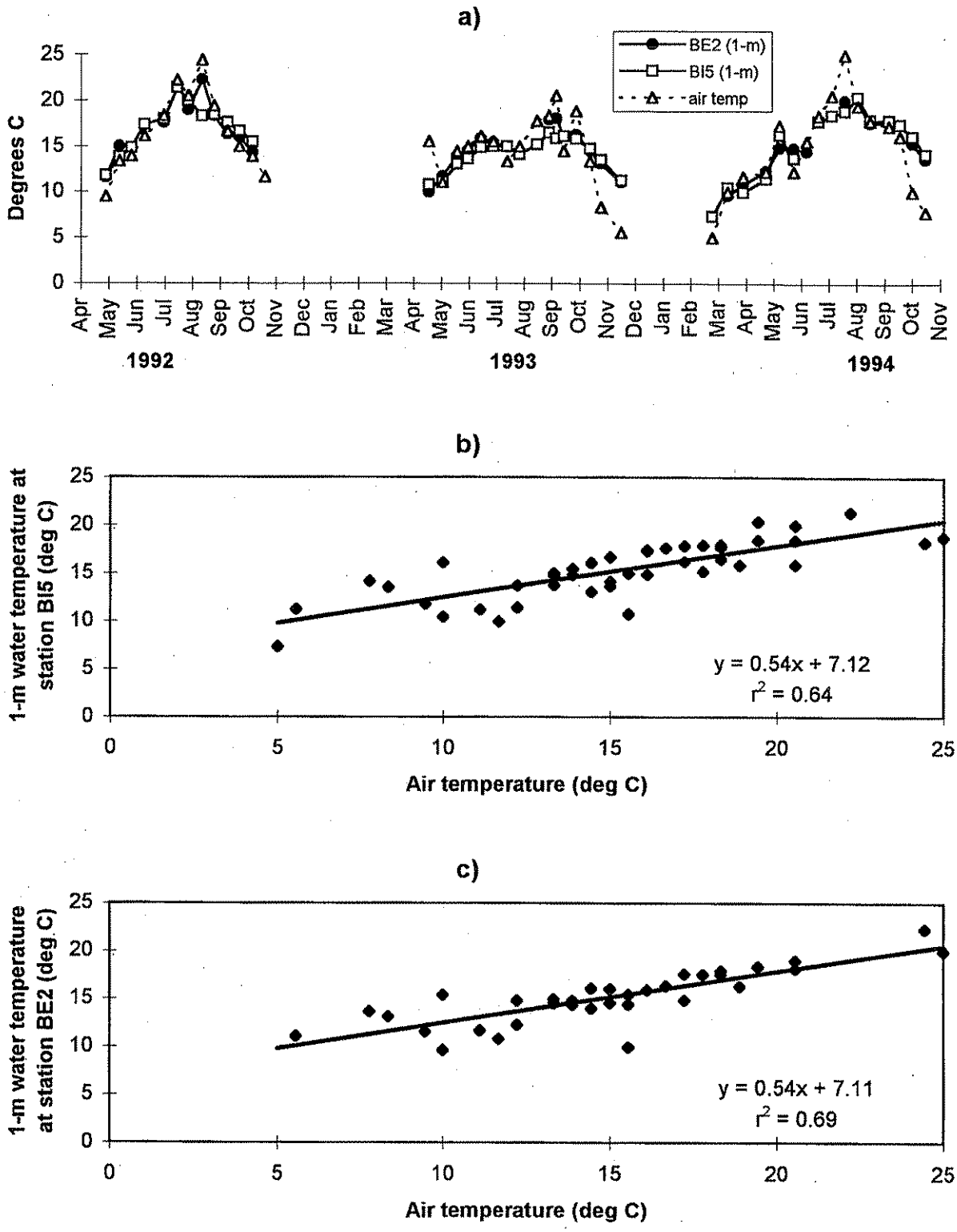


Figure 13. a) Air and 1-m water temperature at stations BI5 and BE2. Linear regressions between air and 1-m water temperatures at b) inner bay station BI5 and c) outer bay station BE2. Air temperatures are the daily mean for each survey date observed at the Olympia Airport by the NWS.

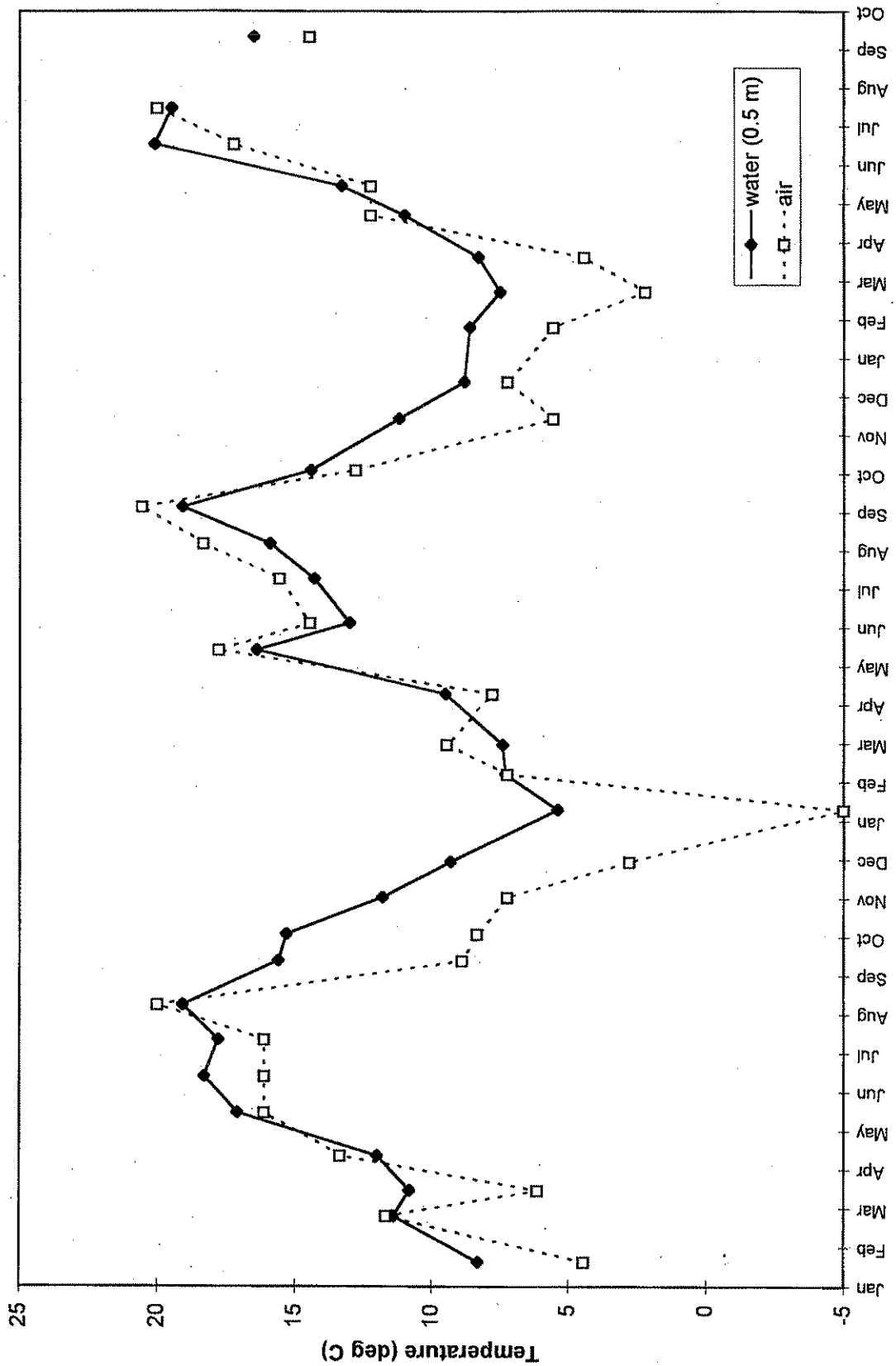


Figure 14. Air and surface (0.5 m) water temperatures for long-term central bay station BUD005. Air temperature is the daily mean temperature recorded by the NWS at the Olympia Airport for the survey date.

Temperature/Salinity (T/S) Diagrams

Progressive TS diagrams display water mass characteristics of temperature and salinity as time progresses. Near-bottom and 1-m depths are shown in Figures 15 and 16, respectively, at inner bay station BI5 and central bay station BC3.

Near-bottom waters became warmer and saltier from April through June in 1992 and 1994, whereas, in 1993 water increased in temperature but not in salinity. From July through October, near-bottom waters became warmer (until August or September) and saltier during all three years, but temperatures and salinities were higher in 1992 and 1994 than in 1993 for comparable months. Lower salinities in 1993 are likely due to increased vertical mixing producing less saline conditions in near-bottom waters. Cooler water temperatures in summer of 1993 correlate with the cooler air temperatures during this time.

At 1-m depths for April through October, 1992 and 1994 had warmer water temperatures but similar or lower salinities in relation to 1993. This water temperature difference was likely due to the warmer air temperatures in 1992 and 1994 compared to 1993. In the inner bay in 1992 and 1994, a cold freshwater influence was seen during the spring and a warm freshwater influence during the summer likely reflecting inputs from the Deschutes River/Capital Lake. For example, the low salinity/ high temperature data point (19 ppt, 21°C) seen at station BI5 in mid-July 1992 was due to the drainage of Capital Lake prior to this survey (Figure 16a).

Relative Density Stratification

Larger differences in density with depth mean stronger stratification. The stronger the stratification, the more energy is required by wind or tides to mix the water column. The strongest stratification in Budd Inlet typically occurs in the inner bay during July through October.

Interannual Variation

The weakest stratification was generally seen during 1993 (Figure 17 and Table 6). Greater interannual differences in stratification were seen in the inner bay than in the central bay. Inner bay stratification was often two to three times stronger in 1992 and 1994 than in 1993 particularly during July through October. At inner bay stations (BI4 and BI5 combined) during July through October, relative stratification values less than 1 were seen 14% of the time in 1992, 24% of the time in 1994, and 62% of the time in 1993. During July through October, 1993 also had lower average precipitation than 1992 or 1994 (Table 4). Since stratification in Budd Inlet is highly salinity driven (correlation between relative stratification and salinity at station BI5 yielded $r^2 = 0.95$, Figure 18), lower precipitation may indirectly result in higher surface salinity and thus weaker stratification.

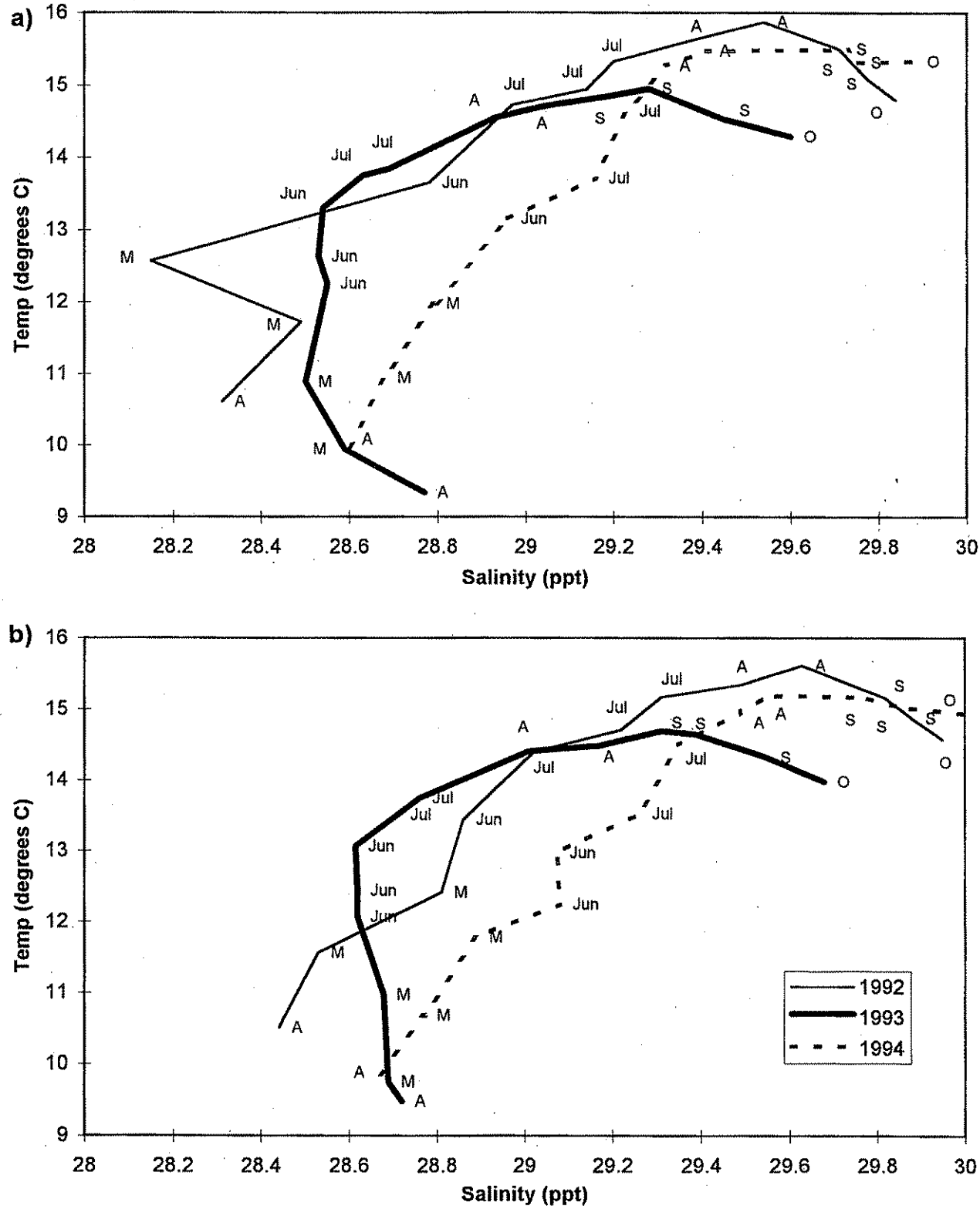


Figure 15. T/S diagrams for near-bottom depths in Budd Inlet during 1992, 1993 and 1994 at a) inner bay station BI5 and b) central bay station BC3.

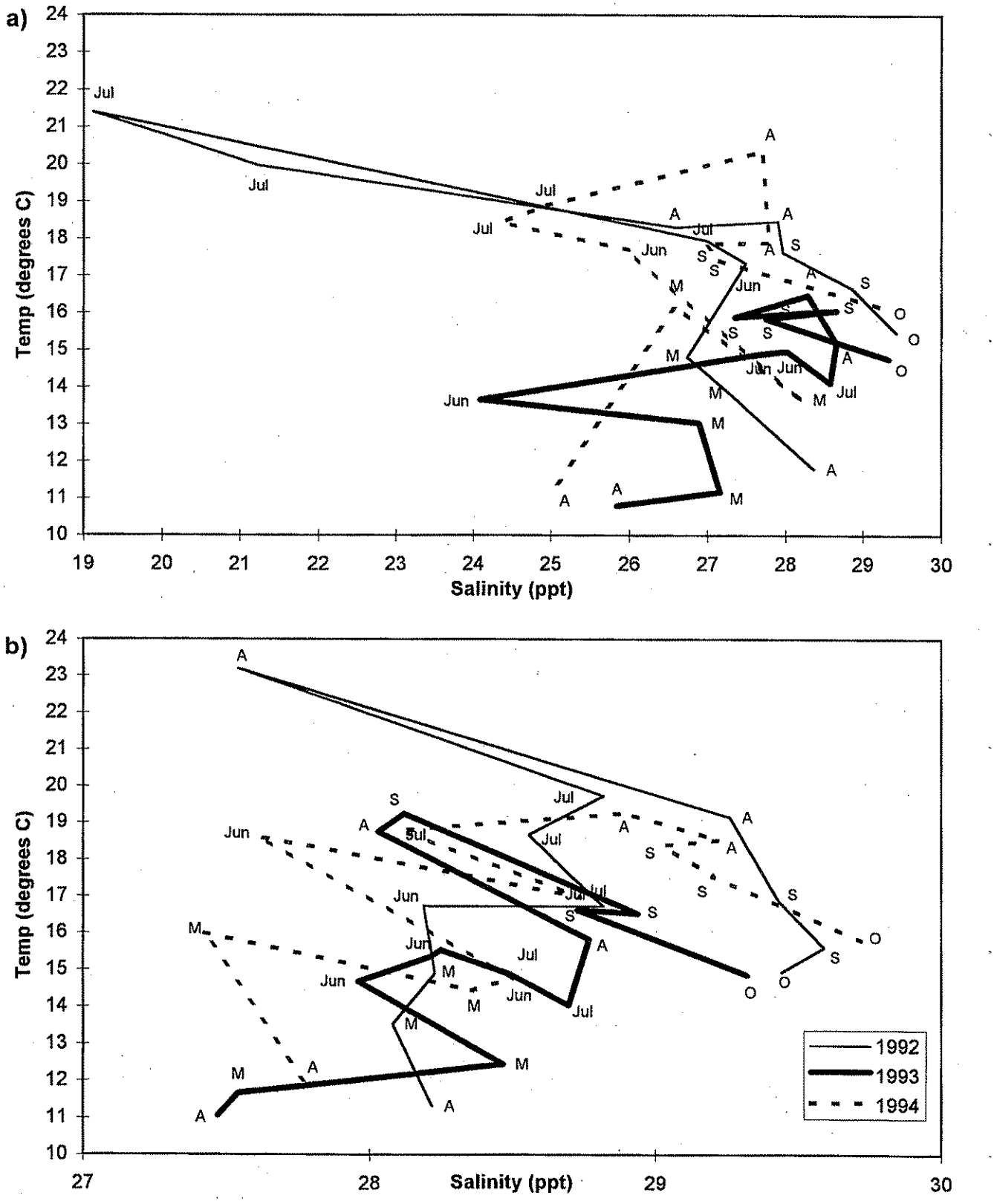


Figure 16. T/S diagrams for 1-m depths in Budd Inlet during 1992, 1993 and 1994 at a) inner bay station BI5 and b) central bay station BC3. Note the change in scale between the 2 plots for salinity.

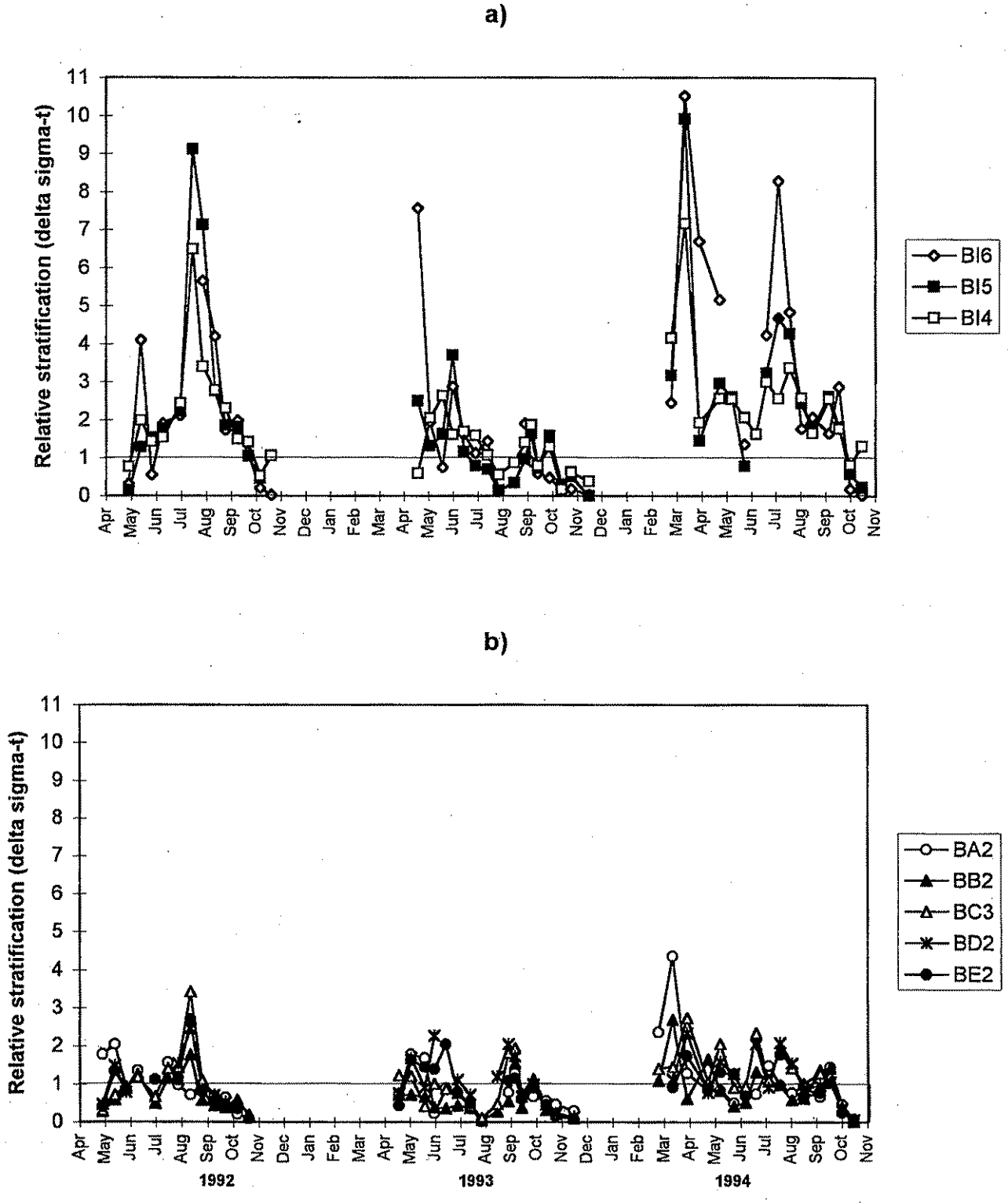


Figure 17. Relative stratification (difference in near-bottom and 1-m density) at a) inner bay stations and b) central and outer bay stations for 1992, 1993 and 1994 in Budd Inlet. Note that near-bottom depths were ~1.5 m shallower in 1992 than in 1993 and 1994.

Table 6. Mean relative stratification (difference between 1-m and near-bottom sigma-t values) for low tide transect data collected from 1992 to 1994 in budd Inlet.

Sigma-t			BI6	BI5	BI4	BI6, BI5, BI4 Combined	BA2	BB2	BC3	BD2	BE2	BA2, BB2, BC3, BD2, and BE2 Combined
Apr-Oct	**1992**	**MEAN**	**2.2**	**2.6**	**2.2**	**2.3**	**1.1**	**0.8**	**1.1**	**1.1**	**1.0**	**1.0**
		sd	*1.9*	*2.7*	*1.6*	*2.1*	*0.6*	*0.4*	*0.8*	*0.7*	*0.7*	*0.7*
	1993	**MEAN**	**1.7**	**1.2**	**1.3**	**1.4**	**0.8**	**0.6**	**0.9**	**1.2**	**1.0**	**0.9**
		sd	*2.0*	*1.0*	*0.7*	*1.2*	*0.5*	*0.4*	*0.5*	*0.6*	*0.5*	*0.5*
	1994	**MEAN**	**3.0**	**2.3**	**2.2**	**2.5**	**0.8**	**0.9**	**1.2**	**1.1**	**0.9**	**1.0**
		sd	*2.5*	*1.4*	*0.7*	*1.5*	*0.4*	*0.5*	*0.6*	*0.6*	*0.5*	*0.5*
	all years	**MEAN**	**2.3**	**2.1**	**1.9**	**2.1**	**0.9**	**0.7**	**1.1**	**1.2**	**1.0**	**1.0**
Apr-Jun	**1992**	**MEAN**	**1.7**	**1.2**	**1.4**	**1.4**	**1.5**	**0.8**	**0.8**	**0.9**	**0.9**	**1.0**
		sd	*2.1*	*0.7*	*0.5*	*1.1*	*0.5*	*0.4*	*0.4*	*0.5*	*0.5*	*0.5*
	1993	**MEAN**	**2.7**	**1.8**	**1.7**	**2.1**	**1.0**	**0.5**	**0.9**	**1.3**	**1.3**	**1.0**
		sd	*2.5*	*1.1*	*0.7*	*1.4*	*0.6*	*0.2*	*0.3*	*0.6*	*0.6*	*0.5*
	1994	**MEAN**	**3.6**	**2.4**	**2.4**	**2.8**	**0.7**	**0.9**	**1.5**	**1.4**	**1.0**	**1.1**
		sd	*2.0*	*1.1*	*0.5*	*1.2*	*0.2*	*0.5*	*0.7*	*0.5*	*0.3*	*0.4*
	all years	**MEAN**	**2.6**	**1.8**	**1.8**	**2.1**	**1.1**	**0.7**	**1.1**	**1.2**	**1.1**	**1.0**
Jul-Oct	**1992**	**MEAN**	**2.4**	**3.3**	**2.6**	**2.8**	**0.8**	**0.8**	**1.2**	**1.3**	**1.0**	**1.0**
		sd	*1.9*	*3.1*	*1.8*	*2.3*	*0.4*	*0.5*	*1.0*	*0.9*	*0.8*	*0.7*
	1993	**MEAN**	**0.8**	**0.8**	**1.0**	**0.9**	**0.6**	**0.6**	**0.9**	**1.1**	**0.8**	**0.8**
		sd	*0.7*	*0.6*	*0.5*	*0.6*	*0.4*	*0.5*	*0.7*	*0.6*	*0.3*	*0.5*
	1994	**MEAN**	**2.7**	**2.3**	**2.1**	**2.4**	**0.9**	**0.8**	**1.0**	**1.0**	**0.7**	**0.9**
		sd	*2.7*	*1.6*	*0.8*	*1.7*	*0.5*	*0.5*	*0.6*	*0.6*	*0.7*	*0.6*
	all years	**MEAN**	**2.0**	**2.1**	**1.9**	**2.0**	**0.8**	**0.7**	**1.0**	**1.1**	**0.8**	**0.9**

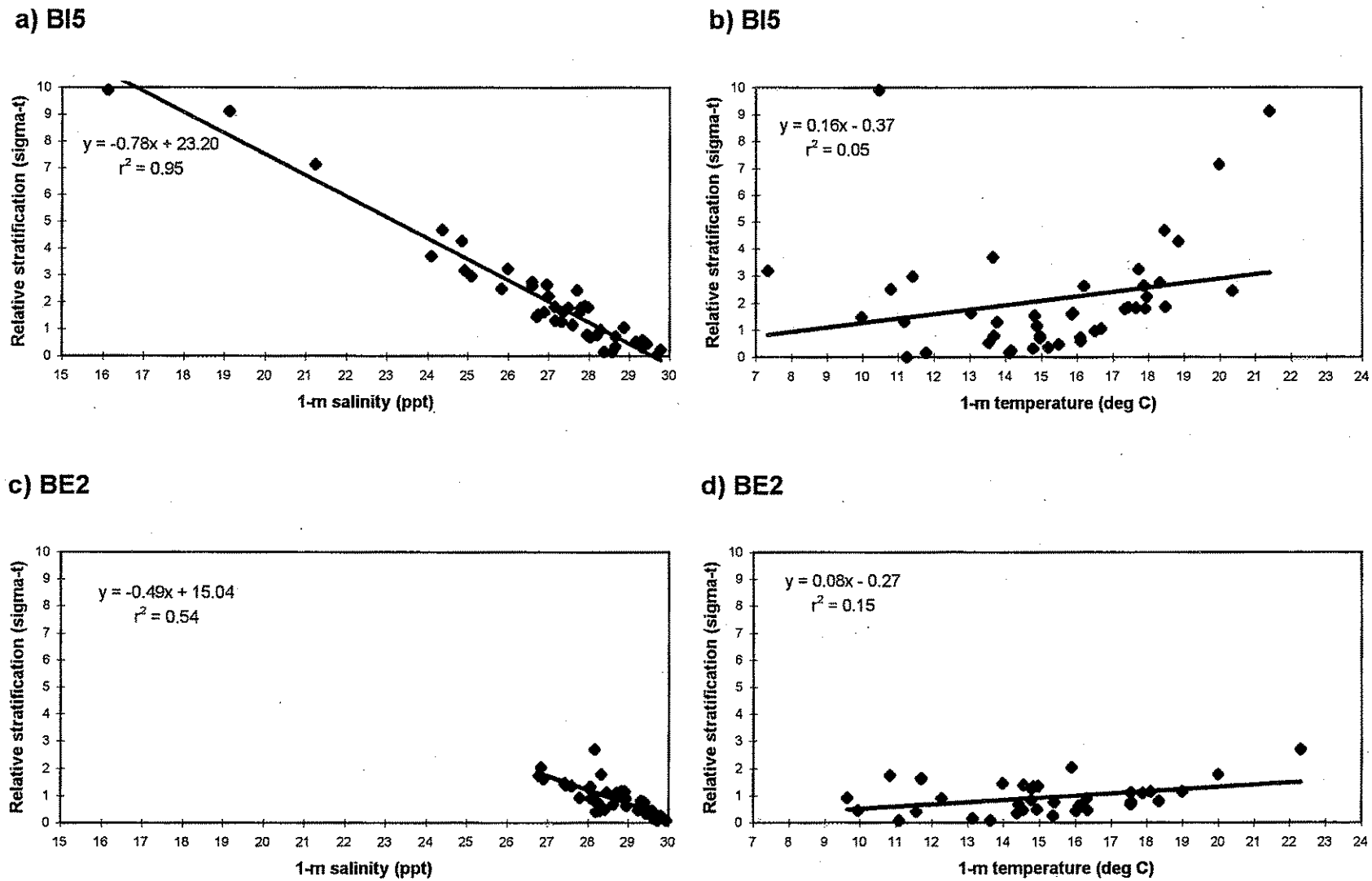


Figure 18. Linear regressions between relative stratification and a) 1-m salinity at BI5, b) 1-m temperature at BI5, c)1-m salinity at BE2, and d) 1-m temperatures at BE2.

