

**LIMNOLOGICAL INFORMATION SUPPORTING THE  
DEVELOPMENT OF REGIONAL NUTRIENT CRITERIA FOR  
ALASKAN LAKES**

**Water Quality Monitoring and Trophic Assessment of Seven Lakes in the  
Matanuska-Susitna Borough**

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**REGIONAL INFORMATION REPORT No. 2A03-24**

**Alaska Department of Fish and Game  
Division of Commercial Fisheries  
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## ABSTRACT

Edmundson, J. A. 2002. Limnological information supporting the development of regional nutrient criteria for Alaskan lakes: water-quality monitoring and trophic assessment of seven lakes in the Matanuska-Susitna Borough. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 2A02-24:72p.

The gradual accumulation of nutrients and organic material in a waterbody accompanied by increased levels of production constitute the natural process of eutrophication. However, human activities can accelerate this process, which may create water quality problems. The most common symptoms of cultural eutrophication (excessive inputs of phosphorus and nitrogen nutrients) in lakes and reservoirs are increased growth of algae or rooted aquatic plants, decreased water transparency, low levels of dissolved oxygen, and fish kills. Although eutrophication is a common problem across the nation, specific responses to over-enrichment in a lake depend on the geographical and climatological setting and the nature of the watershed or catchment. Therefore, to reduce problems associated with excessive nutrients in lakes and reservoirs, U.S. Environmental Protection Agency (EPA) is currently developing criteria for water quality and nutrients on an ecoregional basis. However, nutrient criteria for cold regions, such as subarctic Alaska have not been fully developed. In 2001, a water quality and trophic assessment of seven urban lakes in the Matanuska-Susitna Borough, southcentral Alaska, was implemented as part of the nationwide program for establishing nutrient criteria. Salient limnological variables (e.g., transparency, nutrients, and algal biomass) were measured five times from May through October. Collectively, there was a strong dependence of algal biomass on total phosphorus, suggesting phosphorus was the primary nutrient limiting productivity. In turn, water transparency was regulated mostly by phytoplankton (chlorophyll) rather than inorganic turbidity or color. Five of the lakes developed mid-summer thermal stratification, which was accompanied by hypolimnetic oxygen depletion and vertical heterogeneity in nutrient concentration and algal pigments. Five lakes were considered oligomesotrophic, whereas two were mesoeutrophic. These data will be subsequently used to aid development of appropriate regional nutrient criteria for Alaskan lakes.

## INTRODUCTION

Eutrophication is the process of enrichment of waterbodies by nutrients. In many regions of the United States, eutrophication and its associated symptoms are a primary concern for lake and fishery resource managers. Although nutrient loading and subsequent changes in trophic state occur naturally, anthropogenic influences can accelerate this process. For example, excessive runoff and pollution from impervious surfaces like parking lots and roads, alteration of natural water flow created by flood control structures or channelization, fertilizer drainage from agricultural and recreational areas, and untreated sewage effluents or leachates from landfills have the potential to increase phosphorus and nitrogen concentrations of a water body. In lakes and reservoirs, overloading of nutrients from the watershed can lead to undesirable water quality conditions such as extreme algal growth (i.e., noxious blooms), murky water, hypolimnetic oxygen depletion (anoxia), production of offensive odors, and fish kills.

Most freshwater systems are limited by phosphorus, but they can be co-limited by nitrogen when phosphorus concentrations are very high. That is, the addition of more phosphorus tends to produce higher water column phosphorus concentrations, greater algal biomass, and decreased water transparency. Under conditions of nitrogen limitation, cyanobacteria or blue-green algae can outcompete other phytoplankton thereby increasing the likelihood of nuisance or toxic algal blooms. As such, water quality is often specified or described by three criteria: (1) total phosphorus and nitrogen concentration, (2) the amount of free-floating algae, measured as the concentration of the green plant pigment chlorophyll *a*, and (3) transparency, determined by the Secchi disk depth and subsequently assigned one of several trophic states; e.g., dystrophic, oligotrophic, mesotrophic, eutrophic, or hypereutrophic (Wetzel 1983; Nürnberg 1996).

Although a lake can be classified as nutrient rich (eutrophic) to nutrient poor (oligotrophic), Carlson (1977) proposed a trophic state index (TSI) based on any one of the variables total phosphorus, chlorophyll, and Secchi depth, assuming all of the variables are interrelated. For a specific lake, the TSI assigns a value rather than a classification or grouping associated with water quality conditions. However, because water clarity in some lakes is controlled by non-algal particles, TSI is of limited use particularly in lakes with high concentrations of suspended inorganic sediments, glacial silt or yellow color (Brezonik 1978; Megard et al. 1980; Koenings and Edmundson 1991). For 25 Alaskan lakes, Edmundson et al. (2000) found that TSI values have predictive capabilities only after water transparency, nutrient concentrations, and chlorophyll *a* are considered along with information on the nature of the water source (i.e. lake typology effects). Other important influences on lake processes and nutrient levels are related to hydrologic conditions. Vollenweider (1976) suggested that definition of trophic status should rely on a combination of phosphorus loading, mean depth, and water residence time.

Whatever the particular method or classification scheme designed for lakes, there is often a strong dependence of algal biomass on phosphorus. Over the past three decades, many

empirical relationships have been derived using large data sets from groups of lakes spanning many geographic regions linking total phosphorus concentration to shifts in trophic state (e.g., Sakamoto 1966; Dillon and Rigler 1974; Canfield 1983; Watson et al. 1992; Havens and Mazumder 1999). These phosphorus-chlorophyll *a* regression models are widely used today to help forecast lake water quality responses to changing loading rates, as well as to predict the potential impact of increased development within a lake watershed (Dillon 1975). However, among a particular set of lakes covering a broad geographic gradient, algal biomass can vary by more than an order of magnitude for a given level of total phosphorus. The error associated with specific phosphorus-chlorophyll regression models has been attributed to effects of light limitation (Hoyer and Jones 1983), influences of abiotic particles on phosphorus cycles (Hoyer and Jones 1983), nitrogen limitation (McCauley et al. 1989), differences in thermal structure (Riley and Prepas 1985; Mazumder 1994a), and the extent of zooplankton grazing (Mazumder 1994b). In Alaska, Edmundson and Carlson (1998) showed that chlorophyll response to changing phosphorus levels was strongly tied to lake typology factors. That is, chlorophyll *a* yield per unit total phosphorus was significantly less in stained (colored) and glacial (turbid) lakes compared to clear lakes. Therefore, development of regional values for water transparency, nutrients and algal biomass may make local application of nutrient-phytoplankton models more reliable for lake managers than such models derived from larger geographic areas.

The Matanuska-Susitna (Mat-Su) region of southcentral Alaska contains numerous lakes that vary with respect to their limnological characteristics, all of which influence their water quality and trophic state (Woods 1985b; Edmundson et al. 2000). These lakes represent a valuable natural resource to one of the most populated areas of the state. Lakes in this region offer multiple recreational opportunities including swimming, boating and wildlife viewing. In addition, many of the lakes support populations of anadromous salmon and resident fish species that are increasingly sought after in commercial, recreational, personal use, and subsistence fisheries. However, in the last two decades, the Mat-Su region area has seen considerable growth and development (BLCAC 1998). Consequently, many of these lakes are now accessible by road and many of the watersheds have been developed with seasonal and year-round residences. Changes to such urban lakes can include shoreline alteration, fishing impacts, and the accumulation of nutrients from anthropogenic sources. Eutrophication symptoms have been documented in a few of these lakes (Woods 1985a; Woods 1986; Edmundson et al. 1989). In addition, there has been discussion of constructing a causeway linking the city of Anchorage with Point MacKenzie, thereby increasing the potential for significant land use and hydrologic changes to the watersheds and subsequent impacts on the water quality of lakes in this area.