Seasonal Variation

Periods of strongest stratification were observed during the summer of 1992, the spring of 1993, and the spring and summer of 1994 (Figure 17). The strong stratification observed during mid-July 1992 and 1994 was partially due to the drainage of Capital Lake during this time. Capital Lake was also drained in 1993, however it is difficult to determine the impact on stratification since a survey was not conducted immediately following the drainage (unlike during 1992 and 1994).

Spatial Variation

Density stratification generally decreased from the head to the mouth of the inlet (Table 6; Figure 9 in Eisner, et al., 1994). An exception is the low relative stratification at BB2, probably due to its shallow depth. The mean relative stratification for April through June and July through October periods for all years combined was approximately twice as high at inner than at central bay stations (Table 6). In 1992, stratification typically was stronger along the eastern shore in the central bay (Eisner et al., 1994). During 1992 to 1994, the major pycnocline was above 3 m for approximately 90% of the data from stations along a vertical transect from the head to the mouth of Budd Inlet (Figure 19)

Degree of Determination by Salinity and Temperature

Density stratification in estuaries is usually driven by variations in salinity. This was observed in Budd Inlet with salinity showing a stronger effect than temperature on stratification (Figure 18). Surface salinity and relative stratification had a strong inverse correlation (Figure 18 a, b), with a stronger relation for the inner bay ($r^2 = 0.95$ at station BI5) than for the outer bay ($r^2 = 0.53$ at station BE2).

Degree of Correlation with Wind Stress

Winds on the day of the survey did not noticeably reduce the stratification. Regression of wind speed on the day of the survey (from NWS) and relative stratification yielded no correlation ($r^2 = 0.0006$ and 0.07 at stations BI5 and BC3, respectively). However, the overall high wind speeds during April through June 1993 coincided with weaker density stratification primarily in the inner bay.

Underwater Light Environment

Underwater light values (measured at a depth of 2 m) were higher in 1994 than in 1993 due to the lower percent sky cover in 1994, and hence higher irradiance entering the water. In the inner bay, euphotic zone depths were deeper in 1992 and 1993 than in 1994 during spring and deeper in 1993 than 1992 or 1994 in summer and early fall. Deeper euphotic zone depths were likely related to weaker stratification. In the central bay, euphotic zone depths were similar for all three years during spring and deeper in 1992 and 1994 than in 1993 during summer and early fall. Overall, euphotic zone depths were

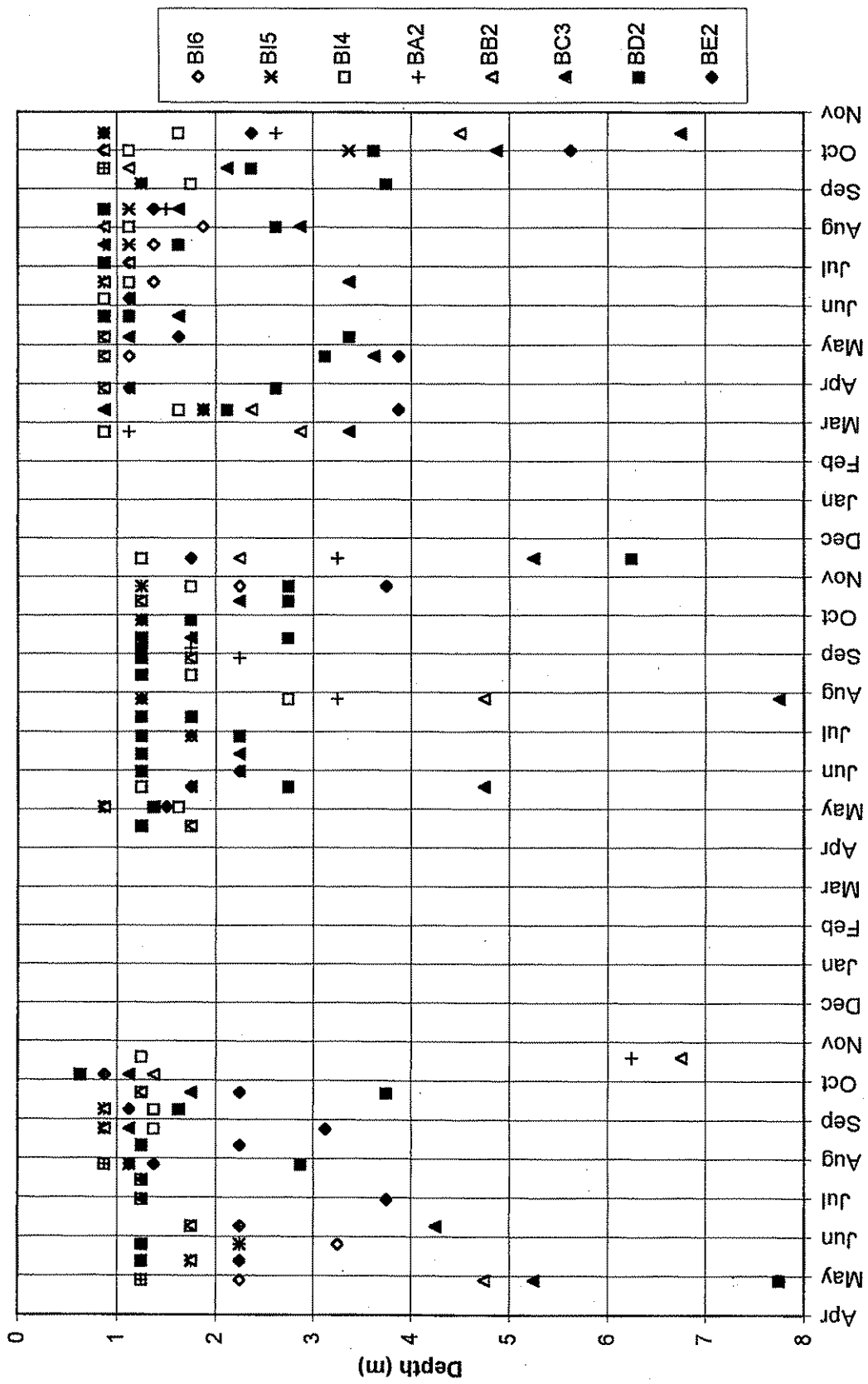


Figure 19. Depth of the major pycnocline for low tide stations during 1992, 1993 and 1994. Note that some data were processed into 0.5 m bins and some into 0.25 m bins which may explain some of the differences between years for pycnocline depths near 1 m.

shallower in the inner bay than in the central bay (particularly during 1992 and 1994) indicating that less light was available to the phytoplankton population in the inner bay. The amount of light attenuation due to phytoplankton versus sediments or other factors was not quantified.

Incident Radiation Level as Indicated by Degree of Cloud Cover

The amount of light that initially penetrates into the water column is determined by the incident radiation level which is influenced by the amount of sky cover by clouds as well as day length. As discussed in the weather section, percent sky cover was much greater in 1993 than in 1992 or 1994. Therefore, there was less light that initially entered the water column in 1993 than in 1992 or 1994. Lower PAR levels were seen in 1993 than in 1994 at both inner bay station BI4 and central bay station BC3 at depths of 2 m (alpha = 0.10 using student's t-test with unequal variances; Figure 20). Therefore, the greater percent sky coverage in 1993 also resulted in lower light levels within the water column. The same comparisons could not be made for 1992 since PAR data were not collected.

Euphotic Zone Depth

Deep euphotic zones reflect the absence of particles which attenuate light. Shallower euphotic zones reflect the presence of suspended particles, which are typically either of sedimentary or phytoplankton origin.

Interannual Variation

Although more incident radiation struck the water surface in times of high chlorophyll concentration, the penetration of light is affected by the particulate matter in the water column. For instance there was less light at 2 m in 1993 than in 1994, due to less incident radiation, however, the euphotic zone depths were deeper in the inner bay in 1993, due to fewer suspended particles which attenuate light.

Comparing all three years, in the inner bay euphotic zone depths were deepest in 1992 and 1993 for April through June, and deepest in 1993 for July through October (Table 7). On a broad scale basis, stratification was inversely correlated with euphotic zone depth with the weakest stratification seen in 1992 and 1993 for April through June, and in 1993 for July through October. Therefore, the deeper euphotic zones were likely due to weaker stratification resulting in the dilution of suspended particles in the water column.

In contrast, in the central bay euphotic zone depths were similar and deep for all three years during April through June, but generally were deeper in 1992 and 1994 compared to 1993 for July through October (Table 7).

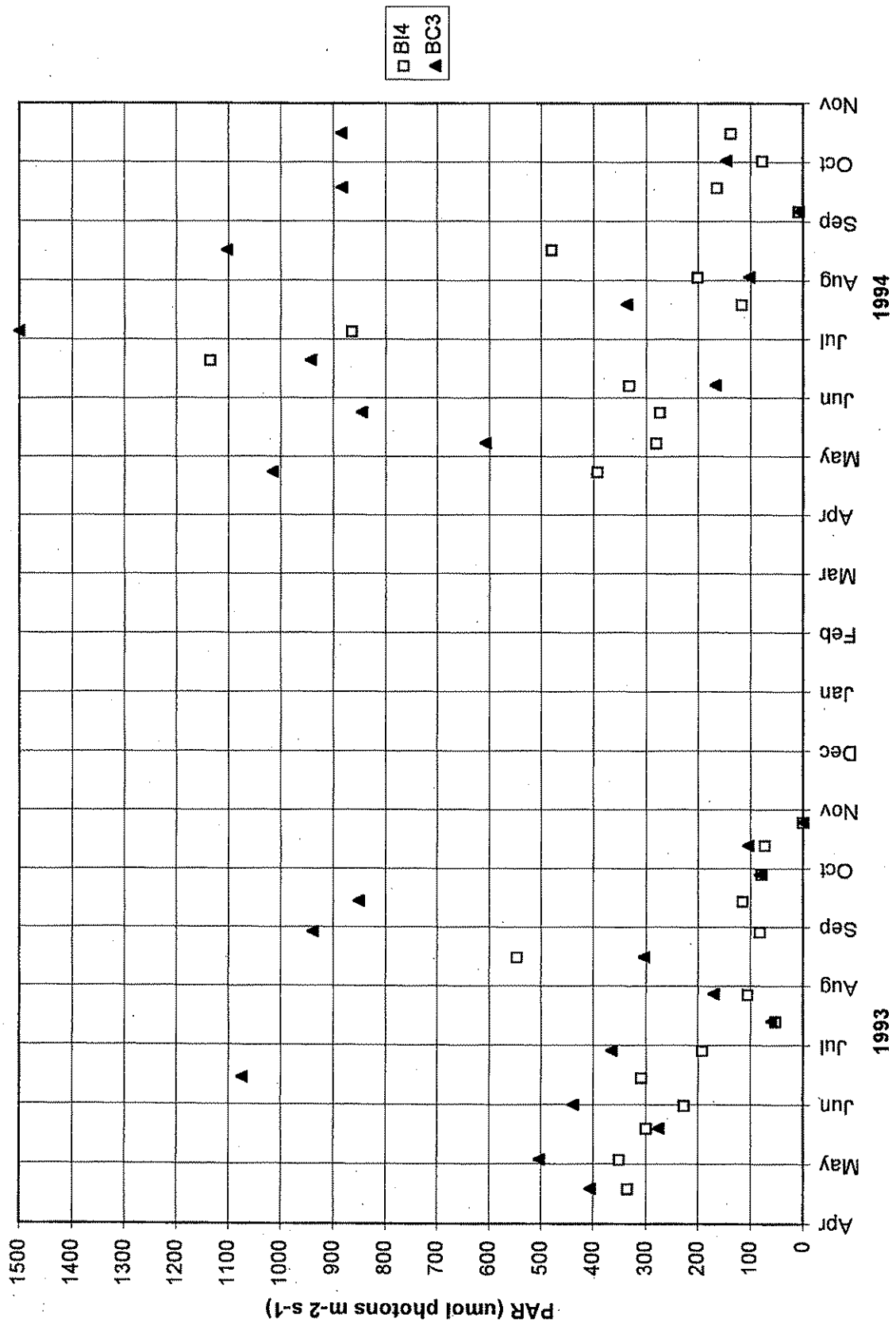


Figure 20. PAR (photosynthetic active radiation) levels at 2-m depths at inner bay station BI4 and central bay station BC3 in 1993 and 1994.

Table 7. Mean values of k (extinction coefficient) for inner and central bay stations for April-June and July-October in 1992, 1993 and 1994. Higher values of k indicate shallower euphotic zones. k = 1.6/Secchi disk depth.

		BI-4	BI-5	BI-6	Mean of BI4, BI5 and BI6	s.d.	BB-2	BC-3	BD-2	Mean of BB2, BC3 and BD2	s.d.
April-June	1992	**0.47**	**0.66**	**0.49**	0.54	0.29	**0.42**	**0.41**	**0.35**	0.39	0.20
	1993	**0.51**	**0.55**	**0.65**	0.57	0.14	**0.42**	**0.38**	**0.34**	0.38	0.09
	1994	**0.62**	**0.88**	**0.78**	0.76	0.26	**0.42**	**0.40**	**0.36**	0.39	0.09
July-October	1992	**0.66**	**0.77**	**0.78**	0.74	0.23	**0.72**	**0.52**	**0.54**	0.59	0.31
	1993	**0.55**	**0.54**	**0.52**	0.54	0.20	**0.95**	**0.78**	**0.62**	0.78	0.25
	1994	**0.55**	**0.74**	**0.65**	0.65	0.26	**0.60**	**0.46**	**0.34**	0.47	0.16

Seasonal Variation

Euphotic zone depths were generally deepest during spring and fall and shallowest in the summer, although considerable variation was seen between stations, survey dates and years (Figure 21).

Spatial Variation

The euphotic zone depths were shallower in the inner bay than in the central and outer bay for the majority of surveys during 1992 and 1994 (75% and 69% respectively) and during half the surveys in 1993 (Figure 21). This indicates that the phytoplankton population was constrained to a shallower portion of the water column in the inner bay than in the central and outer bay. Phytoplankton biomass was not as large in the inner bay as in the central bay (see Phytoplankton section), thus these shallower depths were likely due to the light attenuation by the increased sedimentary load from the Deschutes River/Capitol Lake outlet.

Light Extinction Coefficient

Although variation in the underwater light environment existed between the three years, the influence of phytoplankton biomass in determining the light extinction was about equal. Interannual differences in the light environment were primarily due to changes in stratification and dilution of light attenuating particles.

The extinction coefficient, k, was regressed against mean chlorophyll *a* concentrations at station BI5 and phytoplankton biomass estimates at station BC3 (see Sampling Protocols and Data Analysis in Methods for definitions of terms). These regressions gave a positive slope with $r^2 = 0.26$ and 0.25 for stations BI5 and BC3, respectively (Figure 22), indicating that there was a slight positive correlation for phytoplankton concentration and light extinction. The poor goodness of fit is due to other factors (e.g. sedimentary particles and dispersion of suspended particles from mixing processes) determining light extinction. For July through October at station BI5, at mean chlorophyll *a* concentrations less than 10 µg/L and k values less than 1 (where the majority of the data are concentrated), stronger positive correlations were found ($r^2 = 0.63$, 0.64 and 0.57, for 1992, 1993 and 1994 respectively). These stronger correlations may be a result of removing the high chlorophyll *a* data from the analysis, since at high phytoplankton concentrations self shading and other processes can complicate these comparisons.

For mean chlorophyll *a* concentrations greater than 10 µg/L, the slope of the relation was different. Observed values of k were lower than predicted which indicates phytoplankton blooms attenuated light highly effectively. Also at times, very high light attenuation, (large k), was found when chlorophyll *a* concentrations were low. This suggests that sedimentary particles were responsible for these conditions.

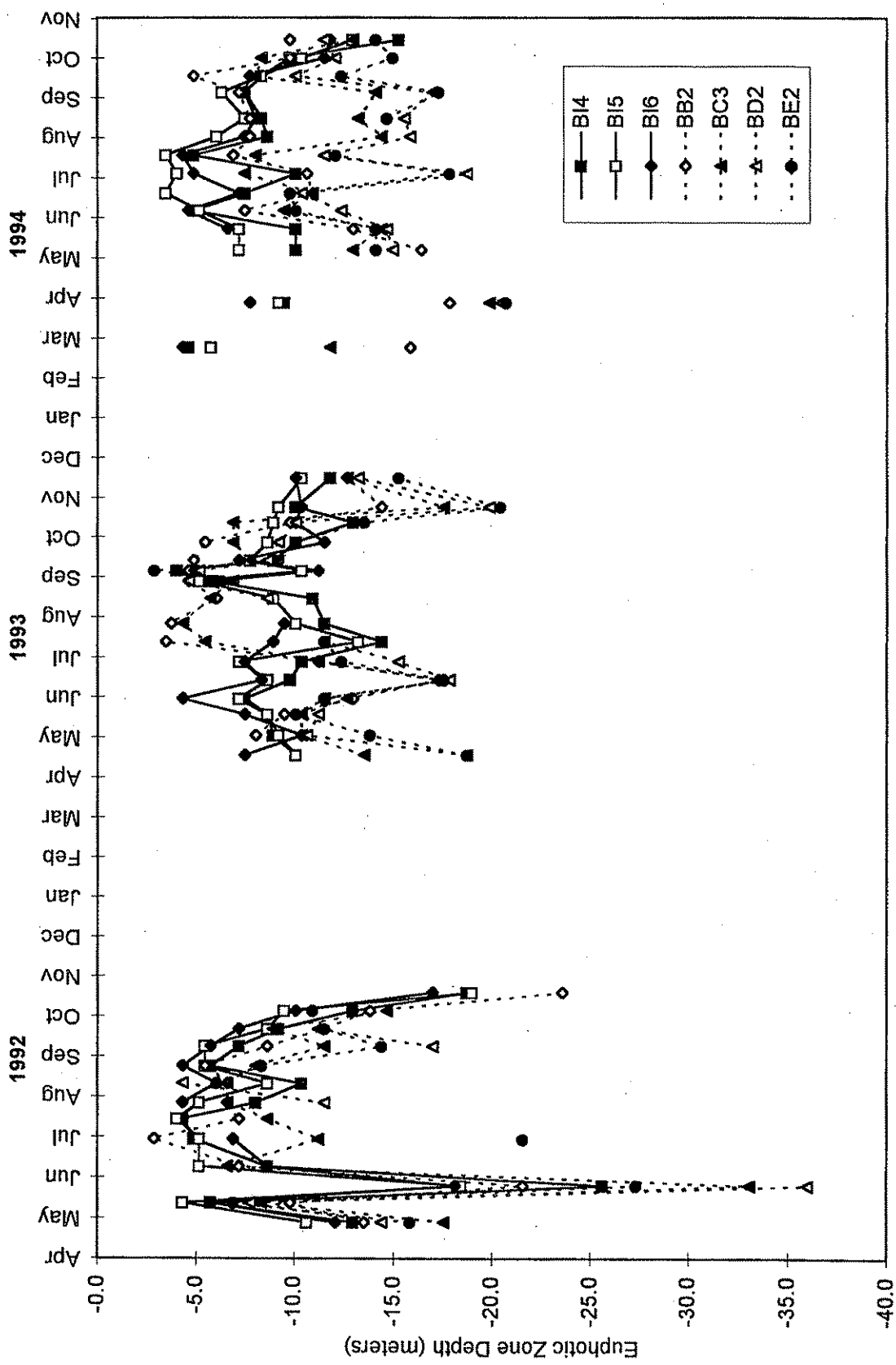
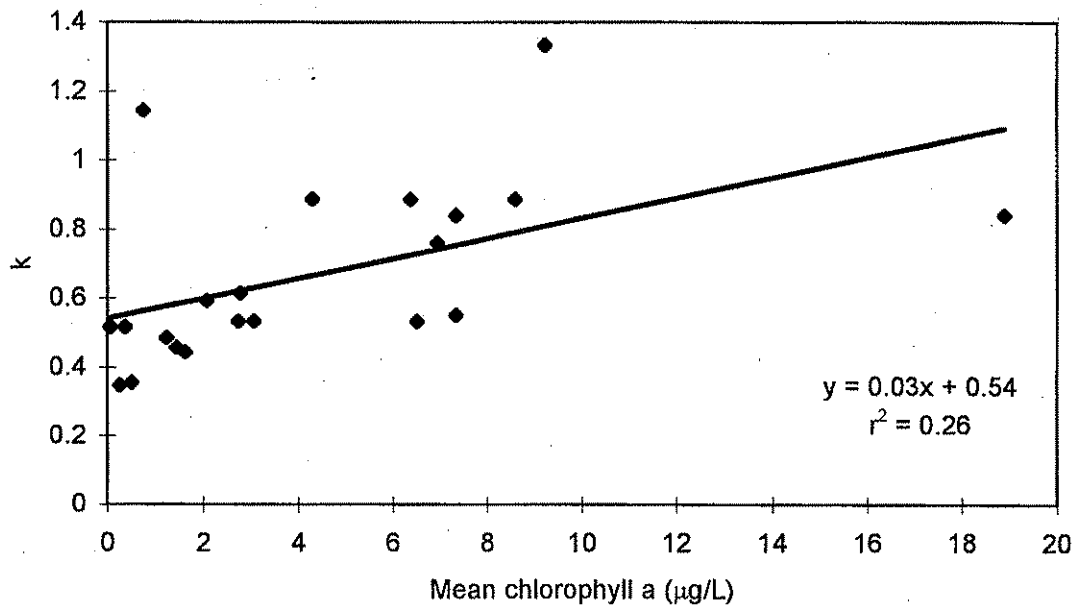


Figure 21. Euphotic zone depths determined from Secchi disk readings for Budd Inlet stations during 1992-1994. Solid lines = inner bay stations. Dashed lines = central and outer bay stations. Average bottom depths were 5 m at BI6, 9 m at BI5 and BI4, 7 m at BB2, 11 m at BC3, 13 m at BD2 and 11 m at BE2.

a) BI5



b) BC3

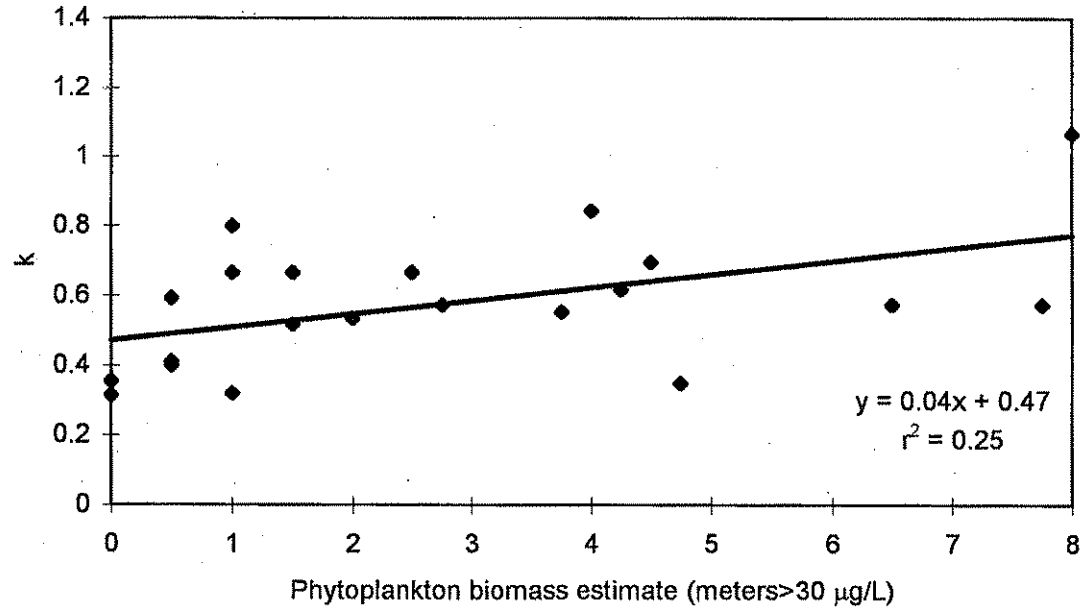


Figure 22. Linear regressions of the light extinction coefficient (K), and a) mean chlorophyll a concentrations (integrated chlorophyll a/bottom depth) for inner bay station BI5 and b) phytoplankton biomass estimate (vertical extent of chlorophyll a concentration > 30 µg/L) for central bay station BC3 during July to October,1992-1994.

The anomalous deep euphotic zone seen on 28 May 1992, corresponded with the lowest chlorophyll *a* concentrations observed in this study (Figures 21 and 28). Two moderate wind events (daily wind speed averages of ~16 km/h (10 mph)) occurred from 18 to 20 May and 25 to 26 May. These winds may have mixed and dispersed the phytoplankton or influenced flushing in the bay.

Nutrients

LOTT reduced nitrogenous nutrients (ammonium plus nitrite and nitrate) in their effluent by 88% for 1994 compared to 1992 and 1993. Subsequently, surface concentrations of nitrate+nitrite-N and ammonium-N (in particular) showed large (64-86% reductions) in both the central and inner bay for 1994 compared to 1992 and 1993. In 1992 and 1993, inner bay N showed large and variable fluctuations; whereas, in 1994 N concentrations followed a seasonal pattern similar to that seen in the central bay and other areas where anthropogenic input is low (Newton et al., 1994). During 1992 and 1993 much higher nutrient concentrations (particularly for ammonium-N) were consistently recorded at West Bay station BI4 (located near the primary LOTT outfall) than at any other station. During 1994, the highest surface nutrient concentrations were usually at station BI4 or BI6 (station closest to the Deschutes River/Capital Lake outlet). However, differences between these stations and other inner bay stations were substantially smaller in 1994 than in 1992 and 1993. These results indicate that the persistence of high surface nutrient concentrations in the inner bay during 1992 and 1993 was likely due to nutrient input from LOTT. In both the inner and central bay, surface nutrients below reporting limits (BRL) were observed for a longer duration in 1994 than in 1992 or 1993. For example, during April through October, surface nitrate+nitrite-N was BRL at inner bay station BI4, ~40% of the time in 1994 and 0% in 1992 and 1993, and at central bay station BB2, ~90% of the time in 1994 and ~60% in 1992 and 1993.

Overall, 1-m nutrient concentrations were higher in the inner bay than in the central bay although the differences were much larger in 1992 and 1993 than in 1994. For all three years, near-bottom nitrate+nitrite-N concentrations were slightly higher in the central bay and near-bottom ammonium-N and orthophosphate-P concentrations were higher in the inner bay. Nitrate+nitrite-N concentrations decreased from early spring to summer during all three years in the central bay and during 1994 in the inner bay. This nutrient decrease likely reflects the seasonal increase of phytoplankton during this time.

LOTT Discharges

The reduction in total inorganic N concentration of the LOTT effluent has been significant since N-removal was implemented in early March 1994. Based on LOTT data, the average concentration in effluent of inorganic nitrogenous nutrients (ammonium plus nitrate plus nitrite) over the growing season (April through October) decreased by 88% in 1994 over the mean for 1992 and 1993 (Figure 23a). Most notable was the 99%

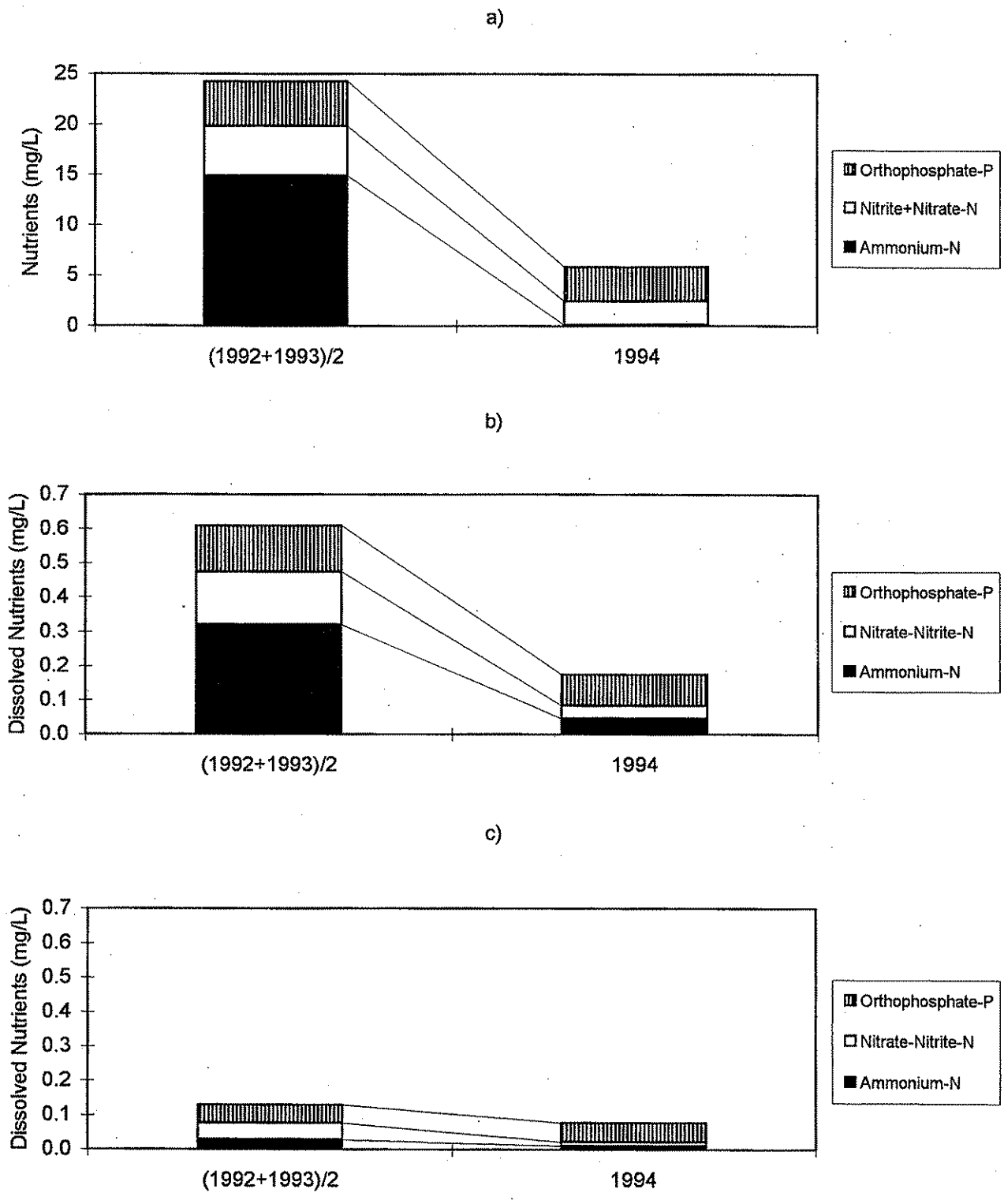


Figure 23. Mean nutrient concentrations from July to October for 1992 and 1993 compared to 1994 for a) LOTT effluent daily averages, and for 1 meter depths in the water column at b) inner bay station BI4 and c) central bay station BB2.

reduction in the ammonium concentration of the effluent. Orthophosphate concentrations were somewhat reduced (23%) in the 1994 LOTT effluent.

A decrease in nutrients is also highly apparent in the 1-m data from inner bay station BI4 located near the LOTT outfall and central bay station BB2 (Figure 23 b, c). The ammonium-N concentration in 1994 showed an 86% reduction at station BI4 and a 64% reduction at station BB2 over the 1992-1993 values, for data averaged from April through October. In addition, the nitrate+nitrite-N concentrations were lower by ~75% at both stations in 1994. This decrease is likely associated with the decrease in LOTT effluent concentration (62% reduction) as well as the probable increased utilization of these nutrients by phytoplankton since ammonium was less available. In 1994, lower water column concentrations of orthophosphate-P were seen at station BI4 but not at station BB2.

Water Column Concentrations

Interannual Variation

In the inner bay, fluctuations in dissolved N during 1992 and 1993 were large and variable; whereas during 1994, fluctuations were smaller and followed a seasonal pattern more characteristic of the central bay. Inner bay 1-m ammonium-N concentrations were much higher than 1-m nitrate+nitrite-N concentrations during 1992 and 1993, but showed comparable values during 1994 (Figure 24 a, b). For all the inner bay stations, 1-m orthophosphate-P concentrations fluctuated at the same time as 1-m ammonium-N during 1992 and 1993, however, the magnitude of the fluctuations were smaller for orthophosphate-P than for ammonium-N (Figure 24 b, c). Orthophosphate-P concentrations continued to show large fluctuations in 1994, whereas ammonium-N concentrations did not.

Seasonal Variation

Generally, higher nutrient concentrations (especially nitrate+nitrite-N) were seen in winter, early spring and fall than in late spring and summer during all three years at central bay stations and during 1994 at inner bay stations. The decrease in nutrients during spring is likely due to uptake by phytoplankton which are increasing at this time. The nutrient increase in fall is due to water column mixing (Eisner et al., 1994). Regeneration processes possibly increased near-bottom N concentrations in late summer and early fall when near-bottom water temperatures were highest.

Spatial Variation

In general, 1-m nitrate+nitrite-N, ammonium-N and orthophosphate-P concentrations were higher in the inner bay than in the central bay (Figure 24). During 1992 and 1993, station BI4 (the station closest to the LOTT outfall) displayed much higher 1-m nutrient levels than all other stations, particularly for ammonium-N. During 1994, station BI4 had

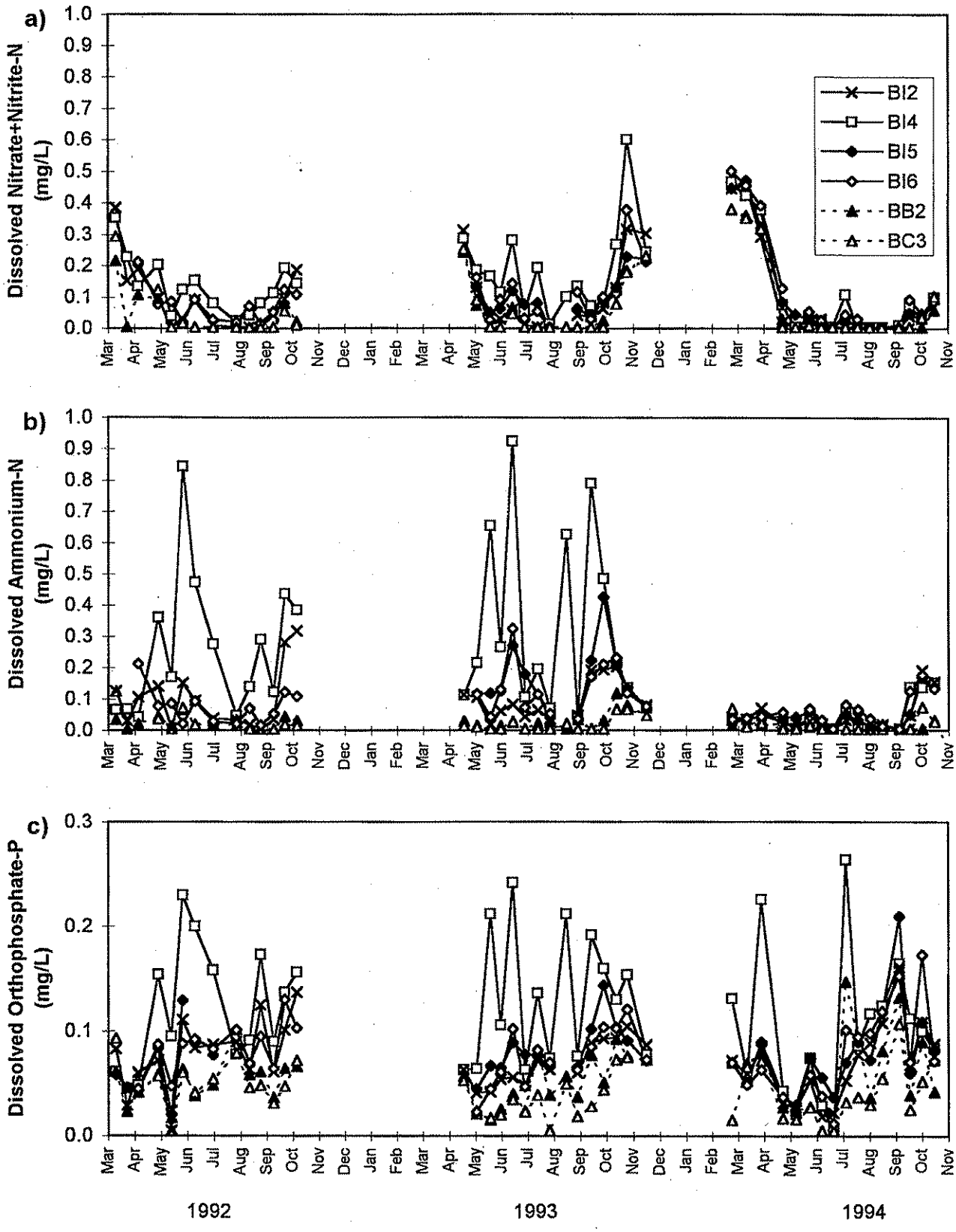


Figure 24. 1-meter dissolved nutrient concentrations of a) nitrate+nitrite-N, b) ammonium-N, and c) orthophosphate-P for stations in the inner bay (solid lines) and central bay (dashed lines). Note a larger range is shown for the nitrogenous nutrients than for orthophopsphate-P.

similar ammonium-N and nitrate+nitrite-N concentrations as other inner bay stations, although orthophosphate-P concentrations were still often highest at station BI4.

For all three years, the near-bottom concentrations of nitrate+nitrite-N tended to be higher in the central and outer bay; whereas, concentrations of ammonium-N and orthophosphate-P tended to be higher in the inner bay (Figure 25). Influx of nitrate-N rich waters from greater Puget Sound accounts for the higher nitrate+nitrite-N signal in the central and outer bay and influence from anthropogenic sources likely accounts for the higher ammonium-N and orthophosphate-P signal in the inner bay. The seasonal fluctuations in the near-bottom concentration of a particular nutrient were consistent at all stations throughout the inlet, although some variation among stations was observed for ammonium-N and orthophosphate-P during 1994 (Figure 25).

Below Reporting Limit (BRL) Concentration Occurrence

Nutrient limitation of phytoplankton growth has been found to vary widely with species, and has not been extensively studied in local waters. Although it is difficult to link the existence of nutrient limitation in the field with a particular nutrient concentration, decreasing concentrations of nutrients with time indicate where loss processes, such as phytoplankton uptake, have exceeded nutrient supply and regeneration. Nutrient concentrations below reporting limits (BRL, 0.01 mg/L = 0.71 µg-atoms/L; Ecology, 1994) may indicate where such a scenario has occurred.

Nitrate+Nitrite-N

At both inner and central bay stations, 1-m BRL concentrations were observed more frequently and for a longer duration during 1994 than during 1992 or 1993 likely due in part to the N-removal by LOTT (Table 8). During all years at the central bay stations, near-bottom nitrate+nitrite-N had a seasonal fluctuation pattern somewhat similar to 1-m nitrate+nitrite-N. However, near-bottom nitrate+nitrite-N concentrations were not below reporting limit for as long a duration as 1-m nitrate+nitrite-N concentrations (Table 8).

At inner bay station BI4, BRL concentrations of nitrate+nitrite-N were observed more often at near-bottom depths than at 1 m during 1992 and 1993, reflecting a surface input of nitrate+nitrite-N at station BI4. This was not the case during 1994 when nutrient inputs were reduced; near-bottom BRL concentrations were always accompanied by 1-m BRL occurrence.

Ammonium-N

Ammonium-N concentrations at 1-m showed an even greater increase in BRL occurrence than did nitrate+nitrite-N concentrations during 1994 compared to 1992 or 1993. As with nitrate+nitrite-N, near-bottom BRL concentrations of ammonium-N did not occur for as

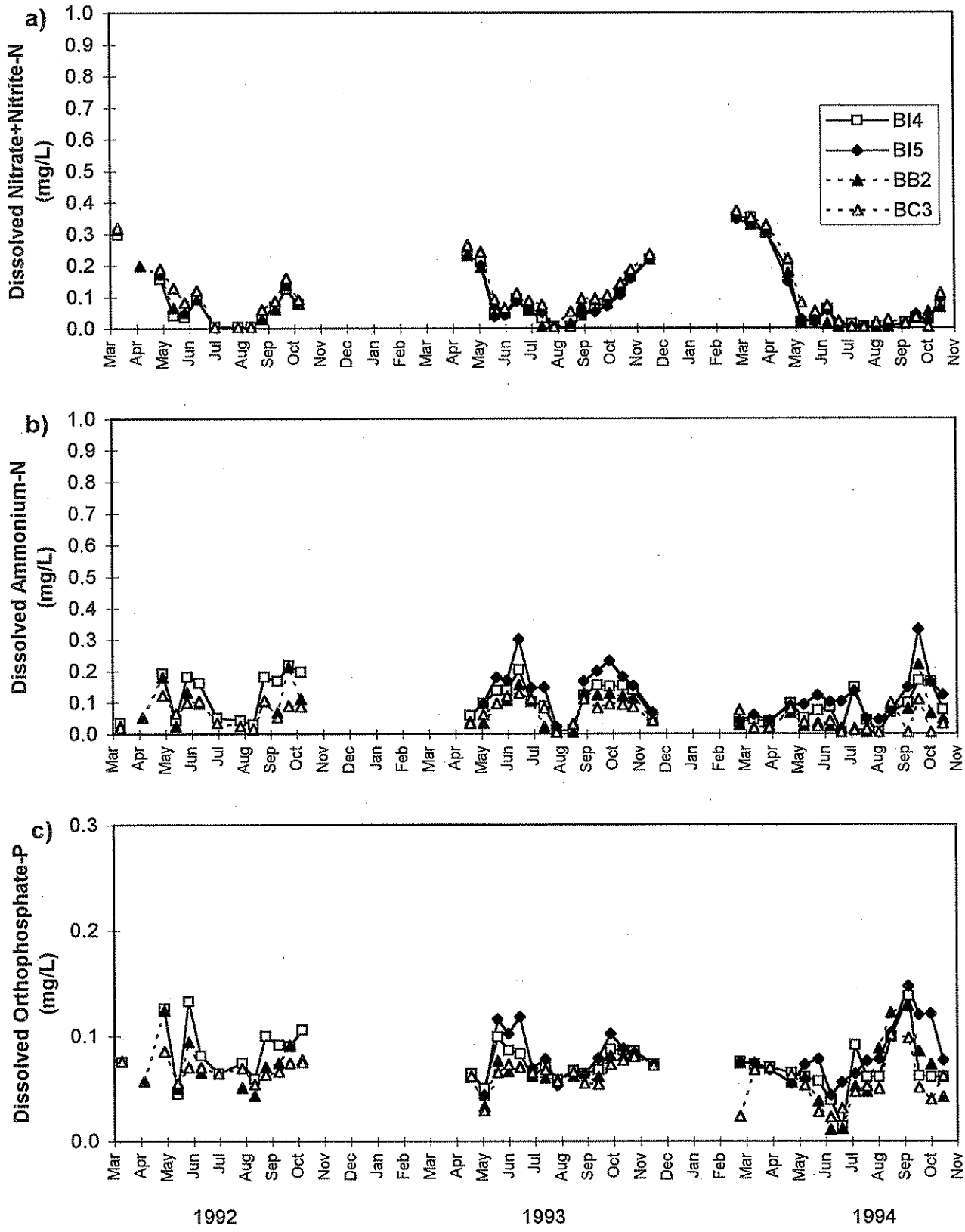


Figure 25. Near-bottom dissolved nutrient concentrations of a) nitrate+nitrite-N, b) ammonium-N, and c) orthophosphate-P for stations in the inner bay (solid lines) and central bay (dashed lines). Note a larger range is shown for the nitrogenous nutrients than for orthophopsphate-P.

Table 8. Below reporting limit (BRL, <0.01 mg/L) dissolved nutrient data for April to October during 1992-1994. s = 1 m (surface). b = 10 m or near-bottom (1 m from bottom). No near-bottom data were collected at stations BI-6 and BI-2 during 1992, 1993 or 1994. No 1-m or near-bottom data were collected at station BI-5 during 1992.

1992													
Station		30Apr	15May	28May	11Jun	2Jul	29Jul	13Aug	26Aug	10Sep	23Sep	7Oct	
BI2	NO2+NO3-N		s				s	s	s				
BI2	NH4-N		s						s				
BI2	oPO4-P		s										
BI6	NO2+NO3-N												
BI6	NH4-N												
BI6	oPO4-P												
BI5	NO2+NO3-N												
BI5	NH4-N												
BI5	oPO4-P												
BI4	NO2+NO3-N					b	b	b					
BI4	NH4-N												
BI4	oPO4-P												
BB2	NO2+NO3-N		s		s	s	s, b	s, b	s	s			
BB2	NH4-N							s	s	s			
BB2	oPO4-P												
BC3	NO2+NO3-N		s		s	s, b	s, b	s, b	s	s			
BC3	NH4-N		s					s	s	s			
BC3	oPO4-P		s										
1993													
Station		20Apr	5May	21May	2Jun	16Jun	30Jun	15Jul	29Jul	17Aug	30Aug	15Sep	29Sep	14-Oct
BI2	NO2+NO3-N							s	s					
BI2	NH4-N													
BI2	oPO4-P													
BI6	NO2+NO3-N								s					
BI6	NH4-N													
BI6	oPO4-P													
BI5	NO2+NO3-N								s, b					
BI5	NH4-N													
BI5	oPO4-P													
BI4	NO2+NO3-N								b	b				
BI4	NH4-N													
BI4	oPO4-P													
BB2	NO2+NO3-N			s	s		s	s, b	s, b	s	s	s		
BB2	NH4-N			s			s			s, b		s		
BB2	oPO4-P													
BC3	NO2+NO3-N			s	s		s	s	s, b	s	s	s	s	
BC3	NH4-N			s	s		s	s	s, b		s	s	s	
BC3	oPO4-P								s					
1994														
Station		25Apr	10May	26May	9Jun	22Jun	7Jul	21Jul	4Aug	18Aug		7Sep	19Sep	3Oct
BI2	NO2+NO3-N		s	s		s	s	s	s	s		s		
BI2	NH4-N					s			s			s		
BI2	oPO4-P													
BI6	NO2+NO3-N					s			s	s		s		
BI6	NH4-N					s						s		
BI6	oPO4-P													
BI5	NO2+NO3-N				s	s	b	s, b	s, b	s, b		s		
BI5	NH4-N					s						s		
BI5	oPO4-P													
BI4	NO2+NO3-N		s			s, b		s, b	s, b	s, b				
BI4	NH4-N		s			s, b		s	s, b			s		
BI4	oPO4-P					s								
BB2	NO2+NO3-N		s	s	s	s, b	s, b	s, b	s, b	s, b		s	s	s
BB2	NH4-N				s	s	s	s, b	s, b			s	s	s
BB2	oPO4-P				s	s								
BC3	NO2+NO3-N	s	s		s	s	s, b	s, b	s	s		s	s	b
BC3	NH4-N	s	s		s	s, b	s	s	s, b	s		s, b	s	b
BC3	oPO4-P				s	s								

Table 8. (cont)

1992		% of times BRL data observed	
Station		1-m	near-bottom
BI2	NO2+NO3-N	36%	
BI2	NH4-N	18%	
BI2	oPO4-P	9%	
BI6	NO2+NO3-N	0%	
BI6	NH4-N	0%	
BI6	oPO4-P	0%	
BI5	NO2+NO3-N		
BI5	NH4-N		
BI5	oPO4-P		
BI4	NO2+NO3-N	0%	27%
BI4	NH4-N	0%	0%
BI4	oPO4-P	0%	0%
BB2	NO2+NO3-N	64%	20%
BB2	NH4-N	27%	0%
BB2	oPO4-P	0%	0%
BC3	NO2+NO3-N	64%	27%
BC3	NH4-N	36%	0%
BC3	oPO4-P	9%	0%
1993		% of times BRL data observed	
Station		1-m	near-bottom
BI2	NO2+NO3-N	17%	
BI2	NH4-N	0%	
BI2	oPO4-P	0%	
BI6	NO2+NO3-N	9%	
BI6	NH4-N	0%	
BI6	oPO4-P	0%	
BI5	NO2+NO3-N	9%	9%
BI5	NH4-N	0%	0%
BI5	oPO4-P	0%	0%
BI4	NO2+NO3-N	0%	15%
BI4	NH4-N	0%	0%
BI4	oPO4-P	0%	0%
BB2	NO2+NO3-N	62%	15%
BB2	NH4-N	31%	8%
BB2	oPO4-P	0%	0%
BC3	NO2+NO3-N	69%	8%
BC3	NH4-N	62%	8%
BC3	oPO4-P	8%	0%
1994		% of times BRL data observed	
Station		1-m	near-bottom
BI2	NO2+NO3-N	67%	
BI2	NH4-N	17%	
BI2	oPO4-P	0%	
BI6	NO2+NO3-N	36%	
BI6	NH4-N	18%	
BI6	oPO4-P	0%	
BI5	NO2+NO3-N	50%	33%
BI5	NH4-N	17%	0%
BI5	oPO4-P	0%	0%
BI4	NO2+NO3-N	42%	33%
BI4	NH4-N	42%	17%
BI4	oPO4-P	8%	0%
BB2	NO2+NO3-N	92%	42%
BB2	NH4-N	67%	17%
BB2	oPO4-P	17%	0%
BC3	NO2+NO3-N	83%	25%
BC3	NH4-N	83%	33%
BC3	oPO4-P	17%	0%

long a duration as 1-m BRL concentrations. Near-bottom BRL concentrations were also observed much more frequently in 1994 than in 1992 and 1993 (Table 8).

Orthophosphate-P

Orthophosphate-P 1-m BRL concentrations were seldom observed and only occurred when nitrate+nitrite-N and ammonium-N BRL concentrations were also recorded (Table 8). Near-bottom BRL concentrations were not observed at any station during 1992 to 1994.

Limiting Nutrient

The relative availability of N and P in marine systems coupled with phytoplankton growth requirements results in N most often being the limiting nutrient in marine systems. In Budd Inlet, nitrate+nitrite-N and ammonium-N were depleted much more frequently than orthophosphate-P. Results from a primary production experiment conducted during September 1994 also indicated that N was the limiting nutrient (see Phytoplankton Section).

Phytoplankton

Phytoplankton chlorophyll *a* concentrations in the inner bay during July through October were lower in 1993 than in 1992 and 1994 likely due to the lower insolation, cooler water temperatures and weaker stratification seen in 1993. In the central bay, phytoplankton concentrations were similar for all three years. Bloom concentrations (defined for this report as chlorophyll *a* > 10 µg/L (mg/m^3)) occurred throughout the bay from March, April or May through October; however, the largest phytoplankton blooms (chlorophyll *a* > 30 µg/L) were generally seen in the central bay from July to September. Phytoplankton concentrations were consistently highest in the central bay, although higher nutrient levels were found in the inner bay particularly in 1992 and 1993. Other conditions such as lower surface salinity and lower light levels possibly inhibited phytoplankton growth in the inner bay, or processes such as advection reduced their population there.

Primary production measured with and without nutrient addition during September 1994 showed that N was limiting to phytoplankton growth in the central bay. The nutrient concentrations in the central bay were BRL at the time. Phytoplankton biomass in the central bay was quite high at the time of the experiment. Primary production was stimulated by nutrient addition by ~70% over ambient samples.

Interannual variation in phytoplankton species composition was seen, some of which may be due to differences in nutrients, salinity, temperature and/or insolation, although differences are difficult to quantify based on the limited data collected. Potentially harmful phytoplankton species (*Pseudonitzschia* spp., *Heterosigma carterae* and *Alexandrium catenella*) were present at central and/or inner bay stations at various times during the

study period in concentrations ranging from 10^3 to 10^6 cells/L. These species have been associated with harm to humans, fish and invertebrates; however, the necessary concentration for effects to be evident and the conditions that promote toxicity (for *Pseudonitzschia* spp) are not presently known. *H. carterae* concentrations were lower in 1994 than in 1992 and 1993.

Chlorophyll *a* (phytoplankton biomass)

Interannual Variation

In the inner bay, mean chlorophyll *a* concentrations were lower in 1993 than during 1994 or 1992 based on Mann-Whitney non-parametric test results (Table 9). The only exception was station BI6 which did not have lower concentrations in 1993 than in 1994. Phytoplankton biomass estimates were similar for 1992 and 1994 in the inner bay (Figure 26). Whereas, in the central bay, phytoplankton biomass estimates were similar for all three years (Figure 27 and Table 9). The only exception was station BA2 which had higher concentrations in 1994 than 1993. Mean maximum chlorophyll *a* concentrations were 2 times higher in 1992 and 1994 than in 1993 at inner bay stations, but had similar values for all three years at central bay stations during July through October (Figure 28 and Table 13)

Seasonal Variation

A phytoplankton "bloom" signifies an accumulation of phytoplankton cells that has occurred because growth rate exceeded loss rates. Chlorophyll *a* concentrations greater than 10 µg/L are defined as blooms in this report. *In situ* fluorometer chlorophyll *a* values of 10 µg/L or greater were observed consistently from July 1992 (the first month the *in-situ* fluorometer was used) to October 1992, from May through October 1993 and from April through October 1994. Prior to use of the *in situ* fluorometer during 1992, lab chlorophyll *a* values greater than 10 µg/L were seen beginning in March. Thus, for all three years bloom concentrations were observed from March, April or May through October. A seasonal decrease in phytoplankton concentration was observed during May or June during all three years likely due to mixing, increases in grazing, and/or decreases in phytoplankton growth due to nutrient limitation. Phytoplankton concentrations were highest during July through October with *in situ* chlorophyll *a* values of 30 µg/L or greater observed during all three years (Figure 28).

Spatial Variation

The maximum chlorophyll *a* concentrations were observed in the central bay generally at stations BB2 and BC3. Phytoplankton blooms were somewhat smaller in size and generally had lower maximum chlorophyll *a* concentrations at inner bay stations than at central bay stations (Figure 28).