In order to better manage and protect lakes, water quality, nutrient levels, algal biomass and associated trophic state must be evaluated and classified on a regional basis to take into account differences in climate, geochemistry, morphometry, and lake usage. Because the ecological context of a lake has an important influence on its attainable water quality conditions or trophic state, development of regional nutrient criteria could provide a better means to assess or predict the degree of change in the trophic state of a lake

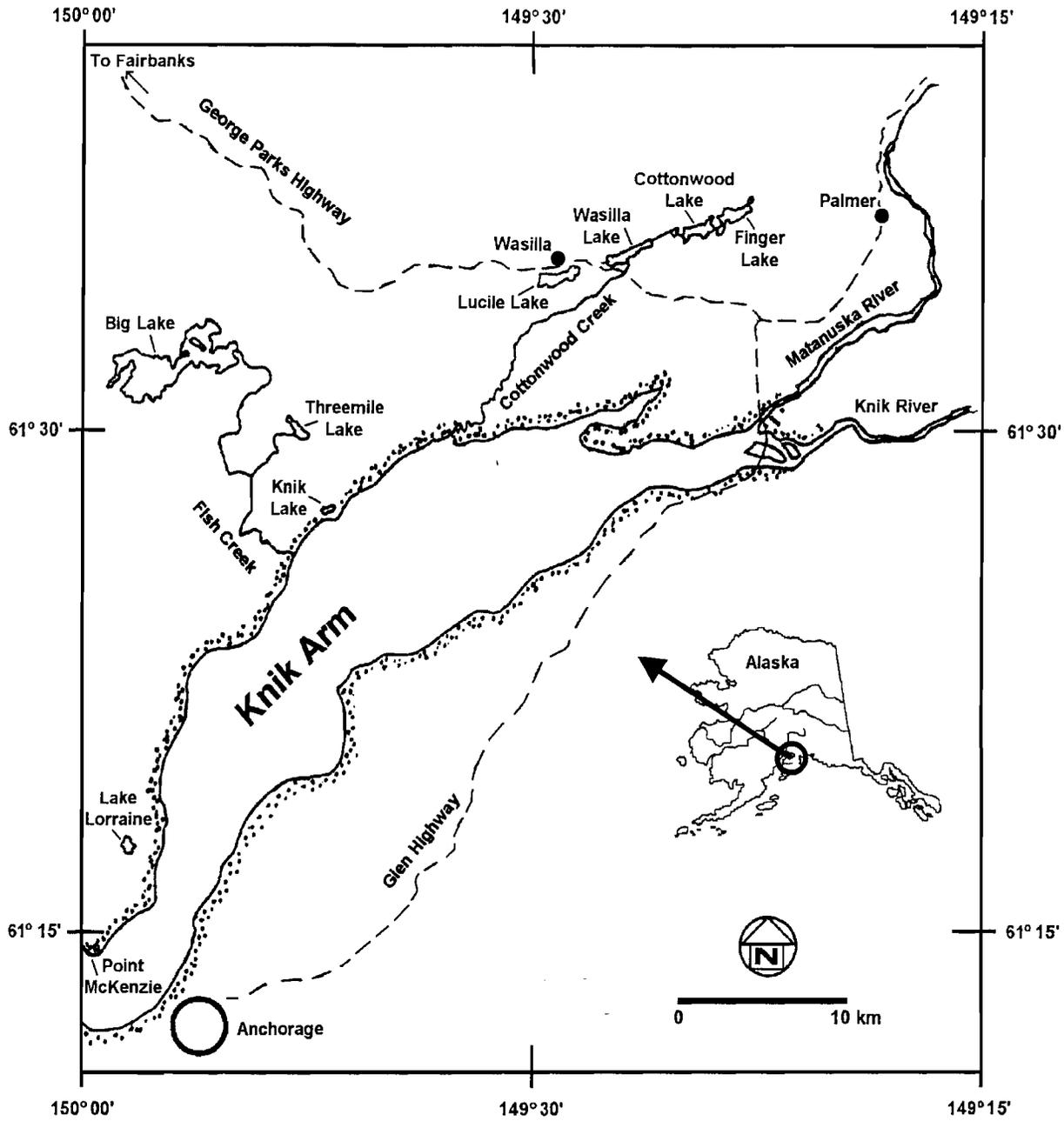
ecosystem arising from an alteration in the concentration of key limiting nutrients (Cooke et al. 1993; Gibson et al. 2000). Thus, the overall goal of this project was to obtain pertinent limnological information from a variety of lakes within the Mat-Su region. These data are to be used to aid in the subsequent development of regional nutrient criteria for Alaskan lakes. This project is part of a larger national program administered by the United States Environmental Protection Agency (EPA) for describing ecoregional nutrient criteria addressing lakes and reservoirs across the nation. The ecoregion framework for lake management is a classification method that considers the geographical and ecological setting as important determinates of attainable or realistic water quality conditions or trophic state (Gibson et al. 2000).

### ***Objectives***

Our primary objective was to implement a data-gathering program to collect limnological information from a variety of lakes spanning a range in trophic state within the Mat-Su region. We developed databases on morphometry, light penetration and water clarity, temperature, dissolved oxygen concentration, water chemistry, nutrient (nitrogen and phosphorus) concentrations, algal biomass (chlorophyll *a*) levels, and algal community composition. Herein, we (1) report on these limnological data for seven selected lakes relative to their trophic status, (2) derive empirical relationships between salient lake variables, and (3) make recommendations for future studies aimed at developing appropriate ecoregional nutrient criteria for lakes.

### ***Description of Study Site***

The locations of the seven study lakes (Big, Cottonwood, Finger, Knik, Lorraine, Threemile and Wasilla lakes) are shown in Figure 1. These lakes are situated in southcentral Alaska within the Mat-Su River valleys. The study area falls within the transitional climatic zone, which includes the northern part of Cook Inlet and the regions south of the Alaska Range and west of the Talkeetna Mountains. Average air temperatures for the area range from  $-14\text{ }^{\circ}\text{C}$  to  $-10\text{ }^{\circ}\text{C}$  in January and from  $8\text{ }^{\circ}\text{C}$  to  $19\text{ }^{\circ}\text{C}$  in July. The mean annual precipitation for the Mat-Su area is around 40 cm. Big Lake is part of the Fish Creek watershed, which empties into western side of Knik Arm. Its shoreline is extensively developed with private residences. Threemile Lake is also located within the Fish Creek drainage; however its outlet is barred. Cottonwood and Wasilla lakes form part of the Cottonwood Creek drainage that also empties into Knik Arm. Most of the shoreline of Cottonwood Lake is privately owned, whereas both private lands and some commercial property surround Wasilla Lake. Finger Lake is a seepage lake located within the same drainage, but it is landlocked from Cottonwood Creek. On the northwestern edge of Knik Arm lies Knik Lake, which is also a landlocked system. The majority of this lake's shoreline is privately owned. Lorraine Lake is a landlocked system situated near the tip of Point McKenzie and it is surrounded by Mat-Su Borough land. Morphometric characteristics of the seven study lakes are summarized in Table 1. Big Lake is the largest in surface area ( $12.1\text{ km}^2$ ) and also the deepest (mean depth 9.0 m) of the seven lakes. All of the other lakes are less than  $2\text{ km}^2$



**Figure 1.** Location of the seven study lakes within the Matanuska-Susitna Borough: Big, Cottonwood, Finger, Knik, Lorraine, Threemile, and Wasilla lakes.