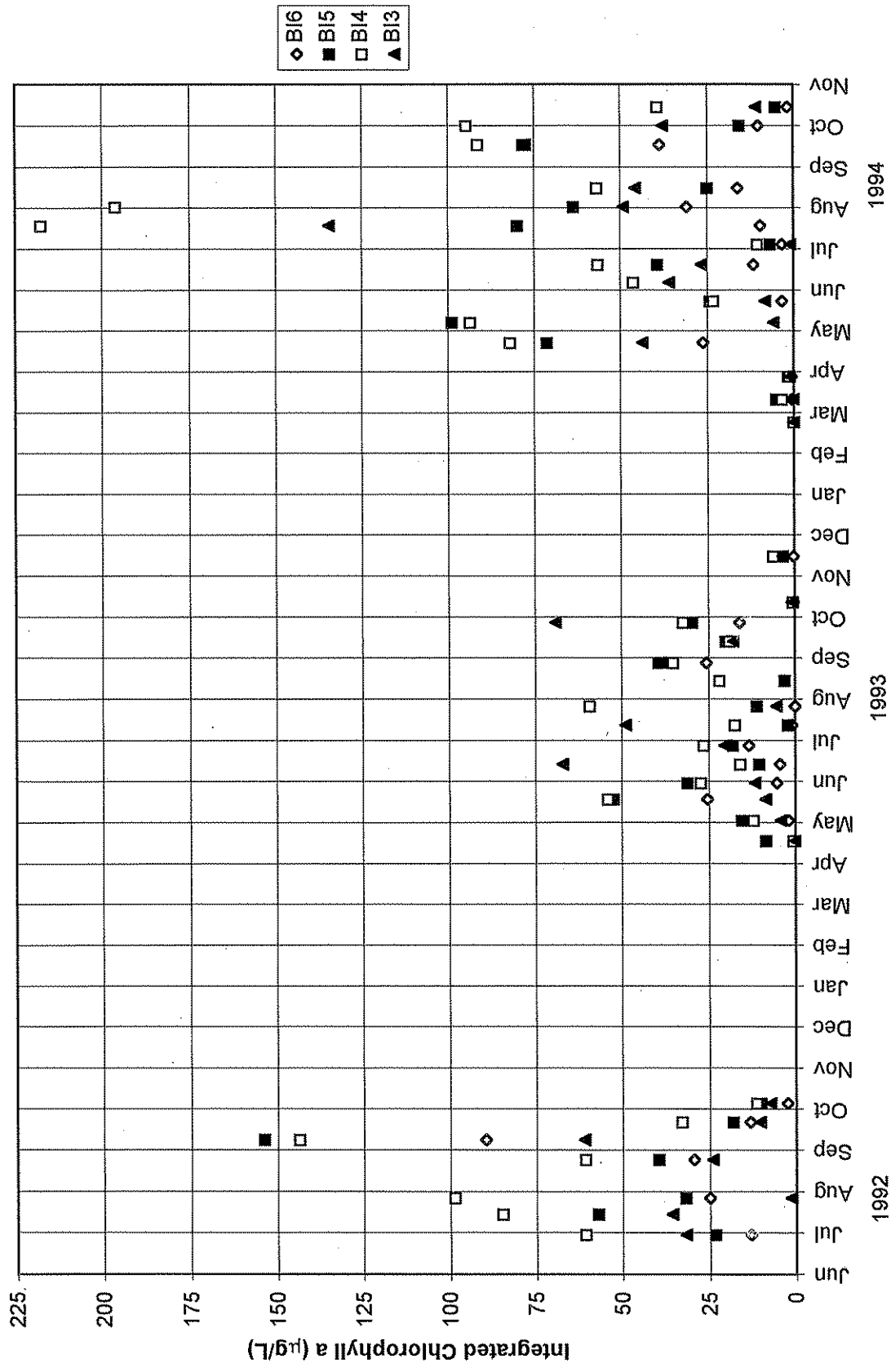


Figure 26. Chlorophyll a concentrations integrated over the water column for inner bay stations for July to October 1992, April to November 1993 and February to October 1994. Data from September 1992 are minimum values since chlorophyll a concentrations were higher than the instrument maximum of 30 µg/L (mg/m^3).

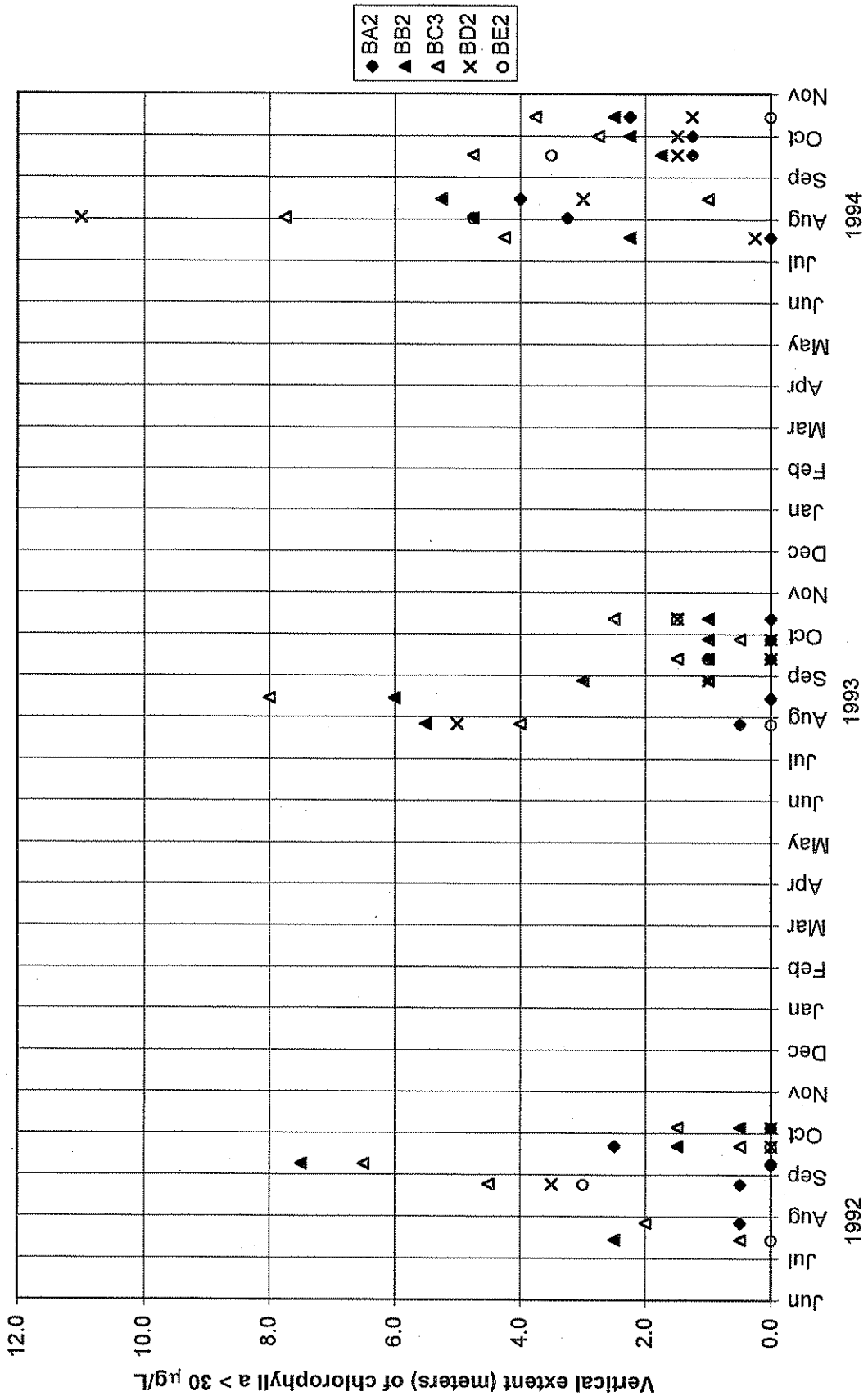


Figure 27. Vertical extent (size in meters) of chlorophyll a concentrations greater than 30 µg/L for central and outer bay stations during July to October 1992, 1993 and 1994.

Table 9. Statistical comparison of phytoplankton biomass estimates for 1992, 1993 and 1994 using the Mann-Whitney non-parameteric test. For inner bay stations, phytoplankton biomass was estimated by chlorophyll a concentrations integrated over the water column. For central bay stations, phytoplankton biomass was estimated by the vertical extent (m) of water column with chlorophyll a > 30 µg/L. The number of tails for each test are in parentheses after the alpha value. Tests showing significance are outlined.

Inner bay stations:		BI-6	BI-5	BI-4	BI-3
93 vs 94	Apr-Oct	no sig diff alpha = 0.10 (2)	u93<u94 alpha = 0.025 (1)	u93<u94 alpha = 0.0025 (1)	no sig diff alpha = 0.10 (2)
	Jul-Oct	u93<u94 alpha = 0.10 (1)	u93<u94 alpha = 0.10 (1)	u93<u94 alpha = 0.025 (1)	no sig diff alpha = 0.10 (2)
92 vs 94	Jul-Oct	no sig diff alpha = 0.10 (2)	no sig diff alpha = 0.10 (2)	no sig diff alpha = 0.10 (2)	no sig diff alpha = 0.10 (2)
92 vs 93	Jul-Oct	u92>u93 alpha = 0.05 (1)	u92>u93 alpha = 0.01 (1)	u92>u93 alpha = 0.025 (1)	no sig diff alpha = 0.10 (2)

Central bay stations:		BA-2	BB-2	BC-3	BD-2
93 vs 94	Jul-Oct	u93<u94 alpha = 0.05 (1)	no sig diff alpha = 0.10 (2)	no sig diff alpha = 0.10 (2)	no sig diff alpha = 0.10 (2)
92 vs 94	Jul-Oct	u92<u94 alpha = 0.10 (1)	no sig diff alpha = 0.10 (2)	no sig diff alpha = 0.10 (2)	no sig diff alpha = 0.10 (2)
92 vs 93	Jul-Oct	no sig diff alpha = 0.10 (2)	no sig diff alpha = 0.10 (2)	no sig diff alpha = 0.10 (2)	no sig diff alpha = 0.10 (2)

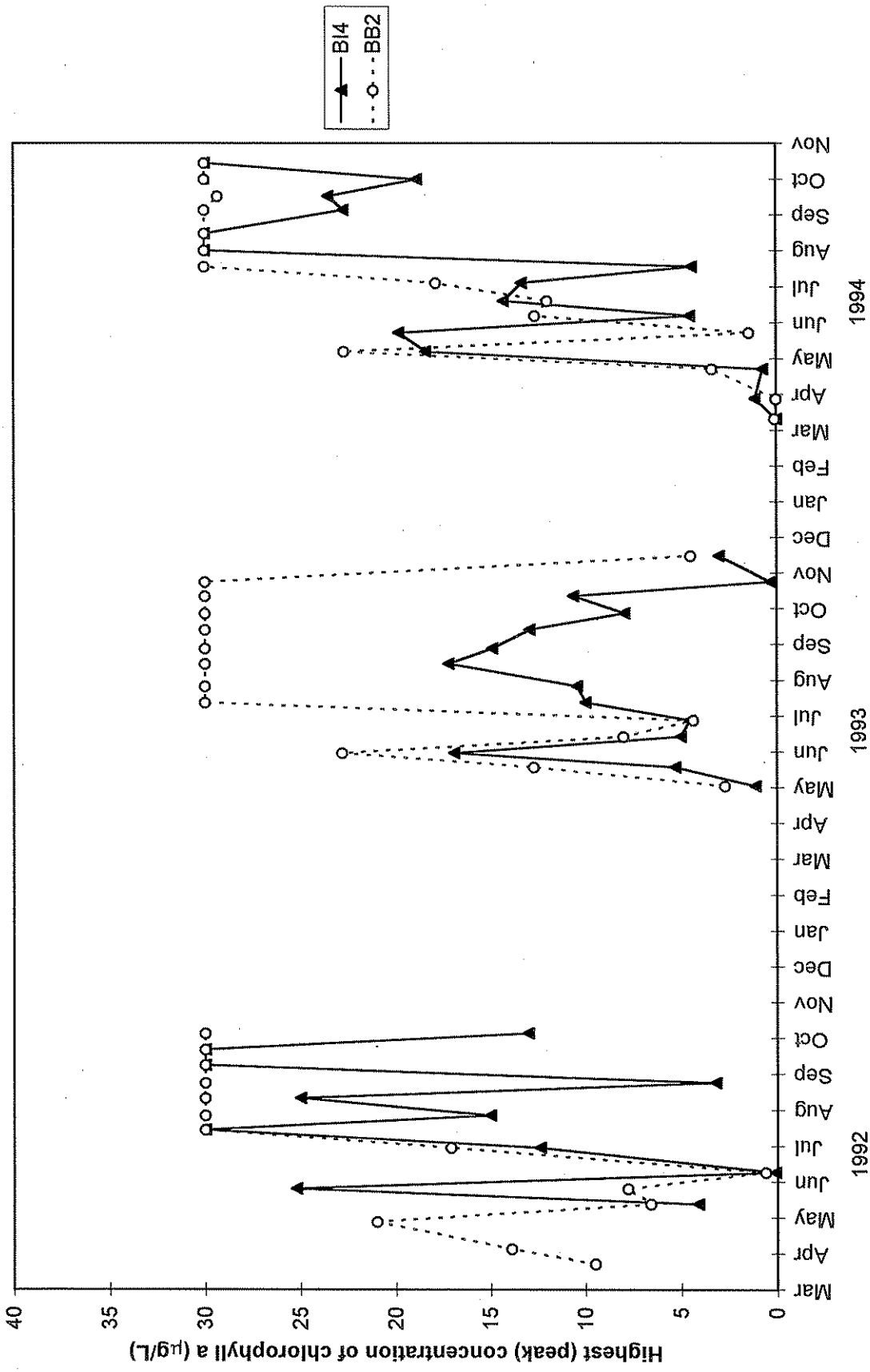


Figure 28. Highest concentration of chlorophyll a seen in the water column at inner bay station BI4 and central bay station BB2. Data are from the in-situ fluorometer on the CTD except for March to June 1992 and 13 August 1992 which are lab data. The maximum range of the CTD fluorometer was 30 µg/L during 1992 and 1993, so this is the maximum shown for all 3 years.

Phytoplankton distributions were influenced by tidal action. The large phytoplankton concentrations seen in the central bay during low tides appears to have been advected further toward the head of the bay during flood tides (Figure 29). The highest chlorophyll *a* concentrations during flood and high tide were frequently in the central bay close to the east side between stations BA2 and BC3 based on analysis of 1992 flood and high tide data (Eisner et al., 1994).

The depth of the maximum chlorophyll *a* concentration for the spring bloom in the inner bay was deeper during 1994 than during 1993 (Figure 30). The deeper spring phytoplankton blooms during 1994 may be due to the higher concentration of nitrate+nitrite-N and ammonium-N (particularly) at depth than in surface waters during spring 1994 (Nut Section Figures 24 a, b and 25 a, b). In contrast, the surface concentrations of inner bay nitrate+nitrite-N and ammonium-N were much higher in 1993 (and 1992) prior N-removal by LOTT.

Degree of Correlation with Insolation Data

Percent sky cover was greatest and inner bay phytoplankton biomass was lowest during 1993. The lower number of extended periods of sunshine (50% sky cover or less for three days in a row or more) in 1993 likely caused some light limitation of phytoplankton growth since a phytoplankton population needs consistently favorable conditions to achieve exponential growth. URS (1986) found that a spring diatom bloom seen during May 1985 in Budd Inlet was initiated by a few consecutive days of clear weather. Also, sustained periods of sunshine during 1993 occurred late in the growing season (first occurrence was early August) so the average day length during these periods was short.

The months with the lowest percent sky cover in 1992 (August) and 1994 (July and August) were also the months with the highest phytoplankton biomass estimates in both the inner and central bay (Figures 4, 26, 27). Monthly means for integrated chlorophyll *a* concentrations and percent sky cover showed a slight negative correlation at inner bay station BI4 ($r^2 = 0.27$) indicating that higher phytoplankton biomass at that station was somewhat associated with clear skies. Regression of phytoplankton biomass with incident solar radiation may yield a stronger correlation, but these data were unavailable.

Degree of Correlation with Water Temperature

As discussed in the hydrography results section, yearly average water temperatures were lower in 1993 than in 1994 and 1992. These lower water temperatures could have reduced phytoplankton growth rates in 1993 compared to 1992 and 1994. A linear regression for mean chlorophyll *a* concentration vs. water temperature at inner bay stations BI6, BI5 and BI4 for 1992-1994 showed slight positive correlations ($r^2 = 0.30$ for 1-m and $r^2 = 0.27$ for near-bottom temperature data) for July through October, the months with largest phytoplankton concentrations (Figure 31). Some of this correlation may also be associated with insolation (see above) and stratification (see below).

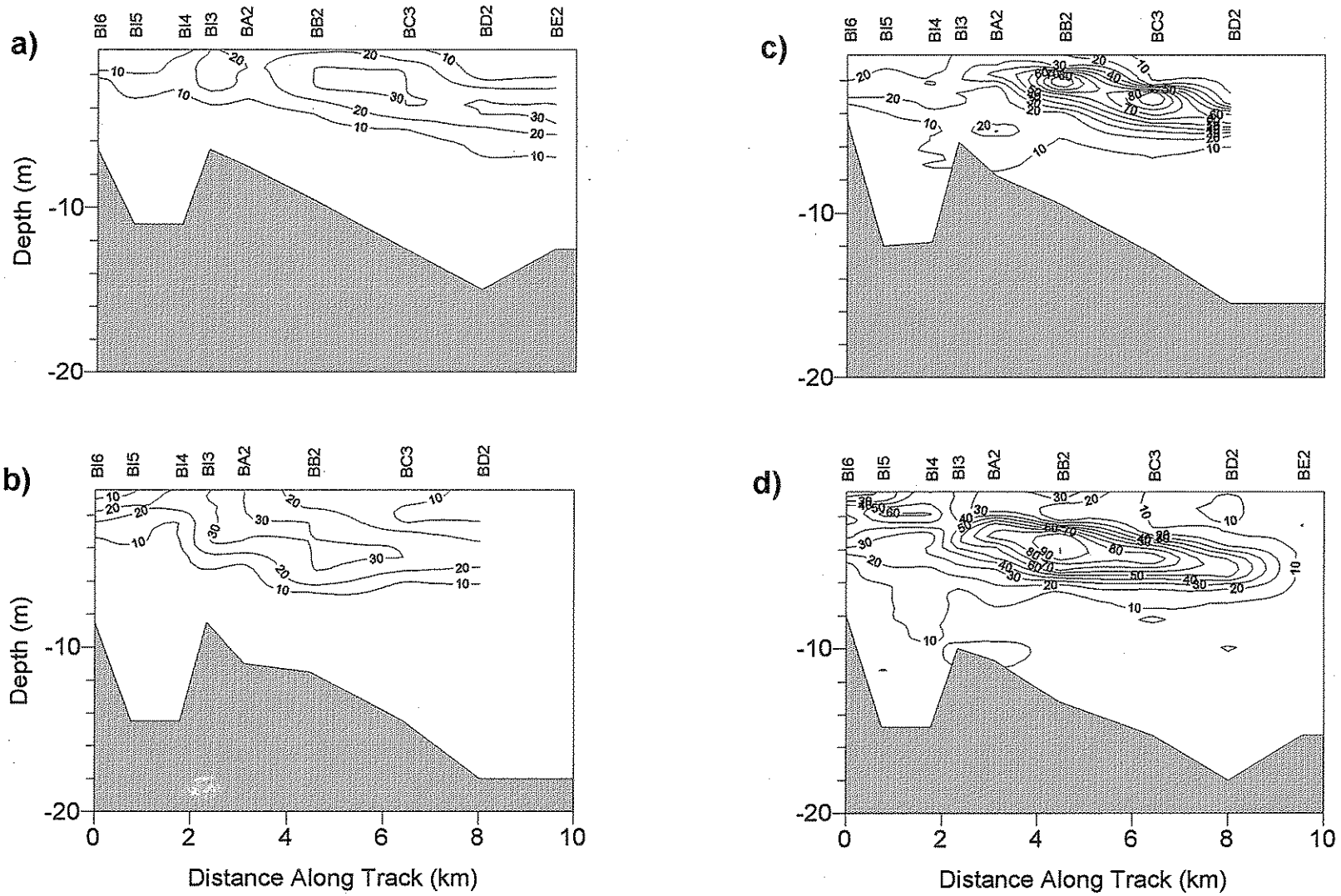


Figure 29. Phytoplankton distributions indicated by chlorophyll a (µg/L) contour plots for 29 September 1993 at a) low and b) high tides and on 19 September 1994 at c) low and d) high tides. Plots show data from transects from the head (station BI6) to the mouth (station BE2) of Budd Inlet. The fluorometer maximum was set to 30 µg/L in 1993 and 100 µg/L in 1994.

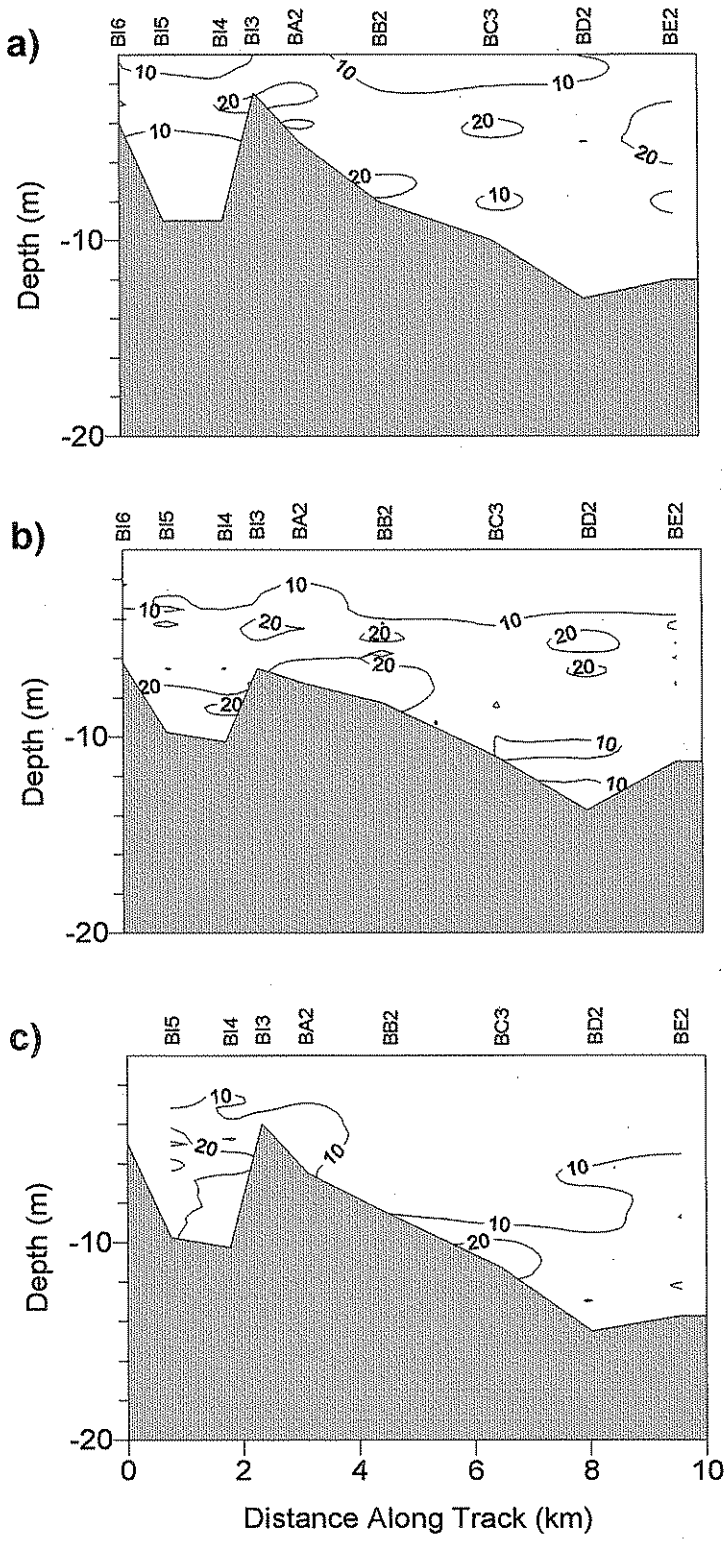


Figure 30. Phytoplankton distribution indicated by chlorophyll a (µg/L) contour plots for low tide transects from the head to the mouth of Budd Inlet during a) 21 May 1993, b) 25 April 1994, and c) 10 May 1994. Shading indicates the sea bottom.

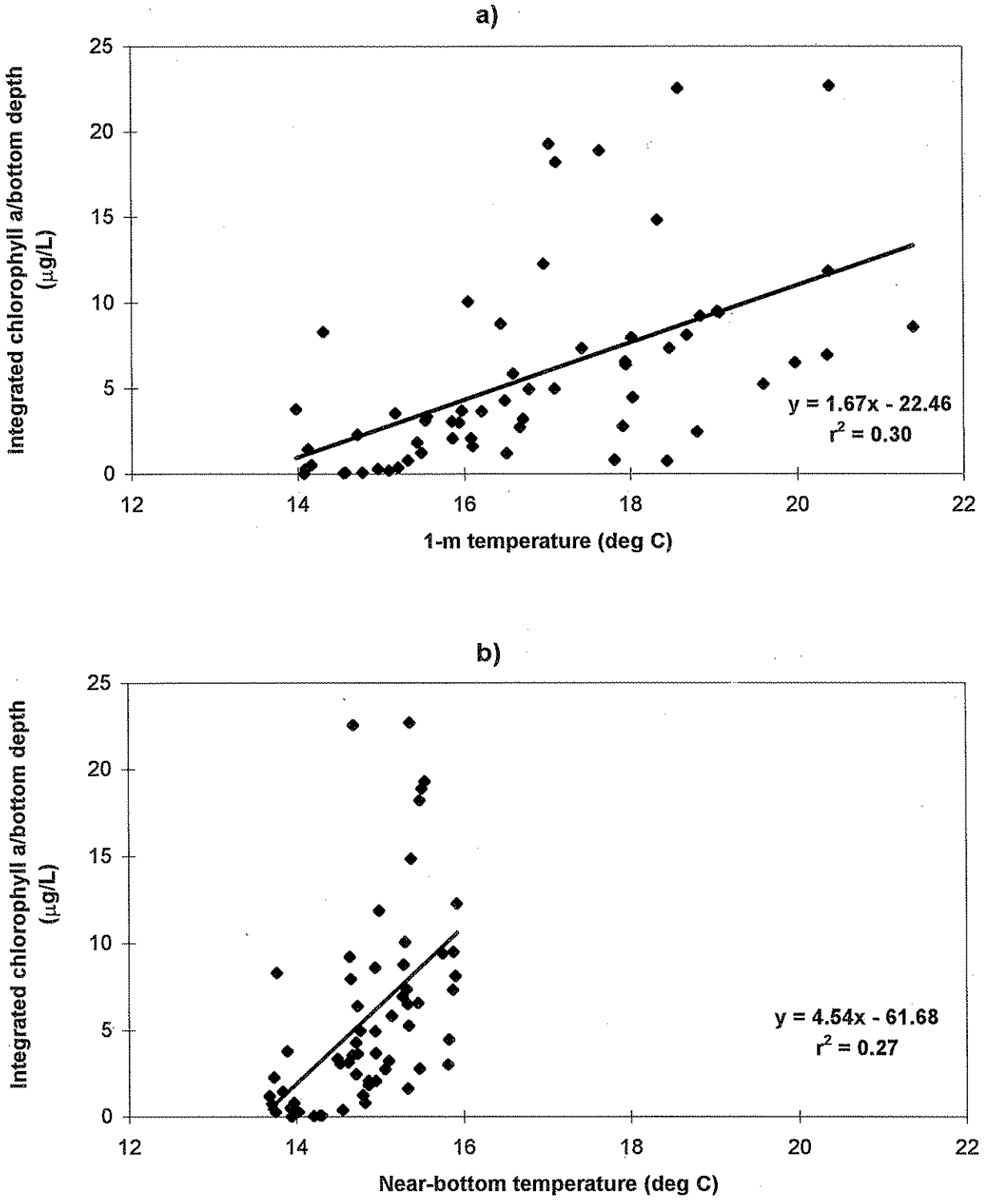


Figure 31. Linear regressions between mean chlorophyll a concentrations (integrated chl a/bottom depth) and a) 1-m and b) near bottom temperatures. Data from inner bay stations BI6, BI5, and BI4 combined forJuly-October 1992, 1993, and 1994.