**Table 1.** Comparison of morphometric characteristics of the seven study lakes.

Lake	Latitude (N)	Longitude (W)	Elevation (m)	Area (km <sup>2</sup> )	Mean depth (m)	Maximum depth (m)	Volume (×10 <sup>6</sup> m <sup>3</sup> )	Shoreline length (km)
Big	61° 31'	149° 59'	43	12.1	9.0	27.0	111.9	41.8
Cottonwood	61° 35'	149° 19'	100	1.1	3.3	12.0	3.5	6.3
Finger	61° 37'	149° 15'	337	1.5	4.7	13.4	6.9	12.6
Knik	61° 27'	149° 43'	12	0.2	5.8	11.3	1.2	2.4
Lorraine	61° 17'	149° 57'	67	0.5	2.8	7.3	1.5	3.7
Threemile	61° 30'	149° 46'	38	0.5	1.0	4.6	0.5	4.2
Wasilla	61° 35'	149° 24'	98	1.5	5.2	14.6	7.9	7.1

in area and fairly shallow with mean depths less than 6 m. Depth-contour (bathymetric) maps of each lake are shown in Figures 2-8. Alaska Department of Fish and Game (ADF&G), Sport Fish Division, conducts fish stocking programs in many of these lakes. The following game fishes are deemed present in some or all of the seven lakes: rainbow trout *Oncorhynchus mykiss* (all seven lakes), Arctic char *Salvelinus alpinus* (Big and Finger lakes), Arctic grayling *Thymallus arcticus* (Finger, Knik, and Lorraine lakes), Dolly Varden *Salvelinus malma* (Cottonwood and Wasilla lakes), burbot *Lota lota* (Big Lake), coho salmon *Oncorhynchus kisutch* (Big, Cottonwood, Threemile, and Wasilla lakes), landlocked coho (Knik Lake) landlocked king salmon *Oncorhynchus tshawytscha* (Finger Lake), sockeye salmon *Oncorhynchus nerka* (Cottonwood and Wasilla lakes), and northern pike *Esox lucius* (Big and Knik lakes).

## METHODS

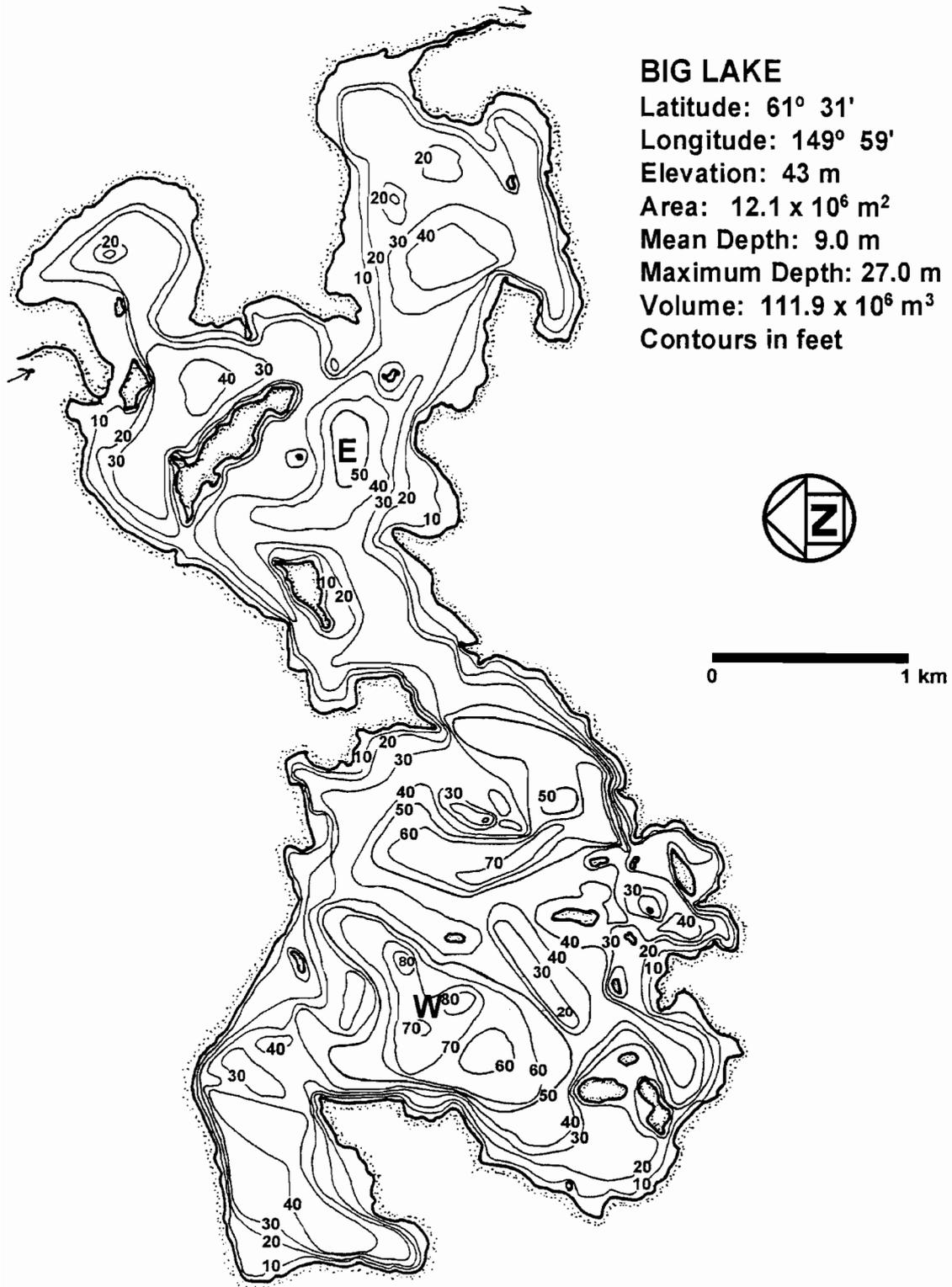
### *Data Gathering*

Big, Cottonwood, Finger, Threemile and Wasilla lakes were sampled five times (29-30 May, 27-28 June, 31 July-01 August, 04-05 September, and 08-09 October) during the 2001 open-water season (May-October). Both Knik Lake and Lorraine Lake were sampled four times. That is, Knik Lake was not sampled during the 27-28 May survey and Lake Lorraine was not sampled during the 08-09 October survey. We established two sampling sites (east and west basin) in Big Lake and Wasilla lakes with the other lakes each having a single mid-lake sampling location. The sampling stations were established at the deepest point of the major basin(s) and during surveys the sites were located using a global positioning system. Bathymetric maps and morphometric data for Big, Cottonwood, Finger, and Wasilla lakes were obtained from Spafard and Edmundson (2000). The original bathymetric maps and morphometric information for Knik, Lorraine, and Threemile lakes were available from ADF&G, Sport Fish Division's "Lake Maps Series", which can be accessed electronically via the worldwide web at <http://www.sf.adfg.state.ak.us/region2/lakemaps/html/lakemap1.stm>.