Degree of Correlation with Stratification

Hydrography data from the inner bay show the water column was more stratified during the summers of 1992 and 1994 than during the summer of 1993. The lower relative stratification in 1993 may have reduced phytoplankton population size due to losses from mixing compared to 1992 and 1994. A linear regression for July through October during 1992-1994 for mean chlorophyll *a* concentrations vs. relative stratification showed a slight positive correlation ($r^2 = 0.46$ for data below a relative stratification of 4 sigma-t and $r^2 = 0.09$ for all data, Figure 32). Above a relative stratification of 4 sigma-t, mean chlorophyll *a* concentrations were low likely due to nutrient limitation. The increased stratification due to the large freshwater inputs during the drainage of Capital Lake may influence phytoplankton biomass during late July.

Degree of Correlation with Nutrients

As discussed in the nutrient section, nitrate+nitrite-N and particularly ammonium-N concentrations were lower in 1994 than in 1992 and 1993. This difference was associated with the reduction in input by LOTT. The reduced nutrient concentrations during 1994 did not result in lower chlorophyll *a* concentrations for 1994 compared to 1992 and 1993. However, it is likely that chlorophyll *a* concentrations may have been even higher in 1994 if nutrient reductions were not implemented based on the results of the nutrient addition primary production experiment conducted during September of 1994. The high chlorophyll *a* concentrations in 1994 may be the result of weather-related factors (e.g. insolation, temperature and stratification), which appear to markedly influence chlorophyll *a* concentrations in Budd Inlet. Another confounding factor in assessing the strength of this correlation was that bacterial uptake and release of nutrients was not measured.

Primary Production

Spatial Variation in Productivity Rate

During the 24-h simulated *in situ* primary production experiment conducted on 19-20 September 1994, the chlorophyll *a* concentrations were much higher at the central bay station BB2 than at the inner bay station BI5 (Figure 33a). Chlorophyll *a* integrated over the euphotic zone (1% surface light level) was 95 mg chl m^{-2} at BB2 and only 56 mg chl m^{-2} at BI5. Although phytoplankton biomass was highest at BB2, the ambient primary production rates were lowest at this central bay station (Figure 33b). Euphotic zone integrated production at BB2 was 2425 mg C m^{-2} d^{-1} for the ambient treatment, whereas at station BI5, rates were 4103 mg C m^{-2} d^{-1} and 3521 mg C m^{-2} d^{-1} for the ambient and nutrient-addition treatments, respectively.

Effect of Nutrient Addition on Productivity Rate

While ambient production was relatively low at BB2, addition of nutrients stimulated primary production substantially, increasing production 70% over the ambient treatment to

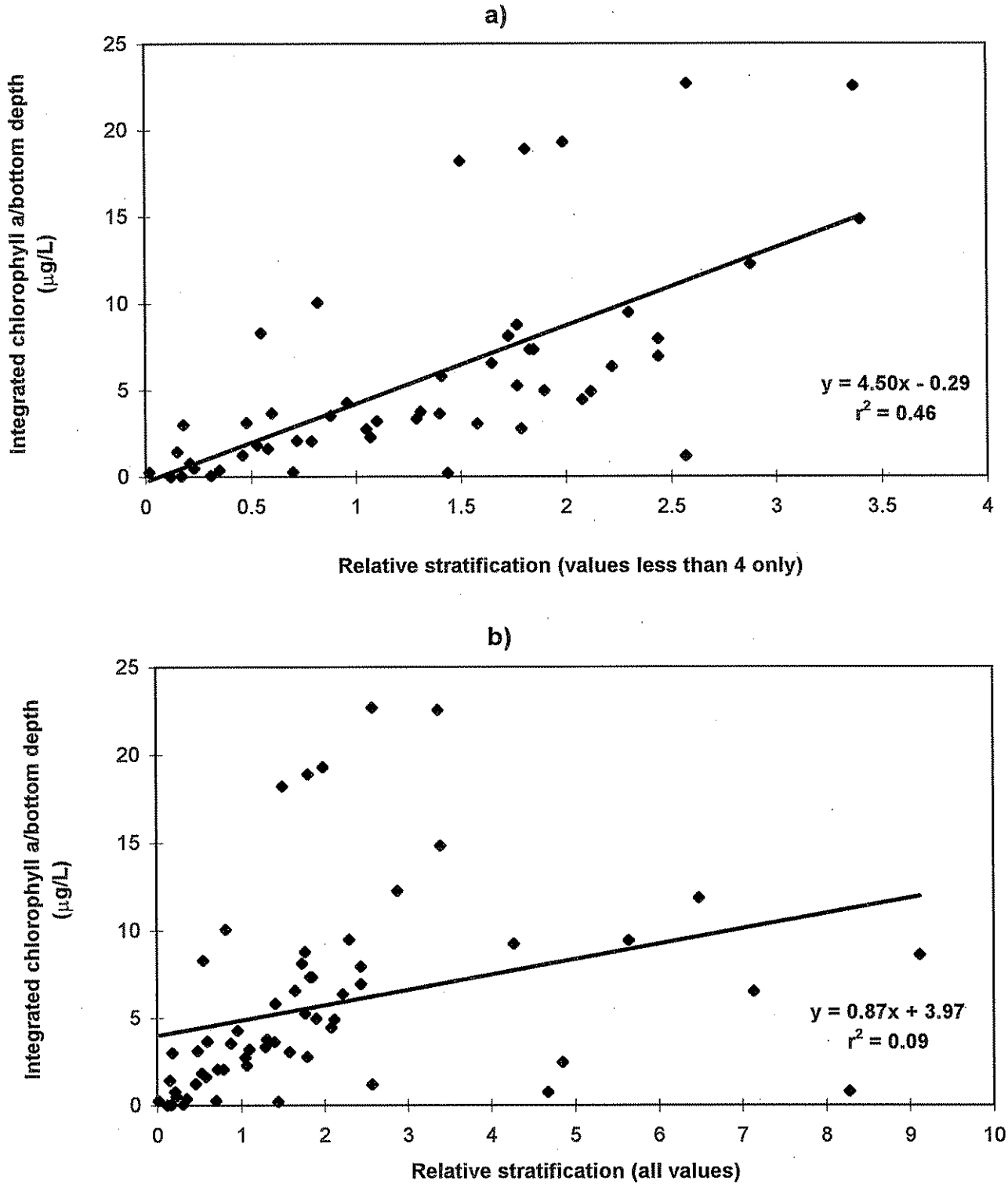


Figure 32. Linear regressions between mean chlorophyll a (indicated by integrated chlorophyll a/bottom depth) and relative stratification (difference between near-bottom and 1-m density (sigma-t)) for a) values less than 4 and b) all values. Data from inner bay stations BI6, BI5 and BI4 combined for 1992, 1993, and 1994.

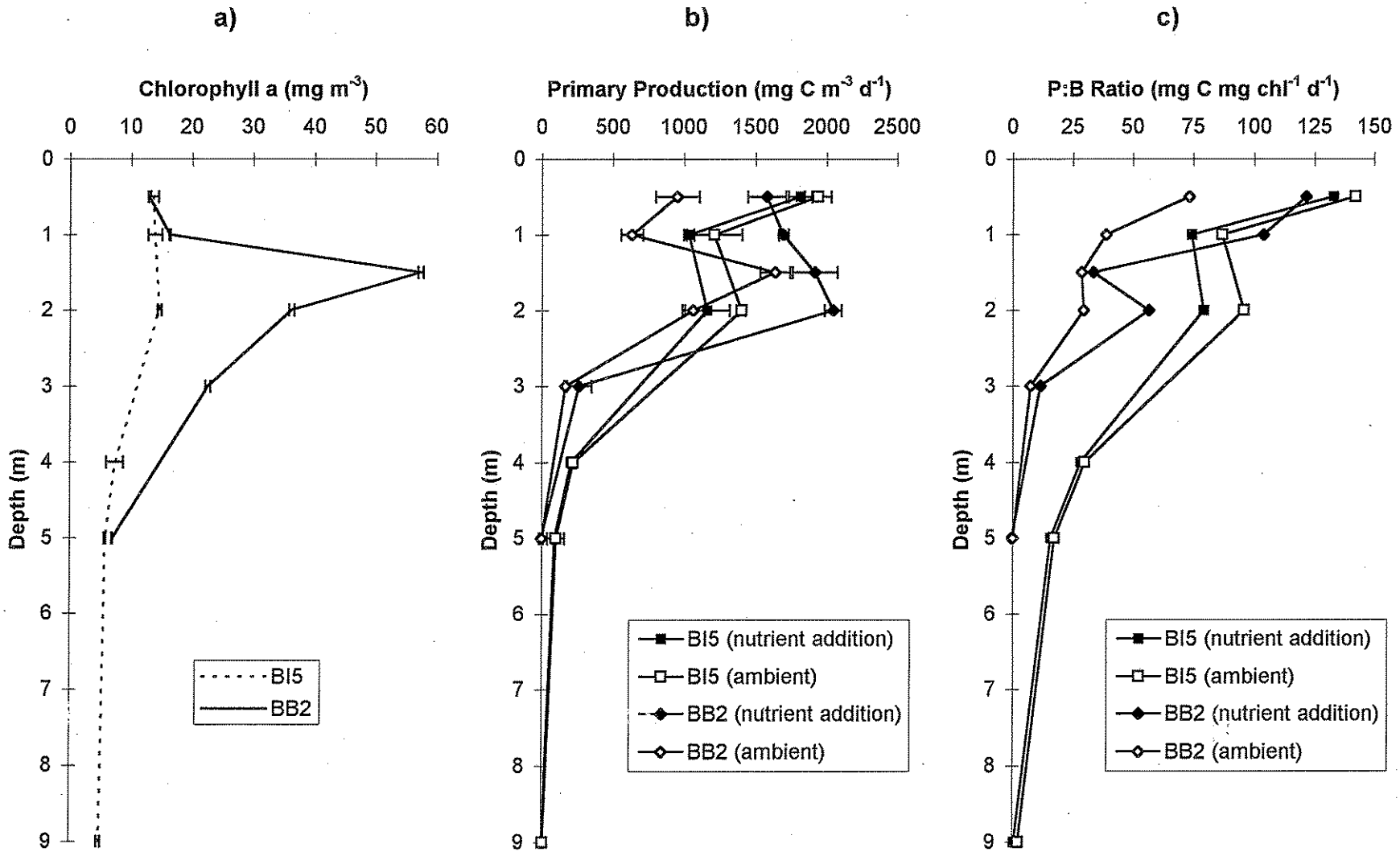


Figure 33. Primary production results from a 24-h *in situ* nutrient additon experiment on 19-20 September 1994. Data from inner bay station BI5 and central bay station BB2 show a) chlorophyll a, b) primary production and c) P:B (production to biomass) ratio. Error bars indicate +/- one s.d.

4124 mg C m^{-2} d^{-1}. This marked stimulation of production by nutrient addition and the high chlorophyll concentration indicate that phytoplankton at station BB2 were plentiful but nutrient-limited. In contrast, station BI5 did not show stimulation of production from nutrient-addition (Figure 33b). Curiously, the results showed a slight decrease in primary production in the nutrient addition treatment. A mechanism for this result is not clear. However, whether negative or positive, the nutrient-addition effect at station BI5 was small (16%).

The different effect of nutrient addition on primary production at these two stations is what might have been predicted based on ambient nutrient concentrations. Dissolved nitrate+nitrite-N and ammonium-N concentrations were BRL (< 0.01 mg/L) at station BB2 from 0.5 to 5 m depths, whereas ambient dissolved inorganic nitrogen (DIN) concentrations were above BRL at station BI5 at all depths (0.5 to 9 m) (Figure 34). Ambient orthophosphate-P concentrations were above BRL for both stations at all depths sampled. Thus, ambient nutrient concentrations are consistent with the observation that N-limitation of phytoplankton growth was likely occurring at station BB2, but probably not at station BI5.

Biomass normalized production (P:B ratio, in mg C mg chl-1 d-1) can be considered analogous to the phytoplankton specific growth rate, except that bias may be introduced into the ratio from cellular chlorophyll *a* concentration variation due to photoadaptation. Growth rates, as indicated by P:B ratios (Figure 33c), increased substantially in the nutrient addition treatment at BB2 (nearly three-fold at 1 m). At BI5, where nutrient concentrations were well above detection limits such an increase was not observed. The P:B ratio plotted versus incident light (Figure 35) show high growth rates for both treatments at BI5 and the nutrient-addition treatment at BB2, but substantially lower rates for the ambient production at BB2. Although all bottle incubation results must be interpreted with caution, because of the strong stratification in Budd Inlet it is unlikely that the phytoplankton would have been exposed to higher nutrient regimes if not confined to bottles.

The severe drop in the P:B ratio at 1.5 m at station BB2 in the nutrient addition correlates with an exceptionally high chlorophyll concentration (58 mg m-3). It is likely that the exceptionally high phytoplankton biomass in that sample used up the added nutrient spike quickly, thus resulting in a P:B ratio similar to the ambient treatment. The nutrient spike used yielded an added concentration of 0.14 mg/L ammonium-N and 0.03 mg/L phosphate-P. In the 100% light level samples (0 m), the DIN concentrations after 24 h were close to or at BRL levels at both stations, indicating that the nutrient spike added was not large enough (Table 10). This result is of note, since at station BI5 nutrient limitation was not evident from P:B ratios, yet the added ammonium-N was apparently utilized. Orthophosphate-P concentrations were still well above reporting limits after the 24-h incubation at both stations.

Phytoplankton Species for Primary Production Experiment

The species composition of the samples used for the nutrient addition primary production experiments gives information on persistence of the nutrient-limited condition observed in central Budd Inlet (Table 11). The diatoms *Chaetoceros* spp. and *Thalassiosira* spp. were plentiful at both stations. However, two dinoflagellates, *Ceratium fusus* and *Gymnodinium splendens*, were

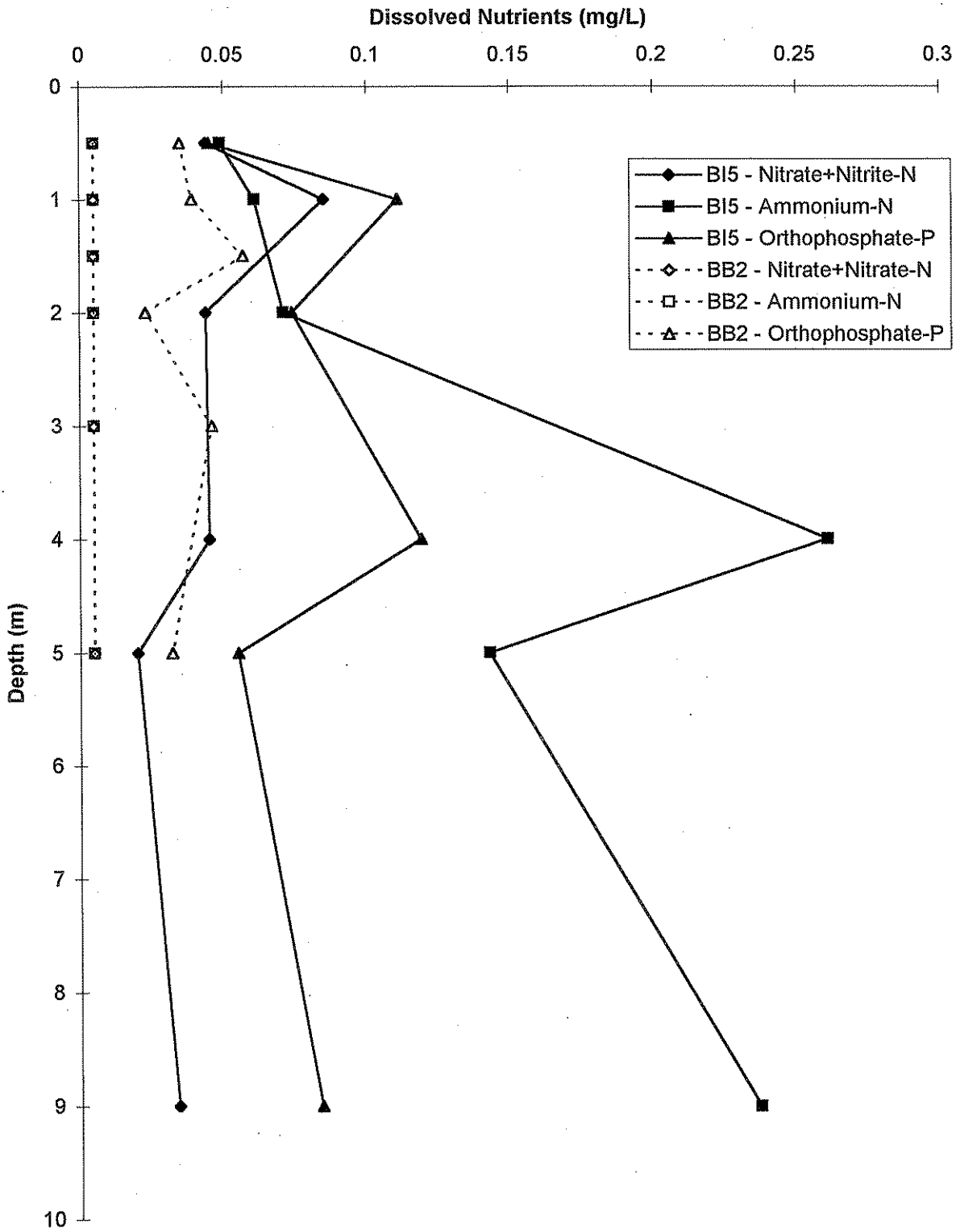


Figure 34. Ambient dissolved nutrient concentrations at inner bay station BI5 and central bay station BB2 on 19 September 1994.

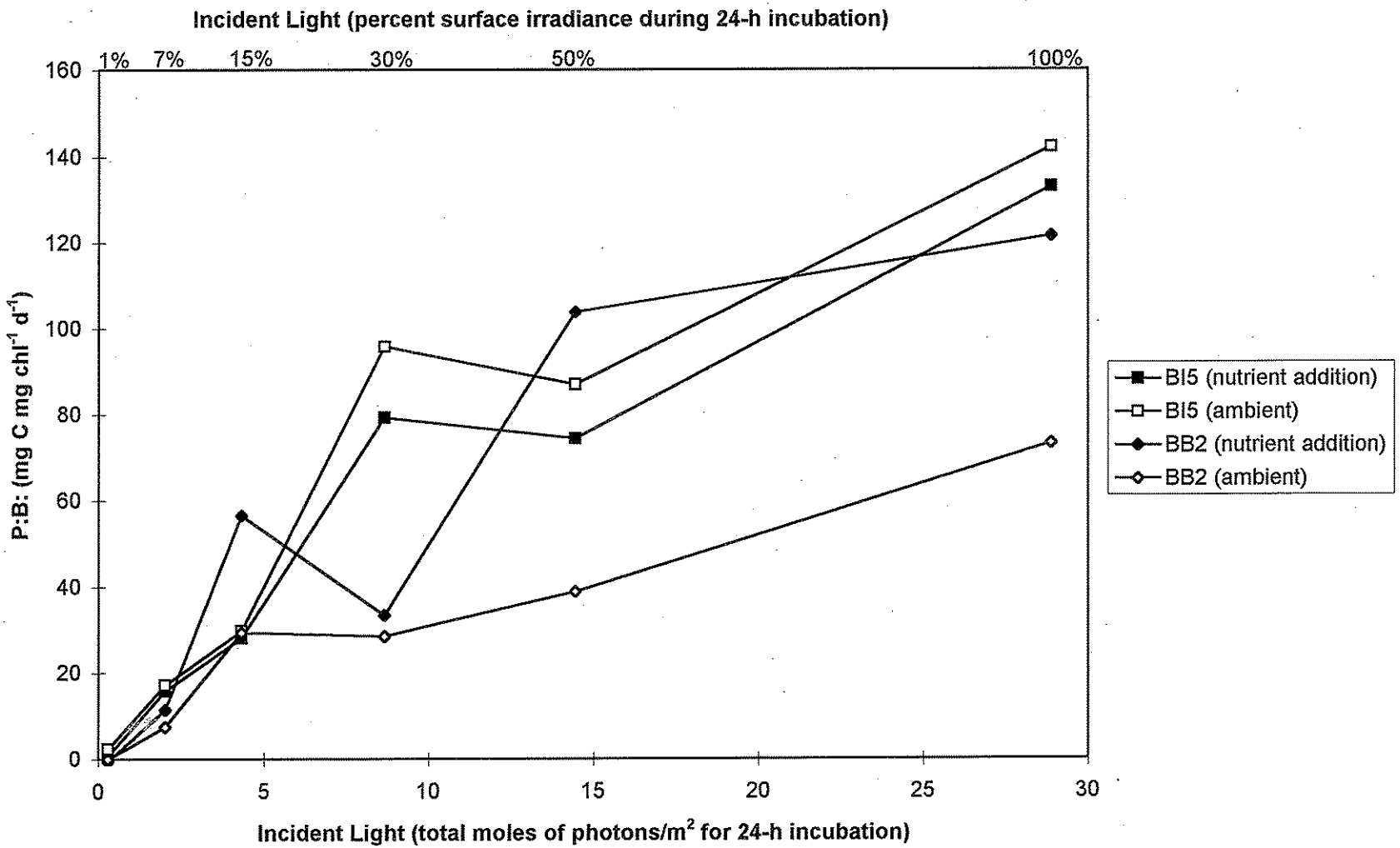


Figure 35. P:B (production to biomass ratios) versus incident light for nutrient addition and ambient conditions at stations BI5 and BB2 on 19-20 September 1994.

Table 10. Dissolved nutrient concentrations for water incubated 24 hours at 100 % light levels during primary production experiment on 19-20 September 1994. Data are from stations BI5 and BB2 with and without nutrient additions. No nutrient addition is considered the ambient condition. BRL indicates below the reporting limit of 0.01 mg/L.

	Nitrate+Nitrite-N	Ammonium-N	Orthophosphate-P
Station BI-5 w/ Nutrients	BRL	BRL	0.058
Station BI-5 w/o Nutrients	0.012	BRL	0.072
Station BB-2 w/ Nutrients	BRL	0.012	0.041
Station BB-2 w/o Nutrients	BRL	BRL	0.039

Table 11. Phytoplankton species from primary production experiment on 19 September 1994 at stations BI5 and BB2 at 0.5, 2 and 5 m depths. Counts are in cells per liter.

Taxonomic Category	BI-5 0.5 m	BI-5 2 m	BI-5 5 m	BB-2 0.5 m	BB-2 2 m	BB-2 5 m
Actinoptychus undulatus	4667	4084	9189	2042		8168
Asterionella japonica	12252					
Asteromphalus heptactis				4667	3500	4084
Cerataulina pelagica			2042	18378		
Chaetoceros danicus			5105		10210	
Chaetoceros septentrionalis	2042					
Chaetoceros misc. spores				169486		6126
Chaetoceros hyalochaete spp.	894396	392064	51050	1070008	673860	76575
Chaetoceros phaeoceros spp.				6126		2917
Chaetoceros spp. total cells	896438	392064	56155	1245620	684070	85618
Coscinodiscus wailesii			1021			
Coscinodiscus spp.	583		1021			
Ditylum brightwelli			1167			
Eucampia zodiacus	4084	4084	9189	28588	5834	
Leptocylindrus danicus		12252	3063		6126	
Leptocylindrus minimus	296090					
Navicula spp.	4084					
Nitzschia closterium		1167	3063	2042		
Nitzschia spp.	6126					
Pleuro/Gyrosigma spp.						583
Pseudonitzschia pungens			1167			
Rhizosolenia delicatula	8168					3063
Rhizosolenia fragilissima			7147	12252		
Rhizosolenia setigera		583			2042	
Skeletonema costatum	12252	4084	6126	32672	28588	20420
Stephanopyxis turris			583			
Thalassionema nitzschioides	14002	8168	4084	46966	38798	26546
Thalassiosira sira anguste-lineata	3500	583	7147			
Thalassiosira rotula/gravida	6126	5834		6126		2042
Thalassiosira spp.	104142	432904	134772	4702500	1374266	44924
Thalassiosira very small spp.	682028	191948	19399		100058	232788
Miscellaneous centric diatom spp.	46966	30630	29609		24504	13273
Miscellaneous pennate diatom spp.	24504	16336	1021	26546	30360	8168
Total Diatoms	2126012	1104721	296965	6128399	2298146	449677
Ceratium fusus	2042			2334	1598850	61260
Dinophysis spp.						1167
Gonyaulax catenella		4084			8168	
Gymnodinium splendens	81093	583			282150	2042
Gymnodinium spp.			1021		583	3063
Minuscula bipes				583		
Noctiluca miliaris	2917	4084	6126	4084	7001	14294
Oxyphysis oxytoxoides						1021
Peridinium spp.	2042			583	3500	583
Misc. colorless dinoflagellates	6126		5105	42882	4084	9189
Misc. pigmented dinoflagellates		2042	1021		2042	1021
Total Dinoflagellates	94220	10793	13273	50466	1906378	93640
Choanoflagellates						4084
Microflagellates < 10 um	149066	79638	54113	181738	271586	131709
Microflagellates 10-20 um	10210	12252	1021	349182	12252	11231
Cryptomonads			583	16336	2042	6126
Total Other Phytoplankton	159276	91890	55717	547256	285880	153150
Total Phytoplankton	2379508	1207404	365955	6726121	4490404	696467

very abundant at central bay station BB2 yet were in lower abundance at inner bay station BI5. Both dinoflagellates are mobile and *G. splendens* is known to migrate vertically when nutrient gradients are present (Cullen and Horrigan, 1981). The unique species assemblage at BB2, only 4 km away from BI5, indicates that surface nutrient limitation of phytoplankton growth in the central bay was persistent enough for migratory dinoflagellates to have established. Their absence at station BI5 helps to confirm the lack of significant nutrient limitation in the inner bay as evidenced by the primary production experiments.

Phytoplankton Species

As mentioned in the Methods section, these results are based on samples collected at one depth at one station in the inner bay and one station in the central bay. Samples were collected every two to four weeks in the inner bay and monthly in the central bay. Thus, the following conclusions offer possible explanations, but should not be considered definitive.

Interannual Variation

Several interannual differences were observed. Higher concentrations of *Ceratium fusus* and choanoflagellates were seen in 1992 than in 1993 or 1994 (Figures 36 and 37). Lower abundances of *Thalassiosira* spp. and higher abundances of *Heterosigma carterae* (in the inner bay), cryptomonads and microflagellates < 10 µm were seen in 1993 than in 1992 and 1994. Lower abundances of *Skeletonema costatum* were seen in 1994 than in 1992 and 1993. Also, large *Ceratium fusus* blooms (> 10^6 cells/L) were observed later in the year in 1994 (October) than in 1992 (July, August) and 1993 (July). *H. carterae* was observed less frequently in the central bay during 1994 than 1992 or 1993.

The spring bloom was dominated by *Chaetoceros* spp. and *Skeletonema costatum* during 1992, by *Chaetoceros* spp., *S. costatum* and microflagellates < 10 µm during 1993 and by *Chaetoceros* spp., *Thalassiosira* spp., *Leptocylindrus* spp. and *Gymnodinium splendens* during 1994 (Figures 36 and 37). The summer bloom was dominated by *C. fusus* during 1992 and 1993 and by microflagellates < 10 µm during 1994. The fall bloom was dominated by *S. costatum* and *Thalassiosira* spp. during 1992, by *H. carterae*, microflagellates < 10 µm and cryptomonads during 1993 and by *Thalassiosira* spp., microflagellates < 10 µm and *C. fusus* during 1994.