Fore each lake survey, we obtained vertical profiles of underwater light penetration, water temperature, and dissolved oxygen. Measurements of underwater irradiance ( $I$ ), expressed in terms of energy units ( $\mu\text{mols}$ , photons), at 0.5- or 1.0-m increments were obtained using a Li-Cor Li250 submarine photometer equipped with a quantum sensor (400-700 nm). The rate of attenuation of  $I$  with depth ( $d$ ) is  $K_d$ , the vertical light-extinction coefficient, and was calculated from the equation:

$$I_d = I_0 e^{-K_d d} \text{ or } \ln I_0 - \ln I_d = K_d d,$$

where  $I_0$  is the irradiance at the surface and  $I_d$  is the irradiance at depth,  $d$  (Kirk 1994). The depth of 1% light penetration or euphotic zone depth (EZD) was given by  $4.6/K_d$  (Kirk 1994). Water transparency was measured with a 20-cm black and white Secchi



**Figure 2.** Bathymetric map of Big Lake showing the location of the east (E) and west (W) limnological sampling sites.

**COTTONWOOD LAKE**

Latitude: 61° 35'

Longitude: 149° 19'

Elevation: 100 m

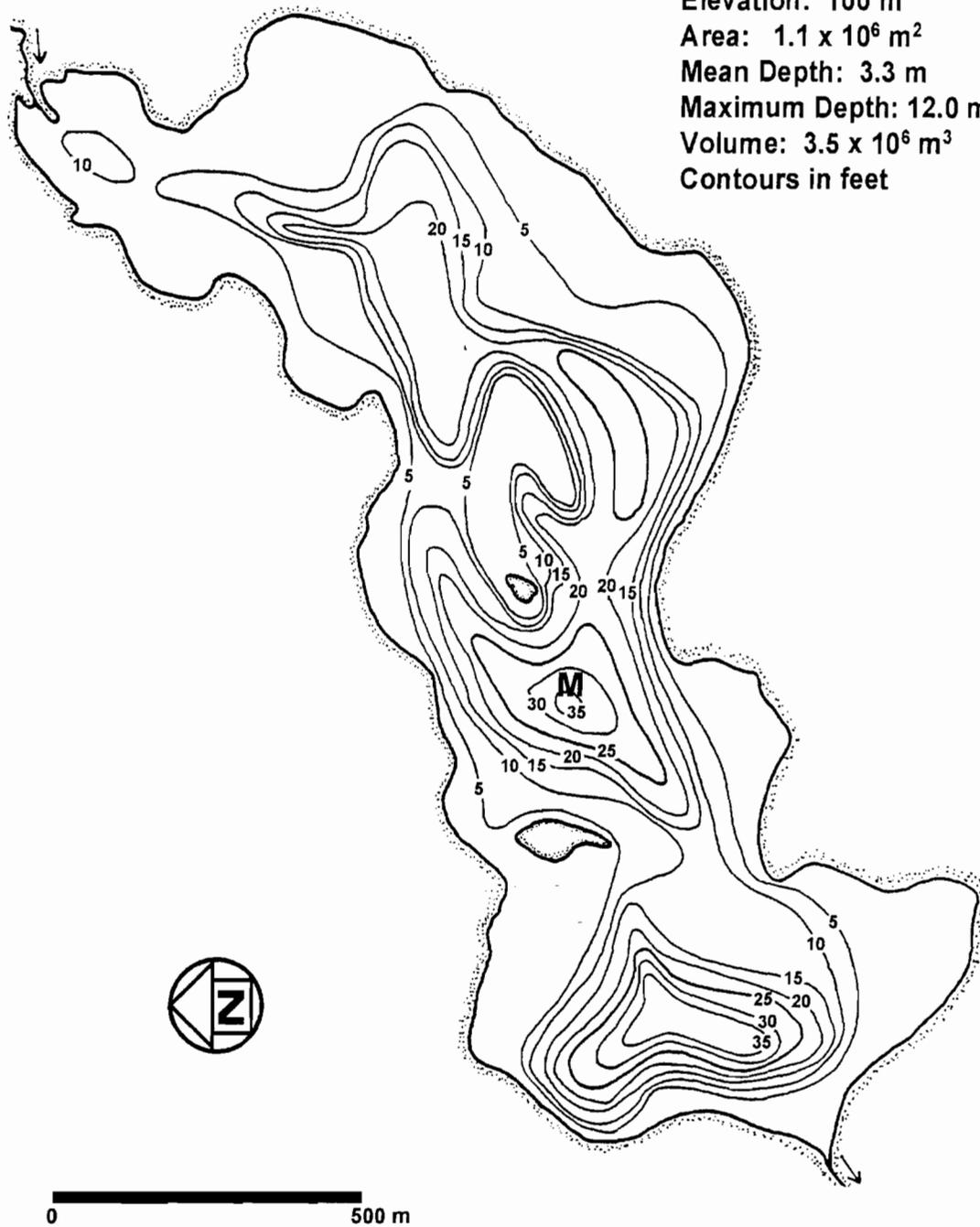
Area:  $1.1 \times 10^6 \text{ m}^2$