Influence of Interannual Variation in Nutrients, Light and Hydrography on Species Composition

H. carterae growth has been shown to be enhanced by high nutrient concentrations (Nishijima and Hata, 1984). Also, maximum cell specific growth rates for *H. carterae* have been found to be higher for cells grown on ammonium compared to nitrate (Wood and Flynn, 1995). Therefore, the higher prevalence of *H. carterae* during 1992 and 1993 could be due to the higher N levels and/or to the higher ratio of ammonium-N to nitrate+nitrite-N during these years. The higher *G. splendens* abundances seen in 1994

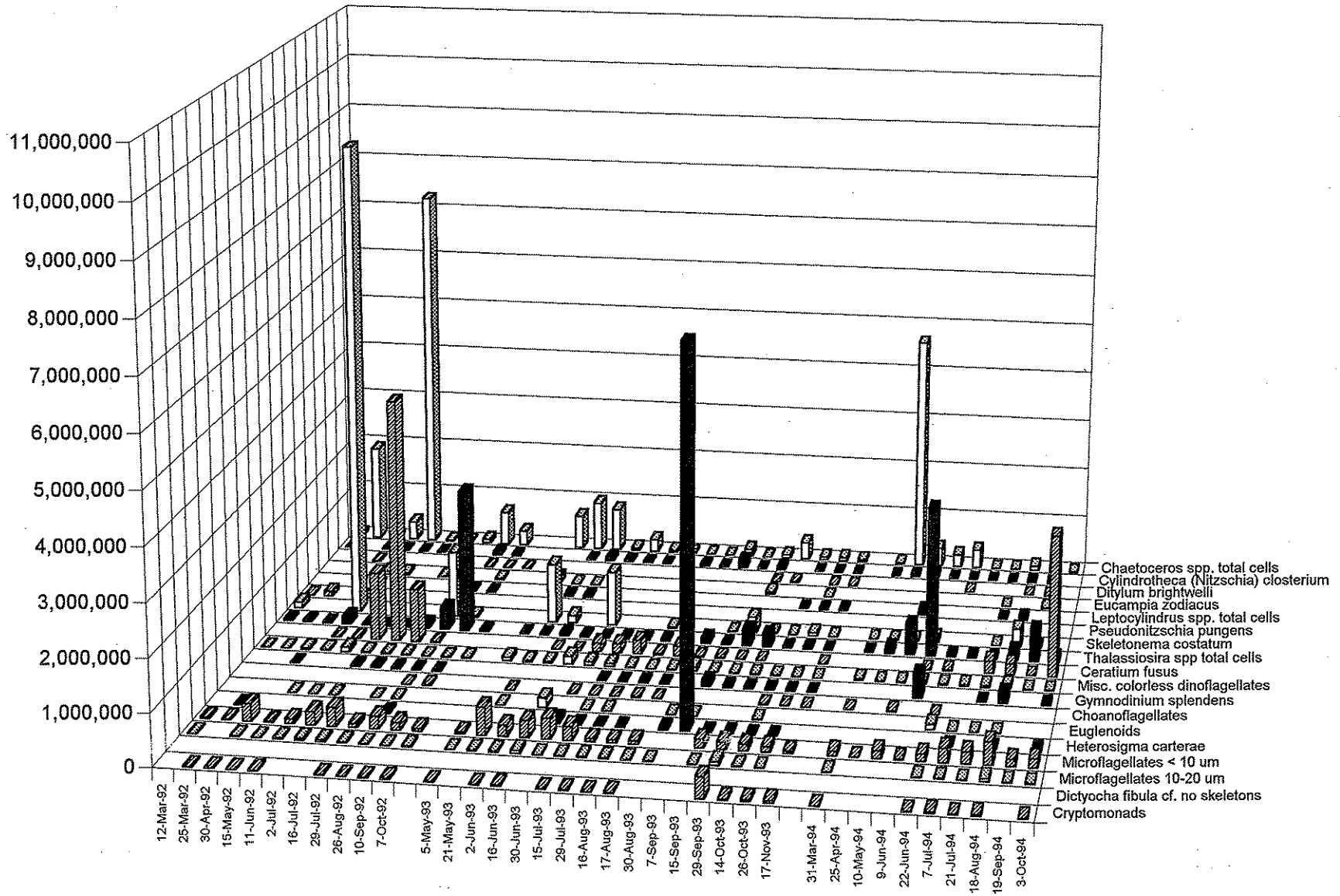


Figure 36. Inner bay phytoplankton species with concentrations of 100,000 cells/L one or more times at stations BI4 or BUD005. Data from station BI4 except for 12 Mar (BI5), 25Mar (BI3). 30Apr (BI5) and 16Jul (BA2) 1992.

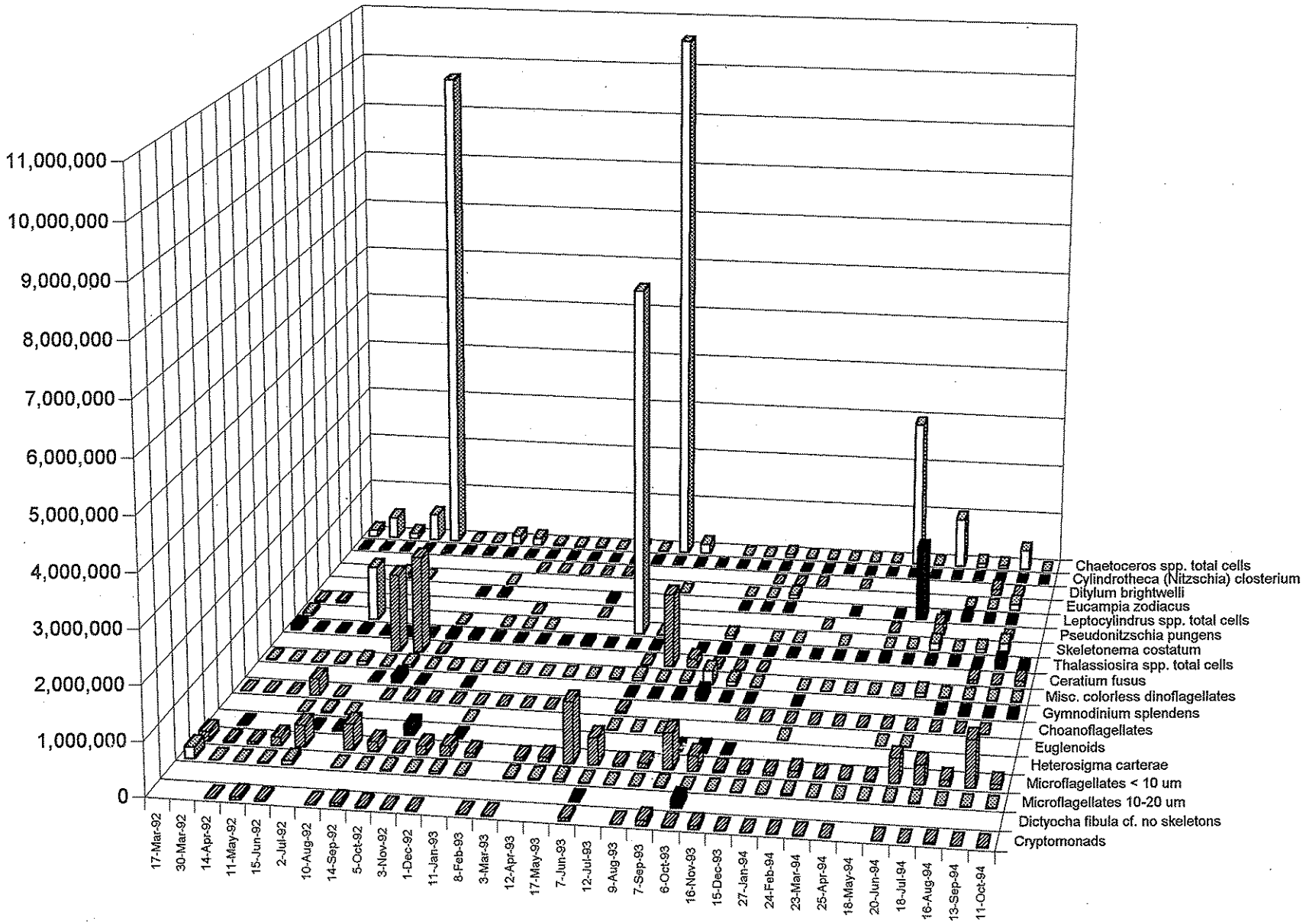


Figure 37. Central bay (long-term station BUD005) phytoplankton species with concentrations of 100,000 cells/L one or more times at station BI4 or BUD005.

(9 June in particular) could be due to the ability of *G. splendens* to utilize very low N concentrations (Thomas and Dodson, 1974).

Low light levels and/or low salinities may have reduced *Thalassiosira* spp. abundances and increased *S. costatum* abundances in 1993, particularly in spring (Figures 36 and 37). Spies and Parsons (1985) found that *Thalassiosira* spp. were out-competed by *S. costatum* at low light levels. Salinities were lowest in 1993 except in the surface waters of the inner bay from July through October. Rijstenbil (1988) found that *Thalassiosira* spp. did not compete well with some other diatom species (*S. costatum* and *Ditylum brightwelli*) at low salinities.

Temperature differences could also influence species patterns, since optimal temperature ranges for growth vary with species (Eppley, 1972). The low temperatures in combination with low light levels in 1993 may have reduced *Thalassiosira* spp. abundances. Ferguson et al. (1976) found that *T. Pseudonana* growth rates were reduced by lower temperatures (17 C compared to 20 C) when illumination was low (1.1 Klux); these growth rates were not affected by temperature at somewhat higher illuminations (2.2 Klux).

In conclusion, although some variation in species composition was observed between 1992, 1993 and 1994, high interannual variation can be expected, especially for sporadic blooms events (Mallin et al, 1991). Samples from several depths and at a higher frequency would be necessary to further elucidate the effect of water quality parameters on species composition. Other factors that influence species abundance such as micronutrient (i.e. silicate) limitation and selective grazing may be important in Budd Inlet.

Seasonal Variation

Chain-forming diatoms (*Chaetoceros* spp., *Thalassiosira* spp., *S. costatum*) were usually the dominant group observed during spring to early summer and during late summer/early fall for all three years (Figures 38 and 39). Higher abundances of diatoms were seen in the spring and early summer than in fall. Dinoflagellates (*C. fusus*) were the dominant group observed during summer (July and August), and during 1994, in the fall (early October).

Other phytoplankton (microflagellates < 10 μm, *H. carterae*) occasionally had higher abundances than diatoms or dinoflagellates during spring through fall. Microflagellates < 10 μm were the dominant group observed during winter in Budd Inlet and at Ecology long-term monitoring stations in the main basin (station PSB003) and Georgia Strait (station GRG002). Studies conducted in waters off B.C. Canada have also shown small flagellates to be dominant during the winter months (Takahashi and Hoskins, 1978; Spies, 1984).

The decline of diatoms during late spring may be due to silicate limitation (Egge and Aksnes, 1992; Conley and Malone, 1992), although this possibility remains untested since silicate was not measured during this study. Also, the decrease of N in the surface waters (in the central bay) may allow diatoms to be out-competed by dinoflagellates capable of

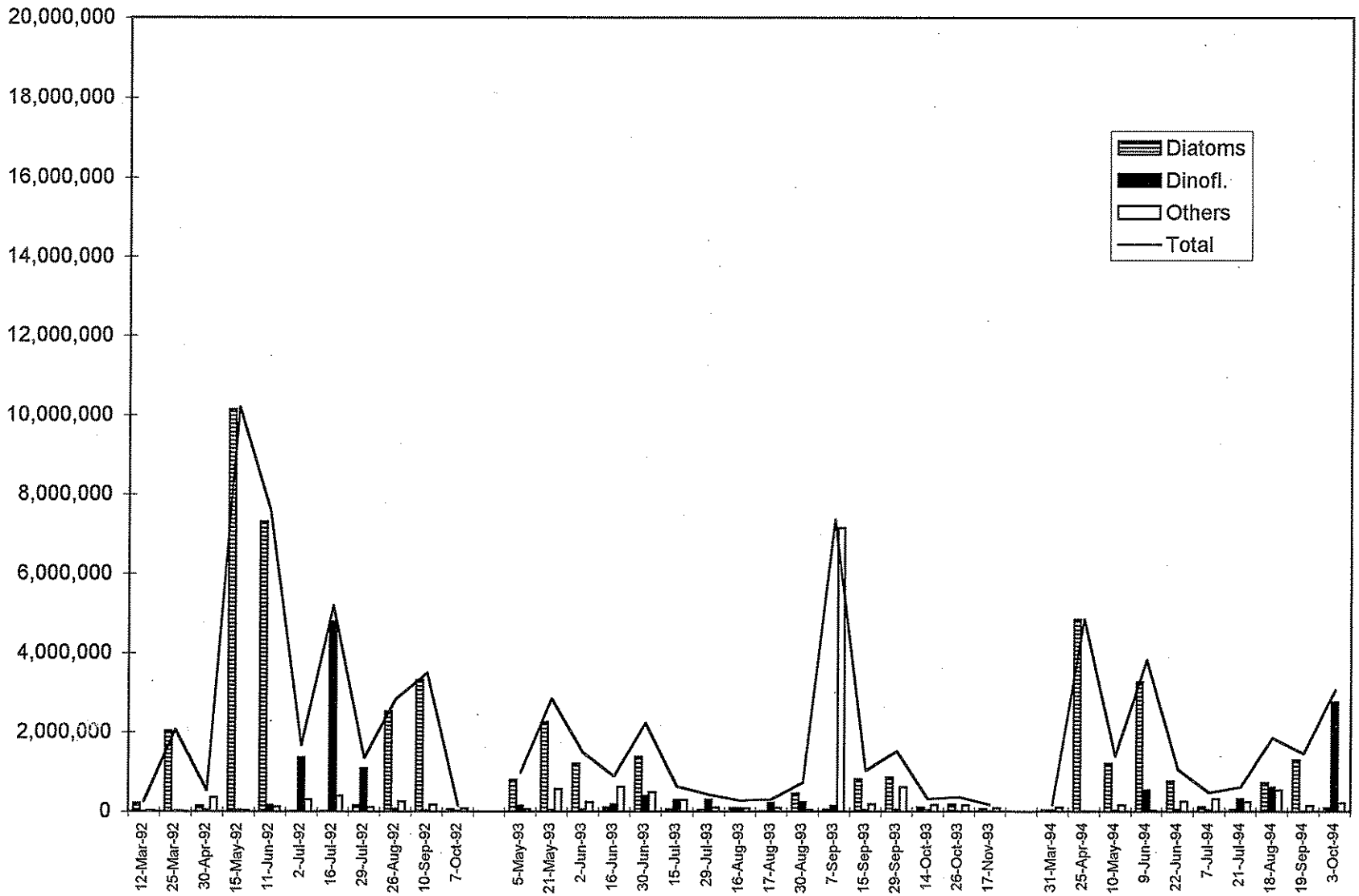


Figure 38. Inner bay abundances of diatoms, dinoflagellates, other phytoplankton (not diatoms or dinoflagellates) and total phytoplankton. Data from station BI4 except for 12Mar (BI5), 25Mar (BI3), 30Apr (BI5) and 16Jul (BA2) 1992.

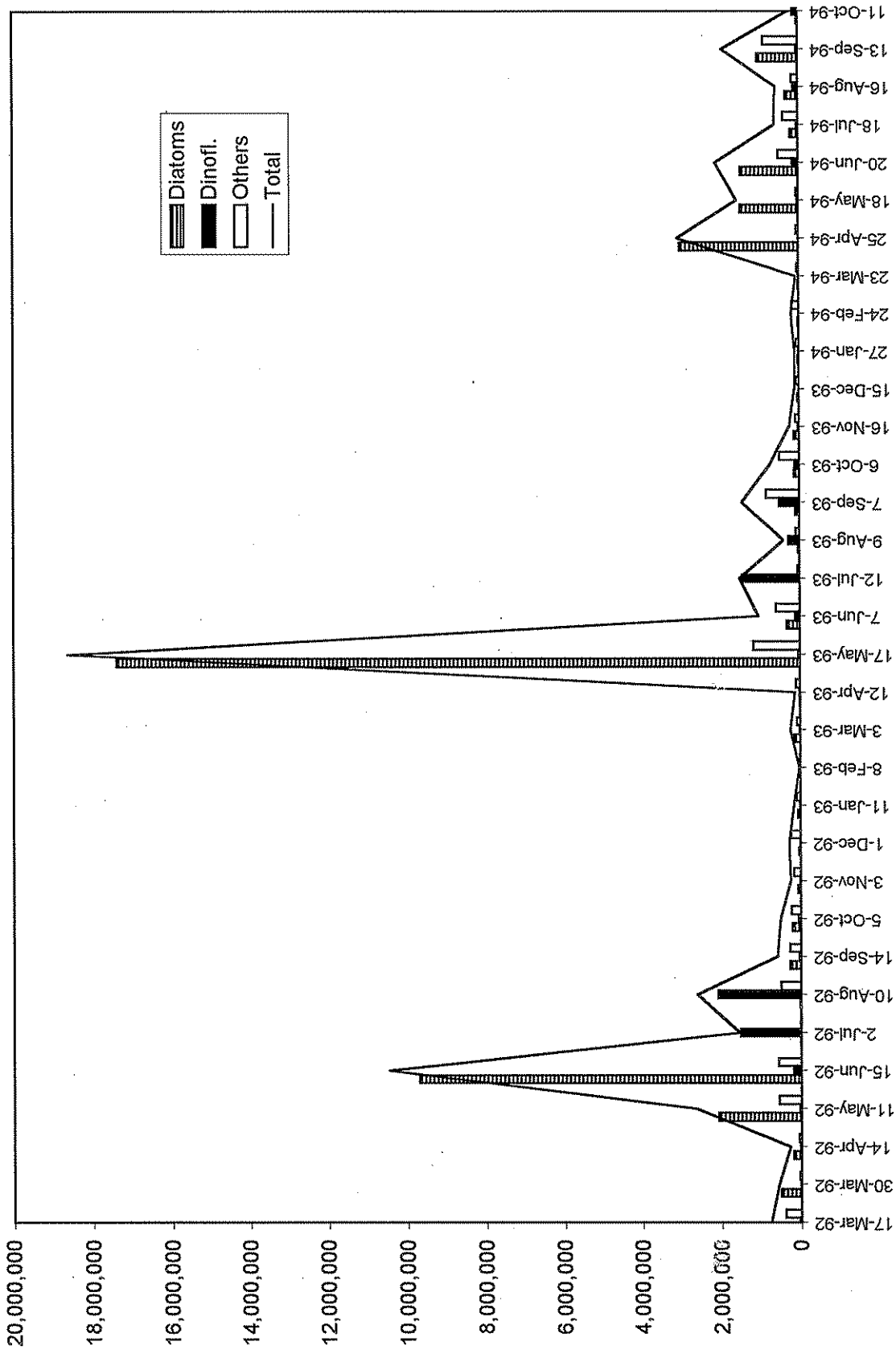


Figure 39. Central bay (long-term station BUD005) abundances of diatoms, dinoflagellates, other phytoplankton (not diatoms or dinoflagellates) and total phytoplankton.

vertical migration, such as *C. fusus* (Staker and Bruno, 1980) and *G. splendens* (Cullen and Horrigan, 1981). These species can migrate down in the water column during the night to utilize nutrients at depth and then move higher up in the water column in the day where light levels are more optimal for growth. Dinoflagellates are also favored by calm, sunny weather in stratified regions where nutrients are in excess (Zenvenboom et al., 1991). These conditions were often met in inner Budd Inlet during the summer particularly in 1992 when both stratification and nutrient concentrations were high. This may account for the high *C. fusus* abundances in 1992. Declines in diatom concentration may also be due to selective grazing on diatoms since diatoms are often a more desirable food than some dinoflagellates and flagellates (Olsson et al, 1992). The switch in dominance from dinoflagellates back to diatoms in fall was likely due increases in surface nutrient concentrations and mixing (which prevents diatoms from sinking).

Comparison of Inner Bay and Central Bay (long-term station BUD005)

Differences in species composition were observed between inner and central bay stations. Higher concentrations of *C. fusus*, *S. costatum* (in early fall 92 and 93), *H. carterae* (7 September 1993 especially), and *Thalassiosira* spp. were seen at station BI4 than at station BUD005. Higher concentrations and greater frequencies of *Leptocylindrus* spp and choanoflagellates were seen at station BUD005 than at station BI4.

Because of the depth differences in sample collection between station BI4 (Table 2) and station BUD005 (0.5 m collection depth), comparison of these data must be made with caution. However, some of the variation may also be due to differences in physical parameters such as salinity. *S. costatum*, for example, grows well in brackish water conditions (Spies and Parsons, 1985) and can tolerate salinity fluctuations (Rijstenbil, 1988). This species may thrive in the inner bay where there is a strong freshwater influence and large salinity fluctuations, but could be outcompeted in the central bay which is farther away from the major freshwater source and has relatively stable salinity.

Occurrence of Harmful Phytoplankton Species

Pseudonitzschia species (*P. pungens*, *P. australis*, *P. pseudodelicatissma*, and *P. seriata*) are pennate diatoms that may produce domoic acid, a neurotoxin that can accumulate in shellfish and other organisms and pose health threats to humans. One or more of these potentially harmful *Pseudonitzshia* species were observed during many months (Table 12). Concentrations were less than 10^5 cells/L except during June 1994 when concentrations of 2 or 3 x10^5 cells/L were seen. The concentration of cells where harmful effects become evident is not known (Horner, 1994) and toxicity concentrations within cells have shown to be variable depending on factors such as stage of cell growth (Douglas and Bates, 1992). Thus, the threat to human health implied by these observations cannot be assessed, but is a factor to be considered.

Heterosigma carterae is a small photosynthetic flagellate that can cause fish kills, by extruding a toxin into the seawater that kills fish (Cattolico, 1996 pers. comm.).

Table 12. Potentially harmful phytoplankton species (Pseudonitzschia australis, P. pseudodelicatissma, P. pungens, P. seriata, Heterosigma carterae, and Alexandrium catenella) concentrations in the inner bay (predominantly BI4) and at central bay station BUD005 (longterm station) in 1992, 1993 and 1994. Concentrations in cells/liter.

Inner Bay						
	P. australis	P. pseudodelicat.	P. pungens	P. seriata	H. carterae	A. catenella
12-Mar-92			5,105	4,084		
25-Mar-92			92,911		1,021	
30-Apr-92						
15-May-92			28,588			
11-Jun-92		1,167				
2-Jul-92						
16-Jul-92						
29-Jul-92						
26-Aug-92			2,334		13,273	
10-Sep-92						
7-Oct-92		583				
5-May-93						
21-May-93				2,334		
2-Jun-93						
16-Jun-93						
30-Jun-93				1,167	69,428	
15-Jul-93					3,063	
29-Jul-93					2,042	
16-Aug-93					2,042	1,021
17-Aug-93						
30-Aug-93					28,588	1,167
7-Sep-93				1,167	7,147,800	
15-Sep-93				3,063	1,021	
29-Sep-93					8,168	
14-Oct-93					2,042	
26-Oct-93				10,210	1,021	
17-Nov-93						
31-Mar-94						
25-Apr-94						
10-May-94				16,336		
9-Jun-94				6,417		
22-Jun-94				323,657		
7-Jul-94					6,126	
21-Jul-94						
18-Aug-94				4,084	4,084	
19-Sep-94						
3-Oct-94					22,462	

Central Bay (BUD005)						
	P. australis	P. pseudodelicat.	P. pungens	P. seriata	H. carterae	A. catenella
17-Mar-92			24,502			
30-Mar-92			37,777		583	
14-Apr-92						
11-May-92	7,001			11,085		
15-Jun-92					583	
2-Jul-92					15,168	
10-Aug-92						
14-Sep-92						
5-Oct-92					183,780	
3-Nov-92						
1-Dec-92			3,063		2,042	
11-Jan-93						
8-Feb-93						
3-Mar-93			5,105			
12-Apr-93						
17-May-93						
7-Jun-93	1,021					
12-Jul-93						
9-Aug-93						
7-Sep-93					40,840	
6-Oct-93					56,155	
16-Nov-93					1,021	
15-Dec-93						
27-Jan-94			4,084			
24-Feb-94						
23-Mar-94						
25-Apr-94			15,315			
18-May-94						
20-Jun-94			222,859			
18-Jul-94						
16-Aug-94						
13-Sep-94			2,917			
11-Oct-94		583				1,167

H. carterae also kills sea urchins by inhibiting their fertilization response and can produce oyster larvae mortality by promoting an increase in carbon levels leading to a rise in bacteria which infect the oyster larvae. *H. carterae* was observed primarily during summer and fall with more occurrences seen in 1992 and 1993 than in 1994 (Table 12). Concentrations were less than 10^5 cells/L except for fall 1992 and 1993. Of particular note are the high concentrations ($7x10^6$ cells/L) seen on 7 September 1993. As with *P. pungens*, the concentration at which harm can occur is unknown.

Alexandrium catenella is a "red-tide" dinoflagellate that produces PSP (paralytic shellfish poisoning). This organism also can accumulate in shellfish and other organisms and pose health threats to humans. *A. catenella* growth is stimulated by warm temperatures and stratified waters (Horner, 1990). *A. catenella* was observed in low concentrations (10^3 cells/L) during August 1993 and October 1994 (Table 12). High levels of PSP toxins can be observed in shellfish when only a few *A. catenella* cells are present (Horner, 1994). However, as with the other harmful species, the concentration of *A. catenella* necessary for harm to occur is unknown.

Phytoplankton Dynamics in Relation to Environmental Variables

Chlorophyll *a* concentrations in the inner bay were higher in 1994 and 1992 compared to 1993, and these differences are primarily due to climatic and hydrologic conditions. Water temperatures were warmer, percent sky cover was lower and stratification was higher in 1992 and 1994 than in 1993. The nutrient reduction in 1994 was not associated with lower chlorophyll *a* concentrations; however, the impact of weather and physical conditions on the 1994 chlorophyll *a* data is difficult to quantify. If nutrients had remained high in 1994, it is probable that phytoplankton growth and biomass would have been higher. The primary production nutrient addition results imply nutrient addition stimulated phytoplankton growth in 1994 in the central bay. Phytoplankton species also showed interannual variation in species composition possibly due to differences in nutrient concentration, salinity and irradiance levels. Nutrient alterations not only affect phytoplankton biomass, but also phytoplankton species composition.

Dissolved Oxygen

Near-hypoxic dissolved oxygen (DO) concentrations (< 3 mg/L) were observed much more frequently in 1994 (July through October) than in 1993 (early September). Low DO concentrations (< 5 mg/L) were observed all three years from July through October, but covered a larger portion of the water column in 1993 than in 1994. In 1992, DO samples were not collected as deep in the water column as in the other 2 years; however, given the similar stratification and phytoplankton biomass in 1992 and 1994, the near-bottom DO concentrations in 1992 likely resembled those in 1994. The majority of the low and all of the near-hypoxic DO occurrences were in the inner bay at near-bottom depths. The conditions resulting in low DO are likely a combination of organic loading and persistent stratification.

Interannual Variation

The vertical extent of near-hypoxic DO concentrations was greater during 1994 than 1993 at station BI5 (Mann Whitney test, alpha = 0.05) (Figure 40a). In addition, occurrences of near-hypoxic DO concentrations were seen more frequently in 1994 than in 1993 at near-bottom depths at both stations BI5 and BI6 (Figure 41). In contrast, the vertical extent of low DO concentrations was greater during 1993 than 1994 at station BI6 (Mann Whitney test, alpha = 0.05) (Figure 40b). At stations BI5 and BI6, 1-m concentrations < 5 mg/L were seen more often in 1993 than in 1994 indicating that low DO extended higher up in the water column during 1993 (Figure 41). No significant differences between 1993 and 1994 were seen in the vertical extent of near-hypoxic and low DO concentrations for stations located further out in the bay.

A comparison of means for mid-July through early October (the period of lowest DO) showed that near-bottom DO was 0.7 mg/L lower in 1994 (3.3 mg/L) than in 1993 (4.0 mg/L) for stations BI6, BI5, and BI4 combined (Table 13). In the central bay, the mean near-bottom DO concentration for BB2 and BC3 combined was equal (6.0 mg/L) for 1993 and 1994.

Interannual variability in near-bottom DO concentration is shown by data from long-term stations BUD002 (inner bay) and BUD005 (central bay) (Figure 42). A 10-year data set from LOTT also shows interannual variability in near-bottom DO concentrations in Budd Inlet at a station that is close to BI5 (Figure 42). The LOTT data are in good agreement with Ecology's focused monitoring and long-term data (Figures 43 and 44), except for the summer of 1993 when DO values from LOTT were much higher than those from Ecology. Variability due to tidal influences could not account for the large difference (~3 mg/L) between the 1993 Ecology and LOTT near-bottom DO concentrations, since the variability in DO is only 1 mg/L or less between low and high tide (Figure 44). Near-bottom DO values seen by LOTT and by Ecology (long-term data at BUD002) remained low in the summer/early fall in both 1994 and 1995 (Figures 43 and 44). These values were within the range of seasonal minima seen in the long-term record (Figure 42).