Mean Depth: 3.3 m

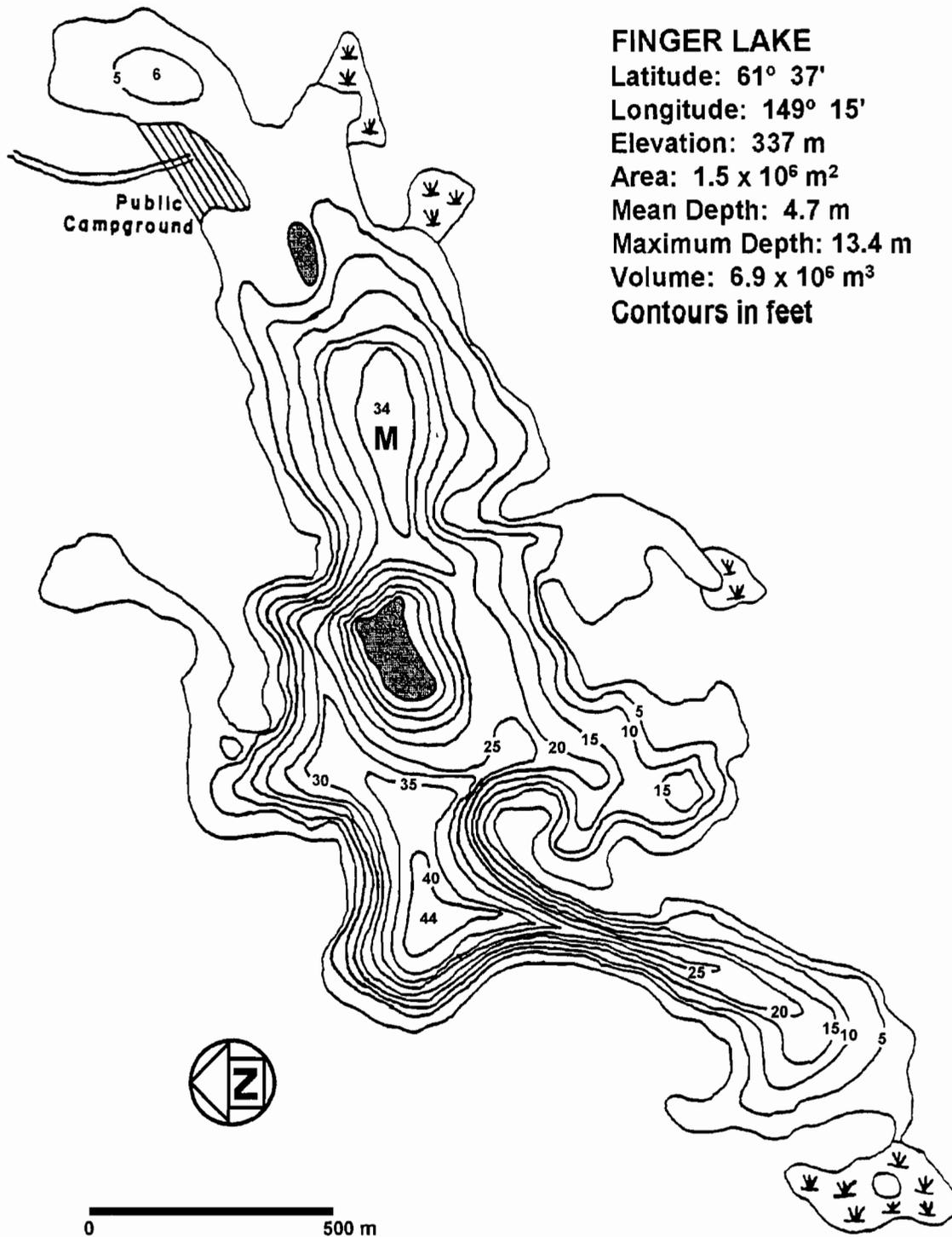
Maximum Depth: 12.0 m

Volume:  $3.5 \times 10^6 \text{ m}^3$

Contours in feet



**Figure 3.** Bathymetric map of Cottonwood Lake showing the location of the limnological sampling site (M).



**Figure 4.** Bathymetric map of Finger Lake showing the location of the limnological sampling site (M).

## KNIK LAKE

Latitude: 61° 27'

Longitude: 149° 43'

Elevation: 12 m

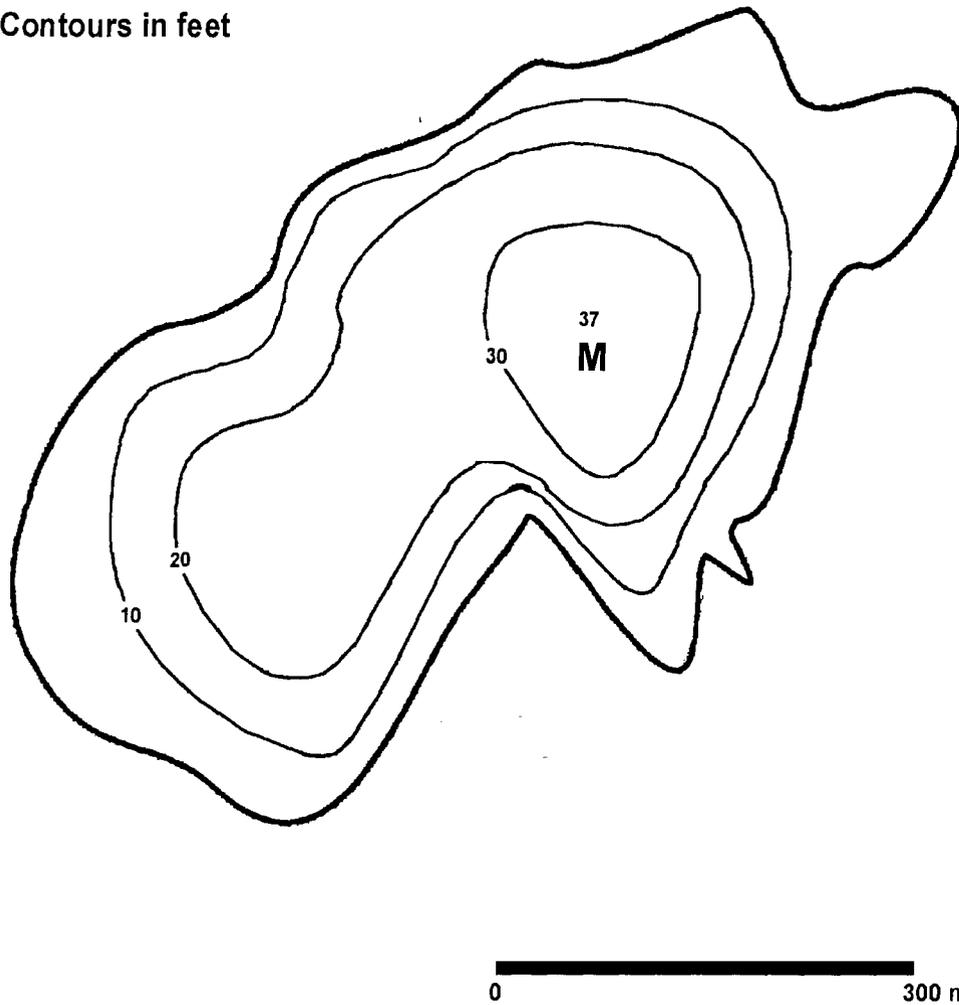
Area:  $0.2 \times 10^6 \text{ m}^2$

Mean Depth: 5.8 m

Maximum Depth: 11.3 m

Volume:  $1.2 \times 10^6 \text{ m}^3$

Contours in feet



**Figure 5.** Bathymetric map of Knik Lake showing the location of the limnological sampling site (M).



### LORRAINE LAKE

Latitude: 61° 17'

Longitude: 149° 57'

Elevation: 67 m

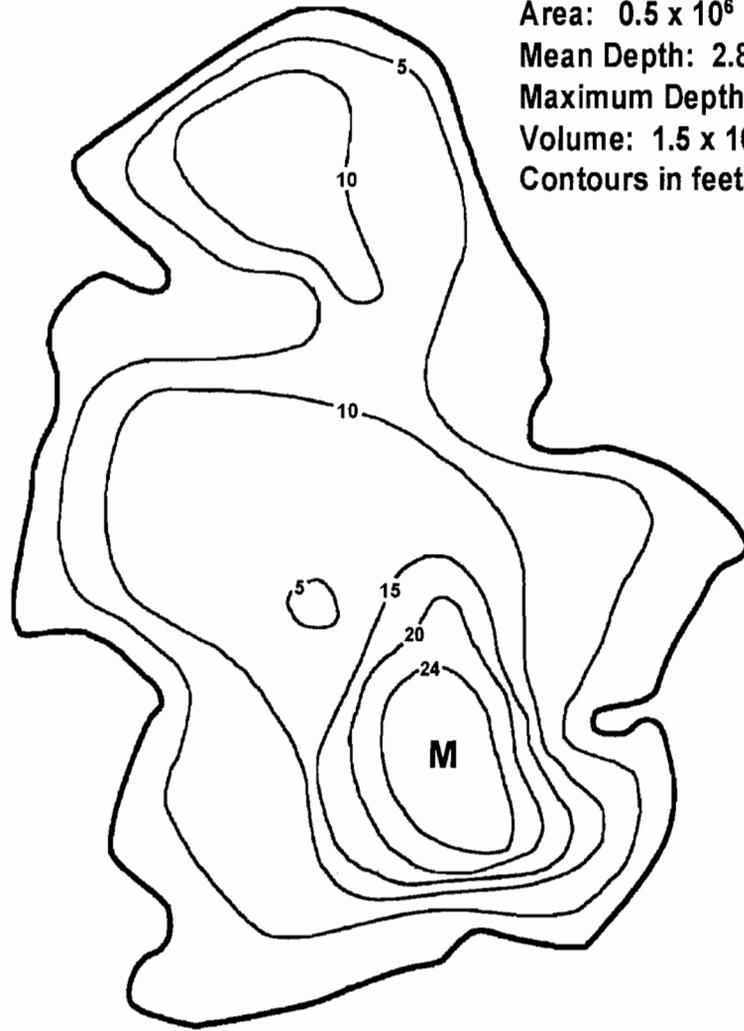
Area:  $0.5 \times 10^6 \text{ m}^2$

Mean Depth: 2.8 m

Maximum Depth: 7.3 m

Volume:  $1.5 \times 10^6 \text{ m}^3$

Contours in feet



**Figure 6.** Bathymetric map of Lorraine Lake showing the location of the limnological sampling site (M).



### THREEMILE LAKE

Latitude: 61° 30'