Seasonal Variation

Near-hypoxic concentrations were observed at near-bottom depths in the inner bay only during August 1992, September 1993 and August to October 1994 (Figure 41). Low DO concentrations were observed at near-bottom depths during all three years from July through October in the inner bay (Figure 41) and during late August or early September in the central bay at station BB2 (Figure 45). The highest near-bottom DO concentrations were during spring in both the inner and central bay (Figures 41, 42, 45). The highest 1-m values were during spring in the inner bay and at various times throughout the growing season in the central bay (Figures 41 and 45).

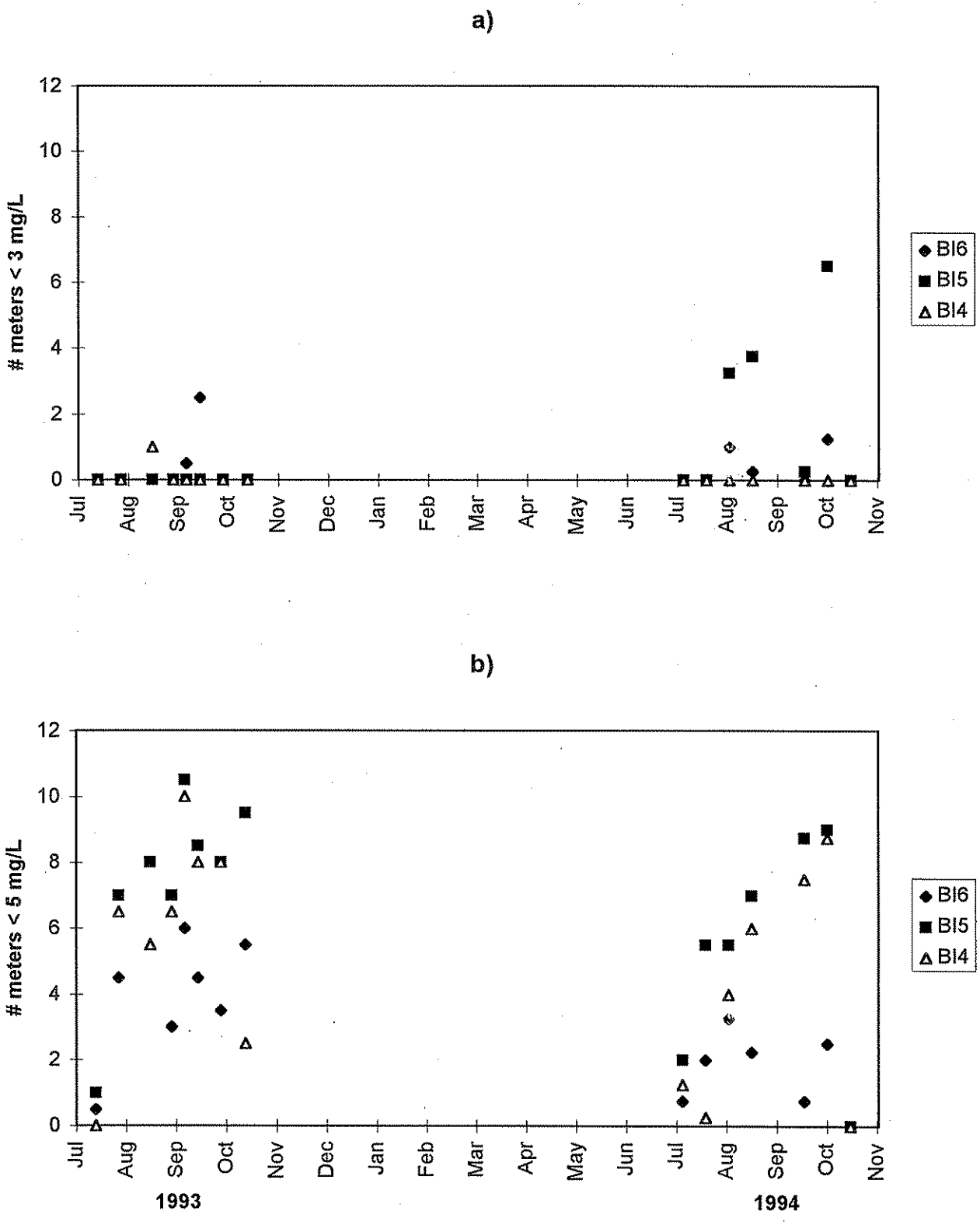


Figure 40. Vertical extent (# of meters) with DO concentrations a) <3 mg/L and b) <5 mg/L during 1993 and 1994.

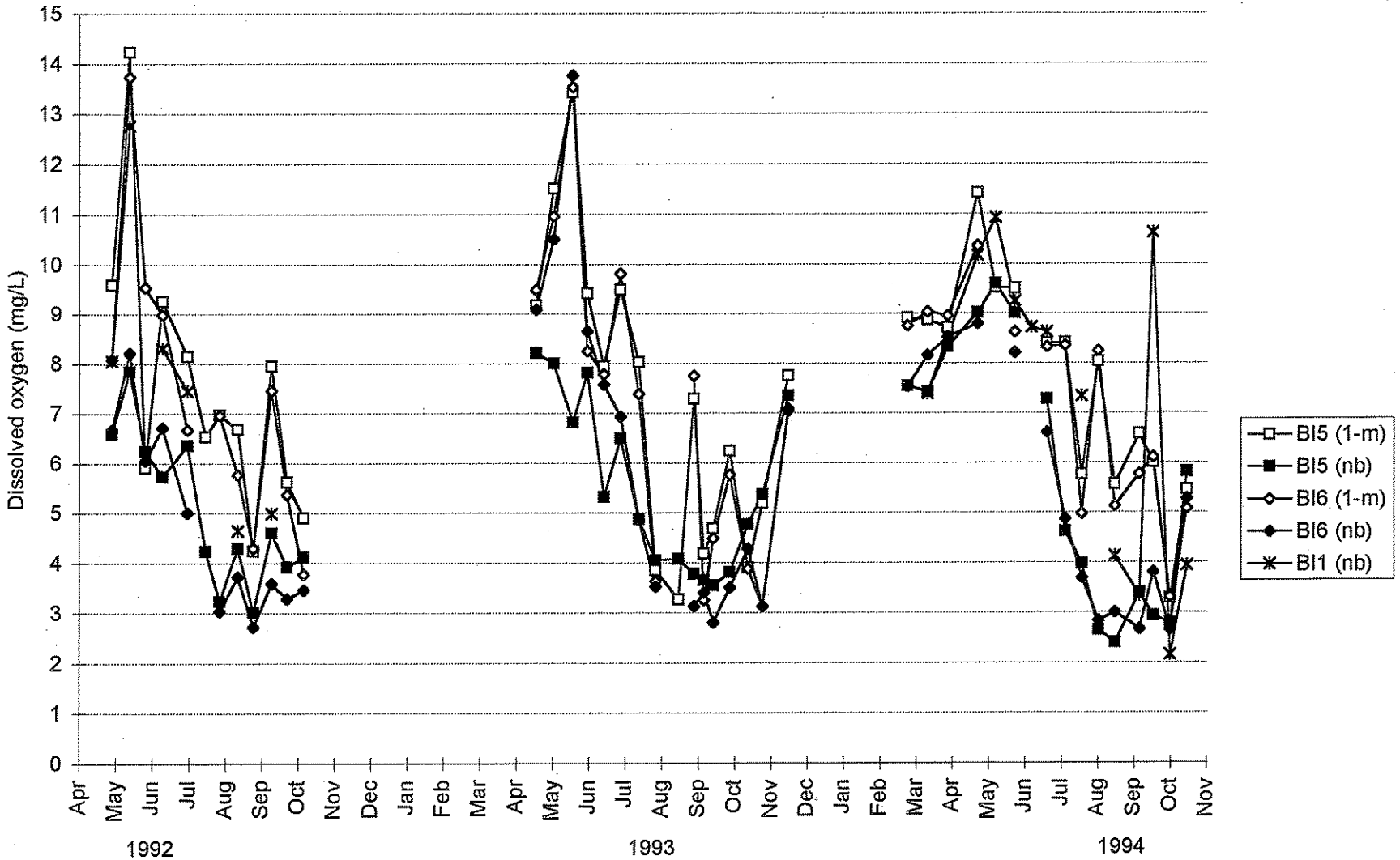


Figure 41. Dissolved oxygen concentrations at stations BI5 and BI6 at 1-m and BI1, BI5 and BI6 at near-bottom (nb) depths. Near-bottom depths were ~1.5 m shallower in 1992 than in 1993 or 1994.

Table 13. Mean values of near-bottom DO, integrated chl a (phytoplankton biomass estimate), maximum chl a and relative stratification for mid-July to early October (15 Jul - 7 Oct) during 1992, 1993 and 1994. Near-bottom depths were ~1.5 m shallower in 1992 than in 1993 and 1994.

		BI6	BI5	BI4	BB2	BC3	BI6,BI5,BI4 combined	BB2, BC3 combined
Mean near-bottom DO (mg/L)	1992	3.3	3.9	4.3	6.5	6.2	3.8	6.4
	1993	3.6	4.0	4.4	5.7	6.2	4.0	6.0
	1994	3.1	3.0	3.8	5.7	6.3	3.3	6.0
Mean integrated chl a (mg/m^2)	1992	32.0	51.8	72.0			51.9	
	1993	12.3	17.4	30.7			20.1	
	1994	21.1	52.3	131.2			68.2	
Mean maximum chl a (µg/L)	1992	13.8	16.5	17.3	31.0	31.3	15.9	31.1
	1993	6.4	7.4	12.3	30.0	30.0	8.7	30.0
	1994	14.0	20.7	25.8	29.9	29.1	20.2	29.5
Mean relative stratification (sigma-t)	1992	2.5	2.5	2.0	0.9	1.3	2.3	1.1
	1993	0.9	0.7	1.0	0.6	1.0	0.9	0.8
	1994	2.4	2.2	2.0	0.9	1.2	2.2	1.0

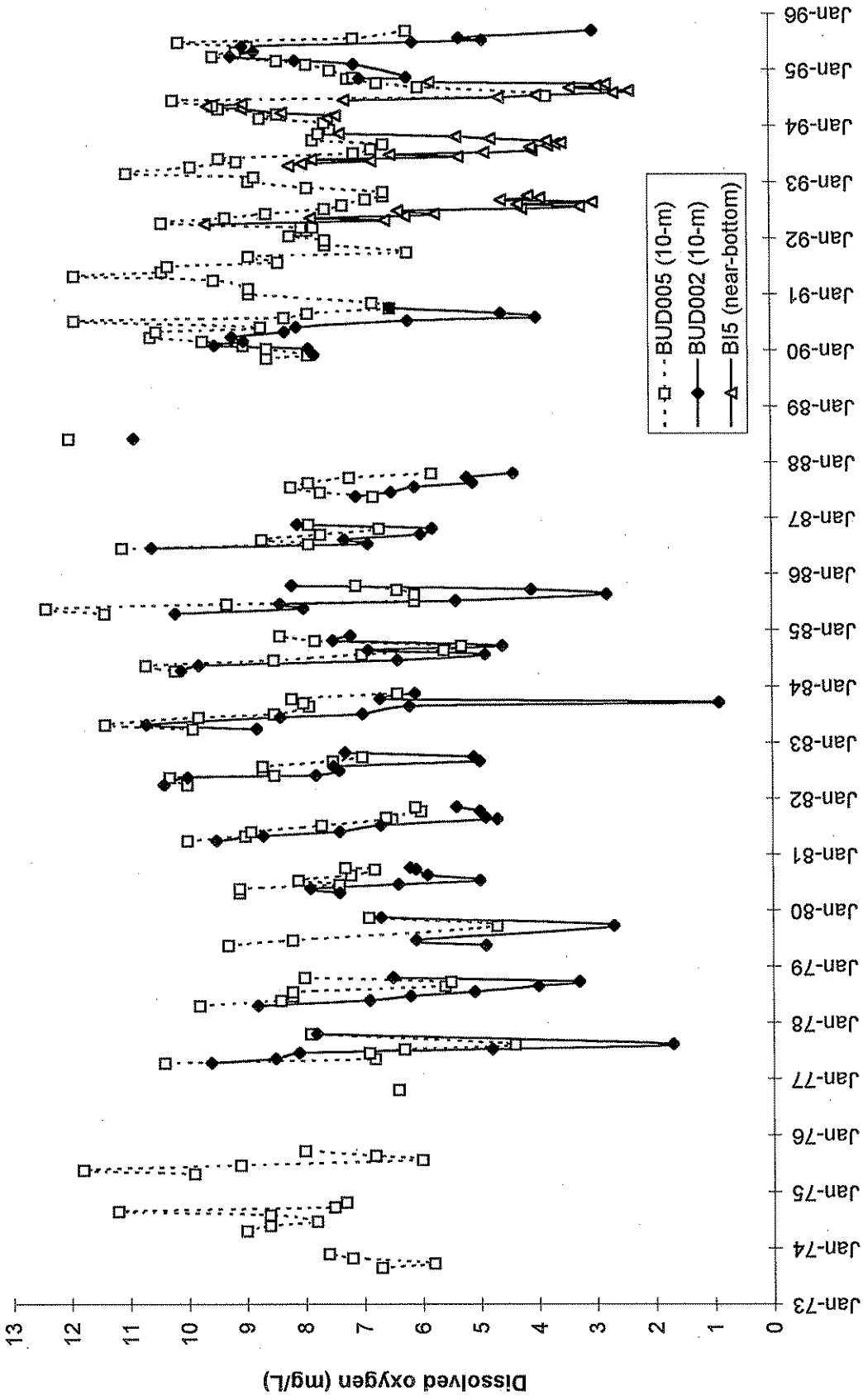


Figure 42. Dissolved oxygen data from longterm stations BUD005 (central bay) and BUD002 (inner bay) at 10-m depths and from station BI5 at near-bottom depths. Stations BUD002 and BI5 have the same loctation. Data collected at various tidal stages at stations BUD005 and BUD002 and at low tide at station BI5.

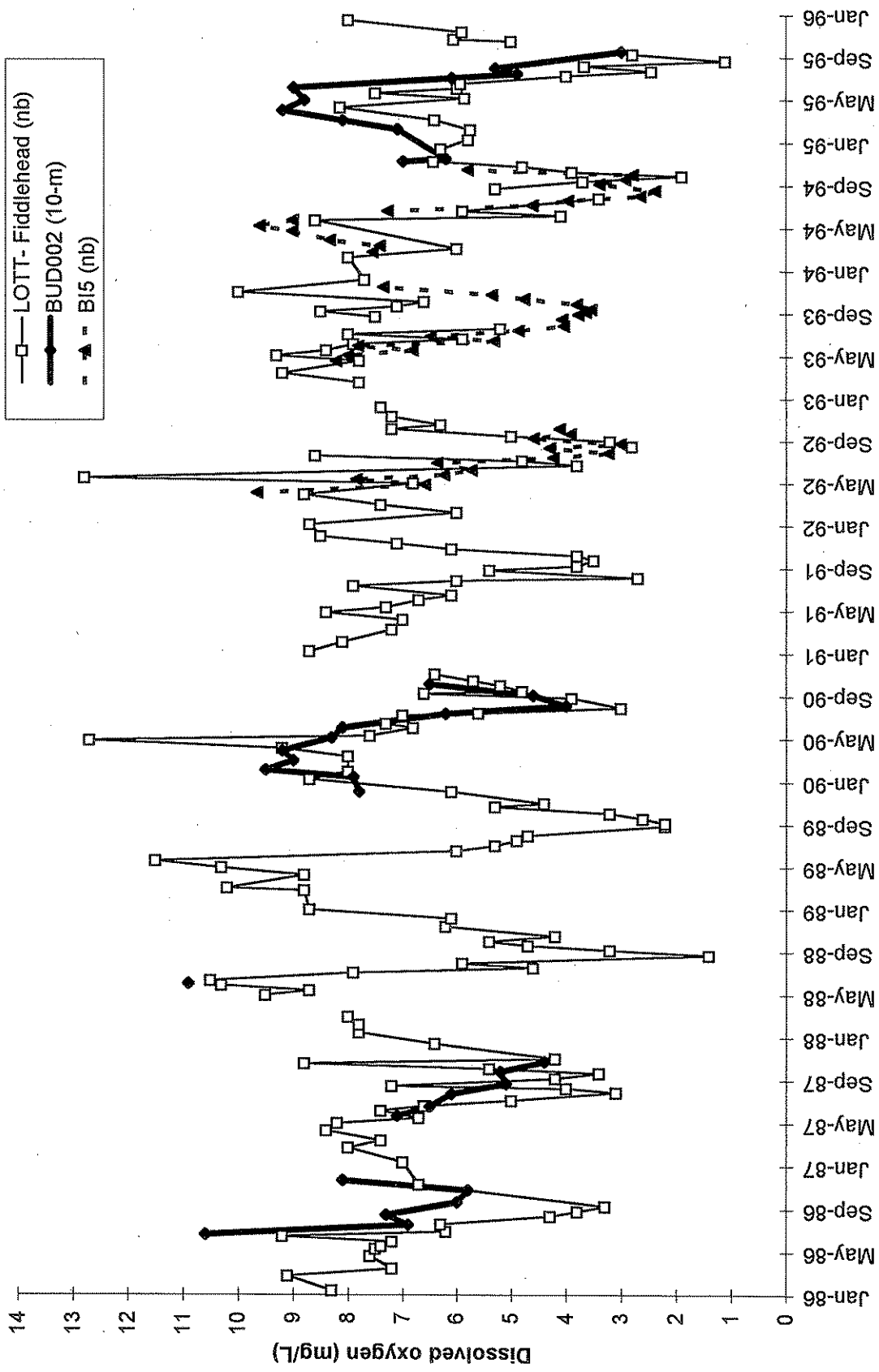


Figure 43. Near-bottom or 10-m dissolved oxygen data from the LOTT station near Fiddlehead Marina, Ecology longterm station BUD002 and Ecology station BI5. Station locations similar for all 3 stations. Data collected at various tidal stages for LOTT Fiddlehead station and station BUD002 and at low tide for station BI5.

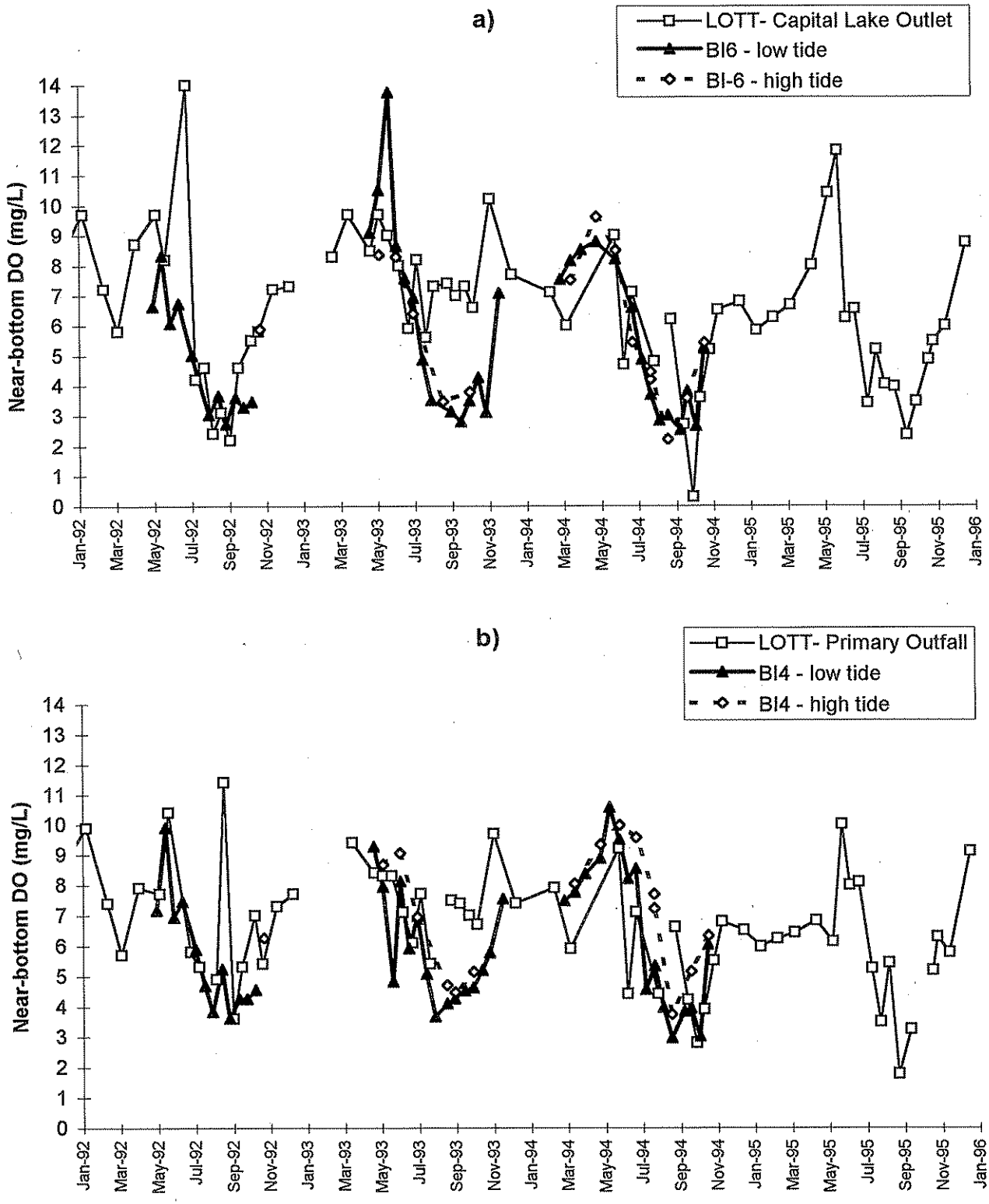


Figure 44. Near-bottom dissolved oxygen data from a) LOTT station near Capital Lake outlet (various tidal stages) and station BI6 at low and high tides, and b) LOTT station near primary (North) outfall (various tidal stages) and station BI4 at low and high tides. Locations are similar for LOTT station near Capital Lake outlet and Ecology station BI6, and for LOTT station near primary outfall and Ecology station BI4.

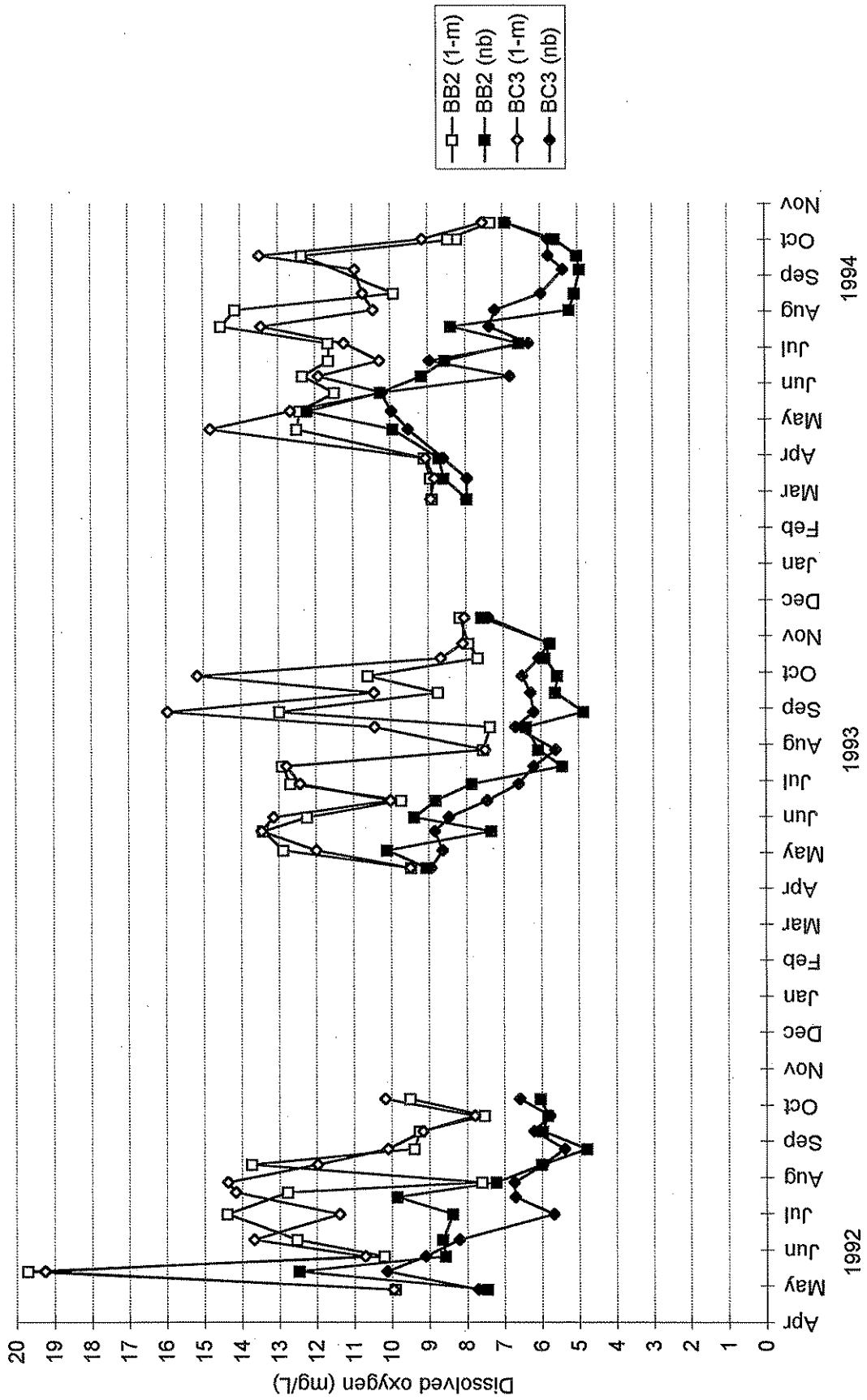


Figure 45. Dissolved oxygen concentrations at central bay stations BB2 and BC3 at 1-m and near-bottom (nb) depths. Near-bottom depths were ~1.5 m shallower in 1992 than in 1993 or 1994.

Spatial Variation

Overall, low DO concentrations were most frequently observed at near-bottom depths in the inner bay. Low near-bottom DO values occurred in inner East Bay (station BI1) as well as in West Bay (stations BI5 and BI6), although concentrations fluctuated more in East Bay likely due to the shallower depths there (Figure 41). Mean bottom depth was 2.5 m at East Bay station BI1 compared to 8.1 and 3.9 m at West Bay stations BI5 and BI6, respectively.

Dissolved oxygen concentrations were lower at near-bottom than at 1-m depths in both the inner and central bay. Principal component analysis conducted on 1992 data showed that DO was most closely associated with depth reflecting the influence on DO of processes that vary with depth such as stratification and phytoplankton production (Albertson, 1995).

During the early spring, DO concentrations were similar or slightly lower in the inner bay than in the central bay for both near-bottom and 1-m depths (Figures 41, 45 and Appendix A). As the growing season progressed and phytoplankton concentrations and stratification increased, inner bay DO concentrations become lower than central bay concentrations (station BC3 minus station BI5) by ~ 2 mg/L at near-bottom and by ~ 4 mg/L at 1-m depths.

Although numerous occurrences of low DO were observed in the inner bay, DO concentrations less than 5 were seen at central bay station BUD005 only during August 1977, September 1979 and July 1994 (Figure 42), based on data from 1973 to 1994. This shows that there is substantial spatial variation in Budd Inlet. Data at central bay stations (e.g. BUD005) do not represent the extent of low DO concentrations throughout the bay. Also, temporal variation is marked, and based on this study, linked to climatic forcing.

Degree of Correlation with Phytoplankton Biomass

It would be expected that high concentrations of phytoplankton would produce low concentrations of DO in near-bottom waters when the blooms sink and decay. Consistent with this, comparison of phytoplankton biomass and near-bottom DO for mid-July through early October in the inner bay yields an inverse relationship. In 1994 compared to 1993, phytoplankton biomass estimates were ~48 µg/L higher and mean near-bottom DO was 0.7 mg/L lower for BI6, BI5 and BI4 combined (Table 13). While an inverse relationship was seen for seasonal means, no strong correlation was found between near-bottom DO and phytoplankton biomass estimates from the same or from the previous survey (i.e. data from ~ two weeks prior) at inner bay stations BI4 or BI5. In the central bay, 1993 and 1994 had similar mean near-bottom DO concentrations, phytoplankton biomass estimates and mean maximum chlorophyll *a* concentrations (Tables 9, 13 and Figure 27).

Phytoplankton photosynthesis can result in supersaturated DO concentrations. In this report, high DO concentrations are defined as those greater than 12 mg/L, since this is well above the possible 100% saturation concentrations for the temperature and salinity ranges observed in Budd Inlet (Eisner, et al, 1994). High DO concentrations (>12 mg/L) were observed at 1 m on 21 out of 39 surveys from April through October for 1992, 1993 and 1994 combined. Dissolved oxygen values >12 mg/L corresponded to times of phytoplankton blooms (chlorophyll *a* > 10 µg/L). However, during July through October when the highest phytoplankton concentrations were observed (chlorophyll *a* > 25 µg/L), DO concentrations > 12 mg/L were not seen for half of the surveys. During these times photosynthetic activity was not as great and/or ambient DO concentrations were lower.

A correlation was not seen between 1-m DO and 1-m chlorophyll *a* values in the inner or central bay (r^2 = 0.02 at BI5 and 0.10 at BC3 for April through October) since high DO concentrations were located at different depths than peak phytoplankton blooms. During 28 out of the 32 surveys that had DO stratification, the highest DO concentrations were located near the surface (~1 m depth), whereas the phytoplankton peak biomass was often located 1-2 m below that or horizontally offset (Figure 46).

The higher nutrient concentrations at depth in the central bay may have promoted blooms deeper in the water column. The greater light limitation in inner bay may have promoted blooms closer to the surface. The location of blooms at the surface instead of at depth would further lower DO in the inner bay since DO produced in photosynthesis would be released into the surface instead of deep waters.

Degree of Correlation with Relative Stratification

Relative stratification is important in regulating low DO concentrations in Budd Inlet. The mean relative stratification in the inner bay was twice as high (difference of ~1.0 sigma-t) in 1992 and 1994 than in 1993 at stations BI6, BI5 and BI4 combined during mid-July through early October (Table 13). The higher mean near-bottom DO concentrations during 1993 were likely due in part to this reduced stratification. Thus, it is misleading to only consider the nutrient and phytoplankton effects on DO when looking at the variation between 1993 and 1994.

In the central bay, mean relative stratification for mid July to early October was only 25% higher (difference of ~0.25 sigma-t) in 1992 and 1994 than in 1993 for stations BB2 and BC3 combined (Table 13). Mean near-bottom DO concentrations in the central bay were the same for 1993 and 1994. Therefore, both relative stratification and near-bottom DO showed smaller interannual differences in the central bay than in the inner bay.

Range of Dissolved Oxygen Variation

The DO concentration is influenced by numerous physical, chemical and biological processes which operate on many different temporal and spatial scales. It is useful to assess the scales of variation for this complex parameter. Variation of DO was evaluated

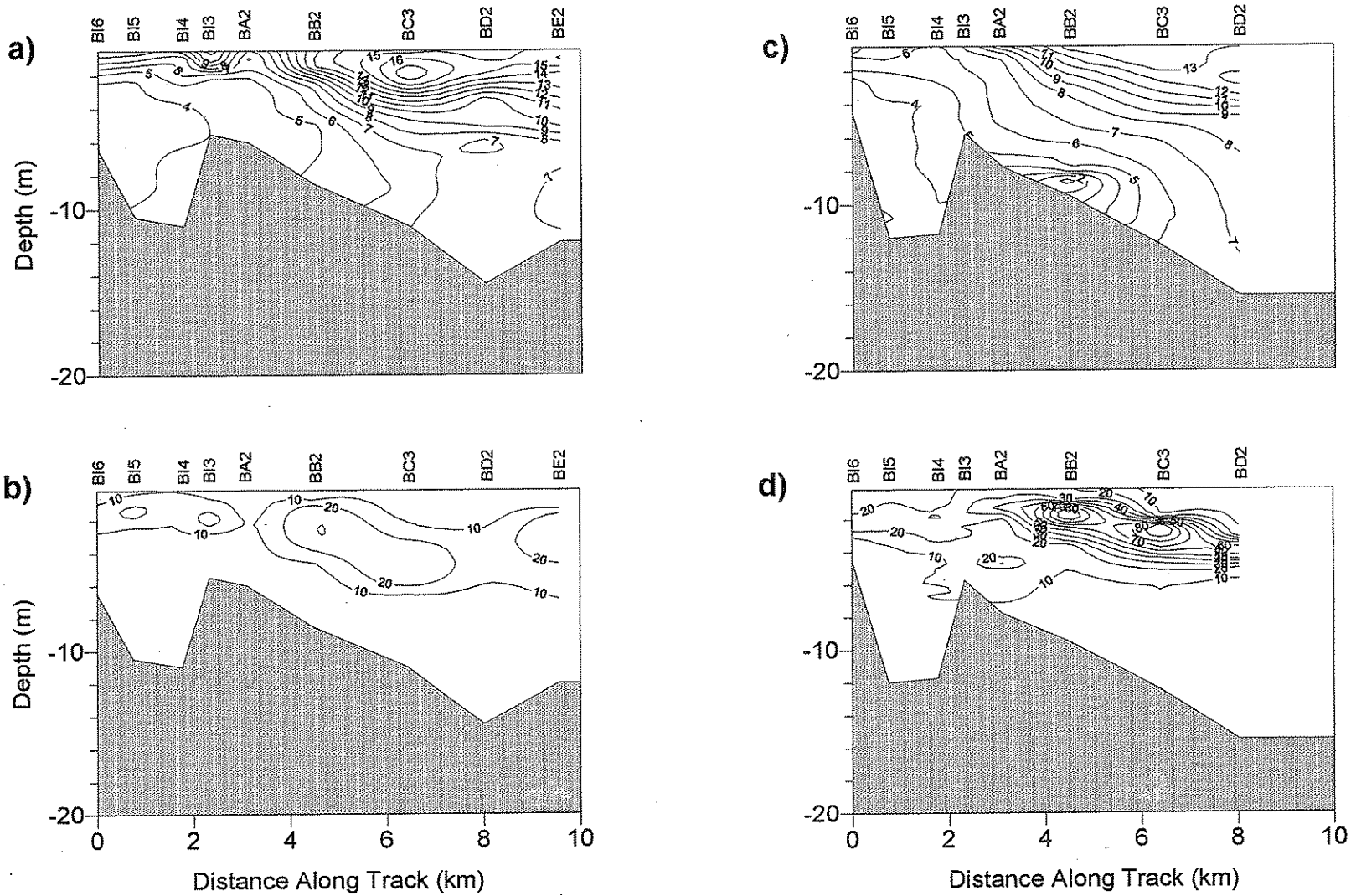


Figure 46. Vertical sections from low tide transects on 30 August 1993 for a) dissolved oxygen (mg/L) and b) chlorophyll a (µg/L), and on 19 September 1994 for c) dissolved oxygen and d) chlorophyll a. Plots show data from transects from the head (station BI6) to the mouth (station BE2) of Budd Inlet. Note that the fluorometer maximum was set to 30 µg/L in 1993 and 100 µg/L in 1994.

over temporal (seasonal, tidal cycle) and spatial (horizontal and vertical) scales for 1992 data (Eisner, et al., 1994). The most substantial variation in DO was seen over the growing season with maximum variation of 16 mg/L at 1 m and 13 mg/L at near-bottom depths. Dissolved oxygen concentrations were ~ 1 mg/L higher throughout the water column during high tide than at low tide. However, it is unknown whether the differences between low and high tide data, varying on 6-h time scales, are due solely to tidal effects or to a combination of diel (e.g., photosynthesis, respiration) and tidal (e.g., advection, mixing) effects.

As mentioned earlier, interannual variation in DO was observed for Ecology seasonal and long-term data as well as for data from LOTT. Interannual variation in the yearly minimum for near-bottom DO concentration was ~1 mg/L for 1993 and 1994 seasonal data, ~ 0 to 4 mg/L for the Ecology long-term data, and ~ 0 to 2 mg/L for LOTT data (excluding 1993) at the inner bay stations located close to the Fiddlehead Marina (BI5, BUD002, LOTT-Fiddlehead) (Figures 42 and 43).

Spatial variation was about the same for both horizontal and vertical scales. Horizontal gradients from the inner to central bay (station BI5 values subtracted from station BC3 values) during low tide ranged from 0 to 8 mg/l at 1-m and 0 to 7 mg/L at near-bottom depths. Vertical DO gradients (near-bottom values subtracted from 1-m values) during low tide ranged from 2 to 9 mg/L in the inner bay (station BI5) and from 0 to 7 mg/L in the central bay (station BC3).

Conclusions

The interannual variability in water quality seen in Budd Inlet during our study period was probably due to both N-removal by LOTT and varying weather and river flow conditions.

Degree of Interannual Variation Associated with LOTT N-removal

Nutrients

The most obvious difference associated with the 88% removal of N in LOTT effluent was the pre-removal (1992-93) versus post-removal (1994) water column concentrations of dissolved ammonium-N and nitrate+nitrite-N. Ammonium-N concentrations in the surface waters of the inner bay showed the most dramatic reductions (86% at station BI4), and this reduction was evident, although smaller, farther out in the bay (64% at station BB2). Nitrate+nitrite-N concentrations also showed significant reductions (~75%) in both the inner and central bays. Orthophosphate-P levels were also slightly reduced (23%) in LOTT effluent and reductions were seen in orthophosphate-P concentrations at 1-m depths in the inner bay (33% at station BI4).

Phytoplankton

Phytoplankton concentrations did not show reductions from the pre-removal to the post-removal years. Phytoplankton concentrations were actually lower in the inner bay in 1993 than in 1992 and 1994. Concentrations in the central bay were similar for all three years. It appears that incident radiation (percent sky cover) had a very strong influence in regulating phytoplankton abundance in addition to stratification and water temperature. However, nutrients did show a limiting effect in 1994. The nutrient addition primary production experiment done during September 1994 showed that N was limiting to phytoplankton growth in the central bay. This indicates that had N reduction not occurred, phytoplankton concentrations would likely have been higher during 1994.

The decrease in nutrient concentrations in 1994 may have altered phytoplankton species composition. For example, the lower 1994 abundances of *Heterosigma carterae*, a species that can cause harm to fish and oyster larvae, were possibly due to lower N levels since growth of *H. carterae* is influenced by N concentration (Nishijima and Hata, 1984). However, since variability can be high particularly when considering sporadic bloom events, and this data set is small, no conclusions regarding phytoplankton species changes can be drawn.

Dissolved Oxygen

Dissolved oxygen concentrations were slightly lower in 1994 than in 1992 or 1993 in the inner bay, likely due to the high phytoplankton concentrations and high stratification seen in 1994. Again, had N-removal not commenced prior to spring 1994, it is likely that phytoplankton concentrations would have been even larger, causing DO concentrations to drop even lower.

Degree of Interannual Variation Associated with Weather and River Flow Conditions

Hydrography

Relative stratification was weaker in 1993 than in 1992 or 1994 due to high winds promoting mixing in spring and due to low precipitation causing less freshwater input to the surface waters in summer. Salinity was generally lowest in 1993, except for the inner bay where the 1-m salinities during July through October were the highest seen for the three years (Table 5). Low surface salinities during spring 1993 were due to high precipitation and high river flows. Low near-bottom salinities in 1993 were due the increased mixing of saltier deeper waters with fresher surface waters during this year. The high 1-m salinities seen in the inner bay during summer 1993 were also due to this increased vertical mixing as well as to the lower precipitation during this time. Water temperatures were generally lower during 1993 than during 1992 or 1994 due to lower air temperatures.

Nutrients

Weather conditions may have indirectly affected nutrient concentrations by influencing hydrography (particularly stratification) in Budd Inlet. However, it should be noted that changes in nutrient concentration due to stratification are much smaller than changes associated with removal by LOTT. Weaker stratification allows nutrients to be better mixed throughout the water column. Weaker stratification in 1993 may explain why near-bottom nutrients were depleted for a shorter duration in 1993 than in 1992 or 1994 (particularly).

Weather conditions also indirectly affect nutrient concentrations by influencing phytoplankton growth. The shorter duration of nutrient depletion in 1993 likely reflects less nutrient uptake due to lower phytoplankton concentrations. Also, nutrients at depth may have been utilized less in 1993 due to lower concentrations of migrating dinoflagellates seen that year, especially compared to 1992.

Phytoplankton

Because of the greater percent sky cover, less light was available in 1993, resulting in fewer phytoplankton. The lower water temperatures and decreased stratification in 1993 also likely caused a decrease in phytoplankton growth.

Higher concentrations of *Ceratium fusus*, a large vertically migrating dinoflagellate, were seen during 1992 compared to 1993 with intermediate concentrations in 1994. *C. fusus* concentrations likely responded to higher water temperatures, density stratification and nutrient gradients in 1992, since dinoflagellate growth is favored by warm stratified waters (Zevenboom et al., 1991).

Dissolved Oxygen

Near-bottom DO concentrations were slightly higher in 1993 than in 1994. Weaker stratification in 1993 may have allowed water with a higher DO content to be mixed down throughout the water column. Also, phytoplankton concentrations were lower in the inner bay during July through October 1993 thus providing less organic material to the bottom waters. Cooler bottom water temperatures in 1993 may lower the rate of nitrification and in turn reduce the amount of DO consumed in this process.

Short-term vs. Long-term Effect of N-removal on Low DO

Nitrogen removal by LOTT did not appear to immediately increase the concentration of DO in near-bottom waters during the months with lowest DO (July through October). The lack of an increase in DO was partially due to the weather conditions of 1994 resulting in high phytoplankton biomass and strong stratification, conditions highly favorable for low near-bottom DO. By not stimulating additional production, N-removal by LOTT may eventually allow the DO concentration in bottom waters of Budd Inlet to increase, however, the time scale for this change is not known. Nutrient release from the sediments may be a significant source and may take several years to exhaust. Interannual variability in weather conditions also influences the DO concentration; therefore, more time is necessary to determine the amount of improvement in DO from the LOTT N reductions. The extent of the remaining sources of N into Budd Inlet (particularly in the inner bay) such as the Deschutes River, LOTT and other non-point sources must be quantified and could be large enough to prevent DO concentrations from improving in the inner bay.

Recommendations

The main focus of Ecology's 1992-94 project was to determine the immediate effect of N-removal by LOTT on near-bottom DO in inner Budd Inlet. Short term effects observed after N-removal have been discussed in this report, however the long-term effects remain to be determined. An important result from this study is the extreme interannual variation due, in part, to weather-related differences in the three years studied. The influence of interannual climatic variability on DO must be further evaluated and quantified in order to predict the impact of N-removal on DO concentrations. In order to better evaluate long-term changes in DO concentration, the temporal variability over short time scales (diel or tidal) also needs to be determined since discrete survey data will have this inherent variation.

Mass balance models of nutrient and DO fluxes must be constructed based on measured boundary conditions and transfer rates. The data presented in this report can be used to calculate the impacts of nutrient additions to Budd Inlet, however additional data are required, such as Capitol Lake and Puget Sound inputs of nutrients. Starting in 1996, a comprehensive 13-month study was commissioned by LOTT to make such an assessment using both these and additional data collected from Budd Inlet. This study involves hydrographic, water quality and sediment modeling and mass budget calculations. Results of the study will be used to guide decisions regarding Budd Inlet's capacity for nutrients.

Further study of this system is highly recommended, not only for utility in establishing waste-load allocations for Budd Inlet but also because of the applicability regarding construction of similar wastewater treatment plants in southern Puget Sound and elsewhere.

Specific recommendations are:

1) Monitoring data must be collected over a longer period.

- With this longer data set, better determine the effects from interannual climatic variability on water quality so that effects due to N-removal can be deciphered. Better assess the effect of weather and river flow conditions on stratification and quantify the effect of stratification on DO concentration.

- Long-term monitoring is important to document long-term changes that may occur. For instance, N levels in Budd Inlet may decrease over time as N flux from the sediments to the overlying water reaches equilibrium (i.e. as the store of nutrients in the sediments becomes more exhausted).

2) Mass balance models of nitrogen and oxygen should be constructed for the inlet that include:

- Quantitative assessment of nutrient sources and sinks to further understand the effects of nutrient dynamics and LOTT N-removal in Budd Inlet;

- Quantitative assessment of the sources and sinks of DO;

- Quantitative assessment of the factors affecting phytoplankton growth and distribution since phytoplankton form the intermediate step between nutrient input and lowered oxygen levels.

Specific measurements are needed in order to make these assessments. Those being addressed by the 1996-7 LOTT study are:

- ◊ Advection, residence times and flushing in Budd Inlet.
- ◊ Nutrient and dissolved oxygen fluxes from the sediments and the influence of interannual and seasonal variability on these rates.
- ◊ Nutrient input to Budd Inlet from regeneration, LOTT effluent, Deschutes River/Capital Lake and any other point or non-point sources.
- ◊ Biochemical oxygen demand (BOD) rates.
- ◊ Oxygen produced from phytoplankton photosynthesis.
- ◊ Oxygen consumed by dinoflagellates that migrate down to bottom waters during the night.
- ◊ Oxygen consumed during nitrification.
- ◊ Oxygen transfer rates across the air-water interface (e.g., Balls et al, 1996).
- ◊ Tidal versus diel influences on DO. Since these processes operate on 25-h and 24-h cycles respectively, a moored sensor that can record data for weeks is necessary to deconvolute these effects.
- ◊ A mechanistic explanation for observed distribution of phytoplankton, which shows a lower concentration in the inner bay than in the central bay. Since the phytoplankton concentration is the net balance of growth and loss processes, it is necessary to determine whether growth is less in the inner bay or if loss processes are greater there.
- ◊ Primary production experiments with and without nutrient additions, in order to determine nutrient uptake rates as well as when and where nutrients (particularly N) are limiting to phytoplankton growth.
- ◊ Silicate concentrations, so that silicate limitation of diatom growth can be better assessed.
- ◊ The degree of tidal influence on the location of phytoplankton blooms. Ascertain whether blooms are simply advected in and out according to the tidal cycle, and thus tend to aggregate in an area. Limited high slack tide data indicate that the blooms tend to be located further in toward the head of the inlet during high tide as opposed to low tide.
- ◊ Phytoplankton species samples at inner and central bay areas at several depths, to see if differences between the inner and central bay phytoplankton concentration are due to differences in species composition.

3) Additional processes that may influence nutrient and oxygen cycling are not being directly measured by the 1996-7 LOTT study. The role of these should be evaluated:

- Quantify bacterial uptake and release of nutrients.
- Assess the grazing impact of planktonic and nonplanktonic organisms on phytoplankton biomass.
- Assess the impact of heterotrophic microbial organisms (bacteria and protozoa) on DO.

Develop news release	Getchell	June 8 – draft June ~~15~~ 29 – final issue date
Focus Sheet for mailing distribution ~~and web page posting~~	Phillips	Draft – June 12 Final – June ~~22~~ 23
Write letters to legislators	Getchell – draft Saunders -- final	Draft – June 16 Final – June ~~18~~ 23
Post focus sheet and 303(d) list on web page	Hilliard	June ~~19~~ 25
Contact with reporters	Getchell Saunders, Butkus be available Plus we should have lists by geographic areas prepared for distribution – via fax and posted on web page	June ~~23~~ 29

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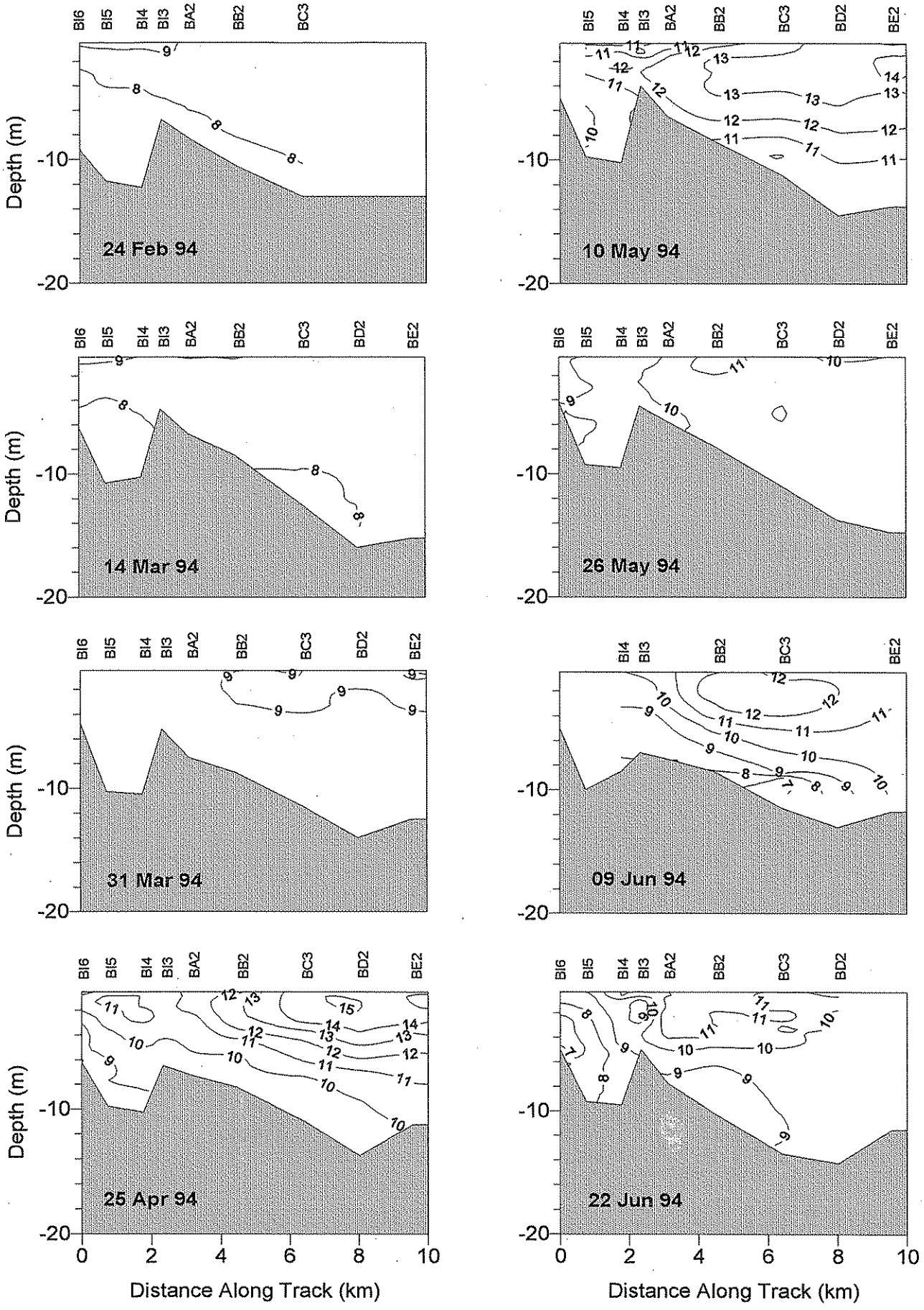
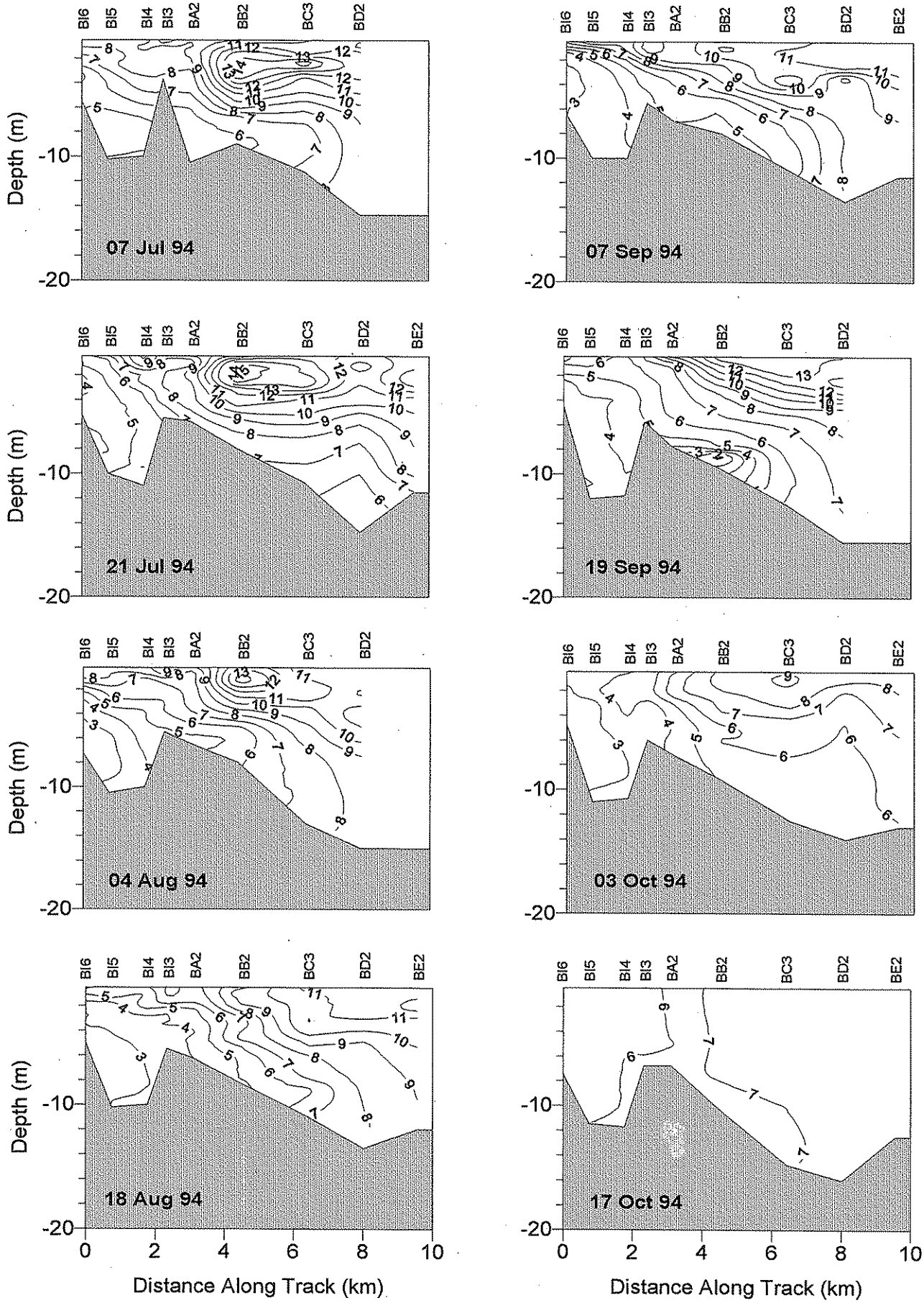
APPENDIX A

Vertical sections of dissolved oxygen data (mg/L) for 1994.

Data are from low tide transects from the head (station BI6) to the mouth (station BE2) of Budd Inlet. Shading indicates the sea bottom.


BI6
BI5
BI4
BI3
BA2
BB2
BC3
BD2
BE2
Depth (m)
-10
-20
24 Feb 94
10 May 94
14 Mar 94
26 May 94
31 Mar 94
09 Jun 94
25 Apr 94
22 Jun 94
0
2
4
6
8
10
Distance Along Track (km)


BI6
BI5
BI4
BI3
BA2
BB2
BC3
BD2
BE2
Depth (m)
-10
-20
07 Jul 94
07 Sep 94
21 Jul 94
19 Sep 94
04 Aug 94
03 Oct 94
18 Aug 94
17 Oct 94
0
2
4
6
8
10
Distance Along Track (km)
Distance Along Track (km)