Longitude: 149° 46'

Elevation: 38 m

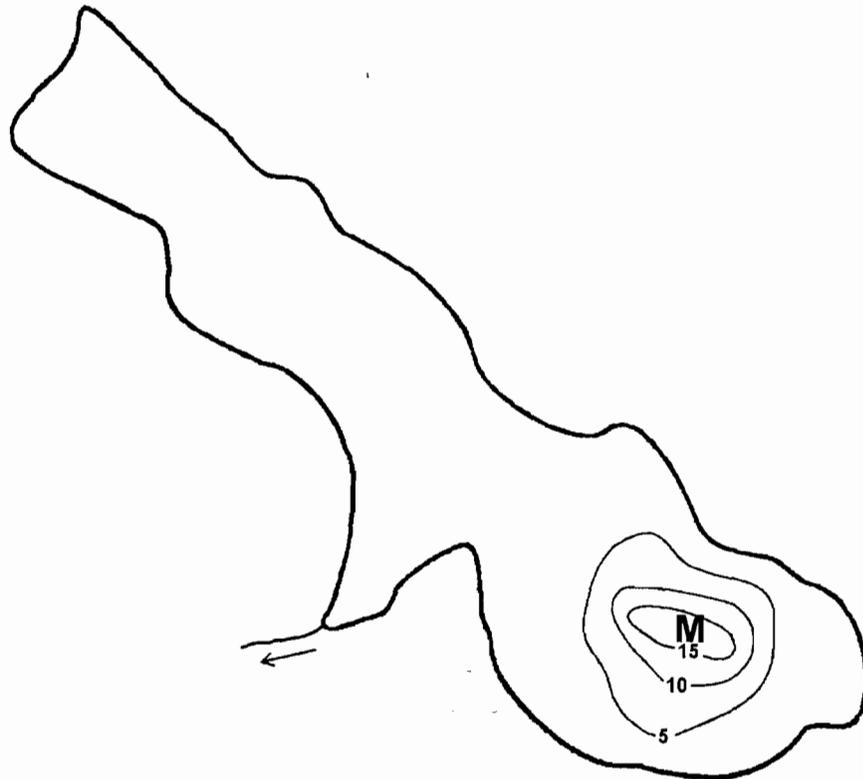
Area: 0.5 x 10<sup>6</sup> m<sup>2</sup>

Mean Depth: 1.0 m

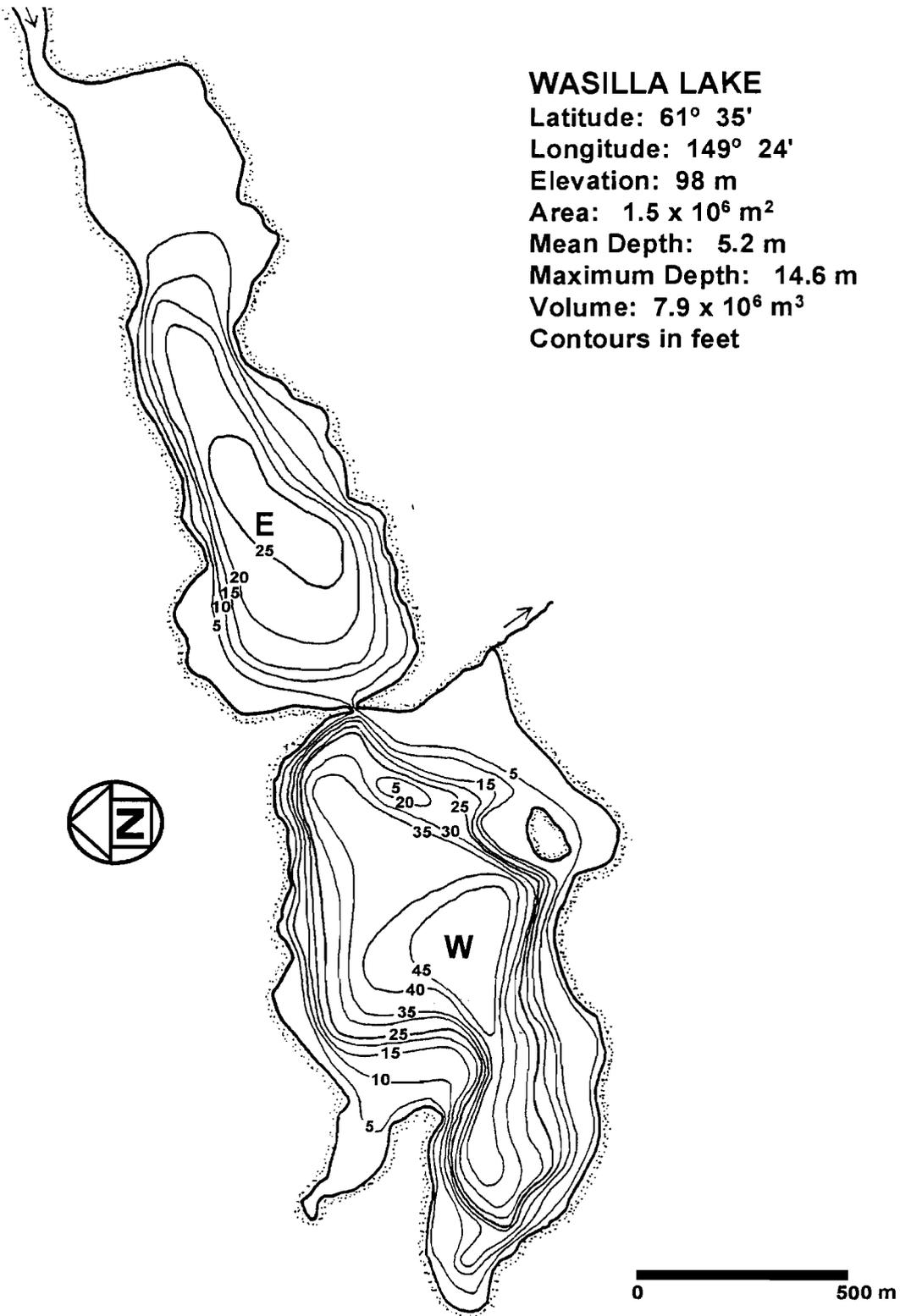
Maximum Depth: 4.6 m

Volume: 0.5 x 10<sup>6</sup> m<sup>3</sup>

Contours in feet



**Figure 7.** Bathymetric map of Threemile Lake showing the location of the limnological sampling site (M).



**Figure 8.** Bathymetric map of Wasilla Lake showing the location of the east (E) and west (W) limnological sampling sites.

disk. Vertical profiles of temperature were measured at 1-m increments from the surface to the lake bottom using a YSI model oxygen analyzer equipped with a thermistor. On each survey, the oxygen content of the surface water, measured using the Winkler method (APHA 1985), was used to calibrate the oxygen probe (sensor).

Water samples were collected from the 1-m depth and at approximately 75% of the total depth using an opaque Van Dorn type sampler. Bulk water samples collected at the field sites were kept cool and dark, transported to a temporary laboratory in Wasilla, and prepared for laboratory analysis. Separate sub-samples from each station were: 1) refrigerated for general tests; 2) frozen for Kjeldahl nitrogen and total phosphorus analysis; and 3) filtered for analysis of dissolved nutrients (nitrogen and phosphorus) and color. In addition, seston samples for the analysis of particulate organic carbon and chlorophyll *a* were obtained by filtering one liter of water each through a separate Whatman 4.7 cm GFF glass fiber filter. Individual filters were stored frozen in Plexiglas petri-slides until analyzed. We also added 1-2 ml of magnesium carbonate to the filter for chlorophyll *a* analysis to prevent possible acidification and conversion to phaeopigments during storage. For the May and October surveys, an additional 100 ml sample of water was collected from the 1-m stratum to which 2 ml of Lugol's acetate solution were added as a photosynthetic and metabolic fixative. These samples were subsequently used for phytoplankton enumeration.

In the ADF&G Central Region Limnology laboratory in Soldotna, conductivity (temperature compensated to 25 °C) was measured using a YSI conductivity meter, and pH was measured with an Orion model 420A pH meter equipped with an automatic temperature compensation probe. Alkalinity was determined by acid (0.02 N H<sub>2</sub>SO<sub>4</sub>) titration to pH 4.5 units. Turbidity, expressed as nephelometric turbidity units (NTU) was measured with a formazin calibrated HF model 00B meter, and color was determined on a filtered (GFF) sample by measuring the spectrophotometric absorbance at 400 nm and converting to equivalent platinum cobalt (Pt-Co) units. Calcium and magnesium were determined from separate EDTA (0.01 N) titrations, and total iron was analyzed by reduction of ferric iron with hydroxylamine during hydrochloric acid digestion. Reactive silicon was determined using the method of ascorbic acid reduction to molybdenum blue. Filterable reactive phosphorus (FRP), which corresponds more closely with orthophosphate in lake water, was analyzed by the molybdenum blue/ascorbic acid reduction procedure as modified by Eisenreich et al. (1975). Total phosphorus (TP) utilized the FRP procedure after acid-persulfate digestion. Nitrate + nitrite was analyzed as nitrite following cadmium reduction, and total ammonia utilized the phenylhypochlorite methodology. Total Kjeldahl nitrogen (TKN) was determined as ammonia following acid-block digestion. We computed total nitrogen (TN) as the sum of TKN and nitrate + nitrite. For particulate organic carbon (POC), we employed the wet oxidation technique of Newell (1982), which used potassium dichromate as the oxidant followed by spectrophotometric measurement (440 nm) of the resultant yellow dichromate solution. For analysis of chlorophyll *a* (chl *a*), we extracted algal pigments by grinding the filters in buffered 90% acetone and refrigerating (4 °C) the slurry in the dark for 2 hr. Following centrifugation, chl *a* concentration (corrected for inactive phaeophytin) was determined by the fluorometric procedure using a calibrated (Sigma Co. chl *a* standards)

Turner model 112 fluorometer (Koenings et al. 1987). The low-strength acid addition recommended by Riemann (1978) was used to estimate phaeophytin. All chemical and nutrient methodologies are detailed in Koenings et al. (1987) and current quality control charts and statistical evaluation of analytical methodologies can be found in Edmundson and Todd (2001). Determination of biomass and composition of phytoplankton was conducted by Kate Howell (<http://web.uvic.ca/~h2o/katy2.htm>), University of Victoria, Environmental Management of Drinking Water Reservoirs Program using the Utermöhl sedimentation technique and inverted microscopy on Lugol's preserved samples.

### ***Database, Statistical Analysis, Trophic State Index***

We compiled a database of general water chemistry, nutrient concentration, and algal pigments (Appendix A and B). For all analytes, we replicated the sample analysis. Data reported in the appendices are the mean values. For the purposes of discussion and reporting herein, we mainly focused on data from the 1-m depth, as these data are the most comparative from lake to lake. That is, deeper water samples were collected from varying depths in the different lakes. Least squares regression analysis was used to test the functional relationship between pairs of variables with a significance level of  $\alpha = 0.05$ . For total nutrient (phosphorus and nitrogen)-chl *a* modeling, we used all data from the seven lakes derived from the 1-m stratum rather than seasonal mean values. We also evaluated the importance of both phosphorus and nitrogen in accounting for the variance in chl *a* using backward elimination, a stepwise regression technique (Neter et al. 1990). The significance for retaining variables was  $\alpha = 0.1$ . When appropriate, data were transformed to  $\log_{10}$  values prior to statistical analysis to meet the empirical requirements of residual normality and constant variance. We used one-way analysis of variance (ANOVA) with depth (i.e., 1-m versus hypolimnion) as a categorical variable to test for differences in TP, TN, and chl *a* concentration between the two depths. All statistical analyses were conducted using SYSTAT version 10. In addition, we computed Carlson's (1977) trophic state index (TSI) values for each lake based on Secchi depth (SD), total phosphorus (TP), and chlorophyll *a* (CHL) concentration using the data from individual surveys rather than using seasonal mean values. The Carlson's TSI equations are:

$$\text{TSI (SD)} = 10 \left( 6 - \frac{\ln SD}{\ln 2} \right)$$

$$\text{TSI (TP)} = 10 \left( 6 - \frac{\ln \left( \frac{48}{TP} \right)}{\ln 2} \right)$$

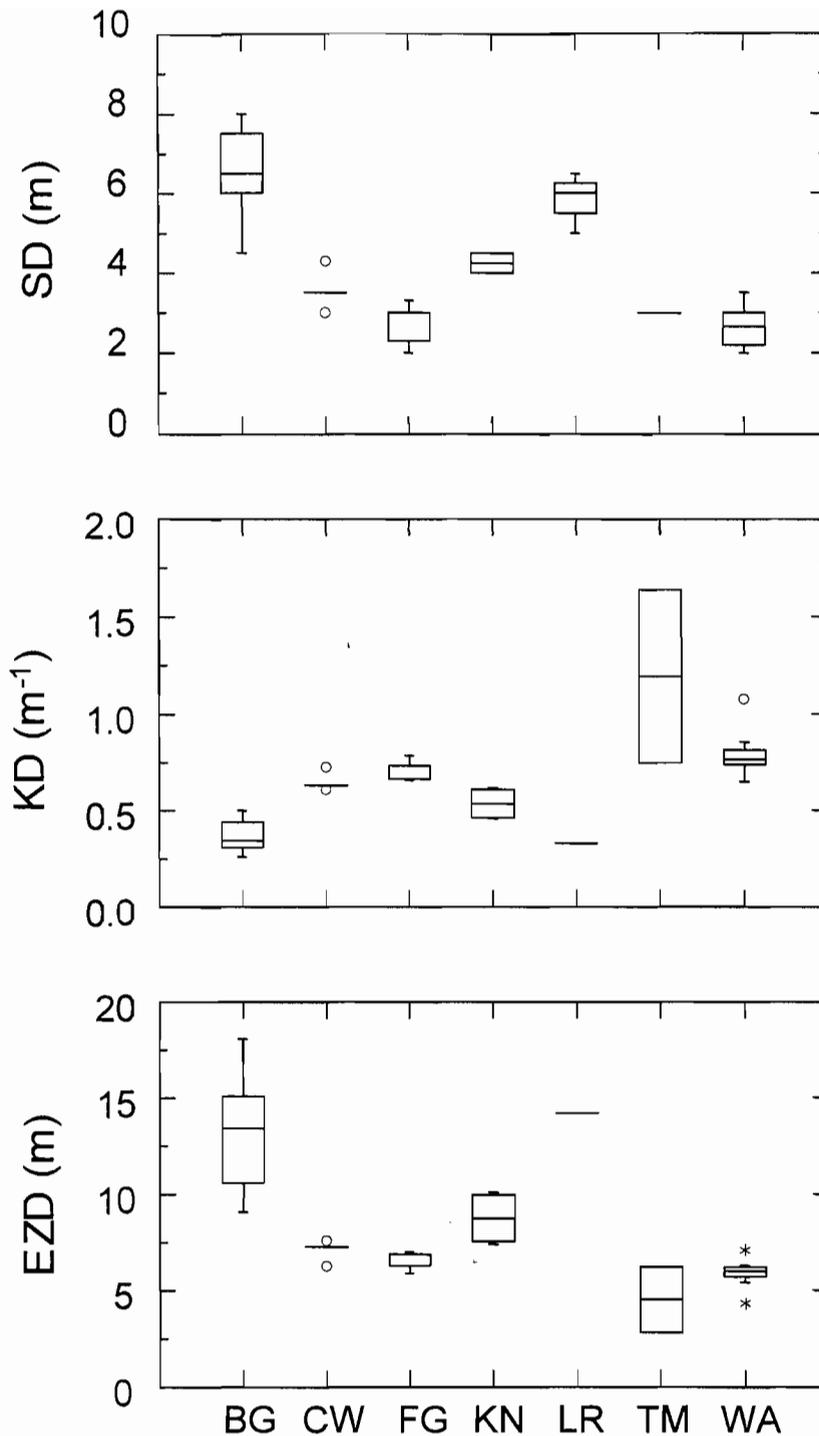
$$\text{TSI (CHL)} = 10 \left( 6 - \frac{2.04 - 0.68 \ln CHL}{\ln 2} \right)$$

## RESULTS and DISCUSSION

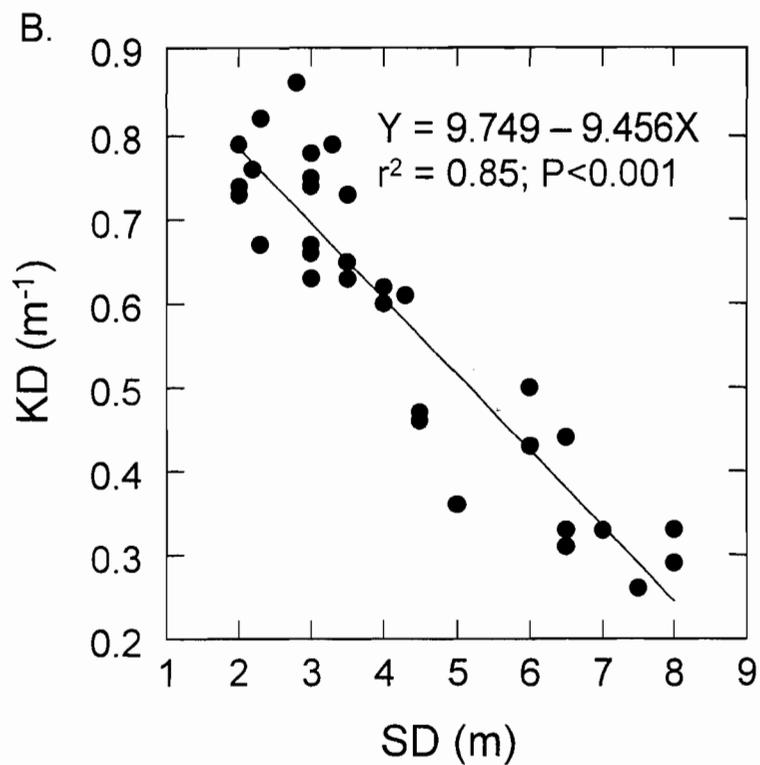
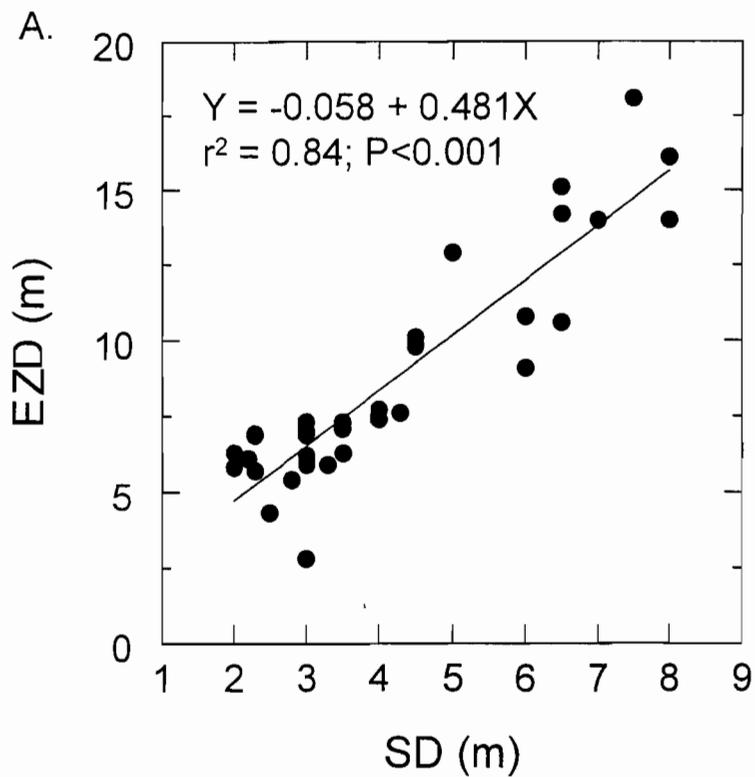
### *Physical Conditions*

The variability in water clarity and light transmission depends on the amount of suspended inorganic (sediment and silt) and organic material (algae) as well as dissolved organic material (yellow color) (Brezonik 1978; Hoyer and Jones 1983; Koenings and Edmundson 1991). Considering the seven study lakes, mean Secchi disk (SD) transparency ranged from 6.5 m (Big Lake) to 2.6 m (Wasilla Lake), which were similar to values reported by Edmundson et al. (2000) for 25 lakes in the Mat-Su Borough. However, in Threemile Lake, the Secchi disk was visible on the bottom (3 m) on all surveys. Thus, the relatively shallow SD readings taken from this lake are not a good indicator of problems with algae, zooplankton grazing, color, or silt. The mean euphotic zone depth (EZD) ranged from 4.5 m (Threemile Lake) to 14.2 m (Lorraine Lake), the latter value of which exceeded the maximum lake depth. Therefore, in lakes where transparency and light penetration are constrained by morphometry, measurements of the rate ( $m^{-1}$ ) at which light is attenuated with depth is a preferable method for comparing the underwater light climate among lakes. Mean vertical light extinction coefficient ( $K_d$ ) values ranged from 1.19 (Threemile Lake) to 0.33 (Lorraine Lake). Box plots of SD transparency,  $K_d$ , and EZD values convey the variation within and among the study lakes (Figure 9). There was major variation in the medians for the seven lakes. However, both Big Lake and Lorraine Lake consistently had the greatest transparency and deepest light penetration. As a group, Cottonwood, Finger, and Wasilla lakes had similar median values and the variability was relatively constant. Excluding Threemile Lake, a strong ( $r^2 = 0.85$ ) relationship was found between EZD and SD transparency (Figure 10A). Similarly, a strong ( $r^2 = 0.84$ ) inverse relationship existed between  $K_d$  and SD transparency (Figure 10B). Thus, photometer estimates of light regimes in these lakes were highly predictable from measurements of SD transparency. In addition, chlorophyll *a* (chl *a*) concentration explained 60% of the variance in SD transparency (Figure 11A) and 62% of the variance in EZD (Figure 11B) suggesting that algal particles were the principle light-attenuating component within the water column. Based on the above-mentioned optical characteristics, all of the study lakes contain generally clear water, as opposed to turbid or stained water, with sunlight commonly reaching the bottom in at least two of the lakes: Lorraine and Threemile lakes.

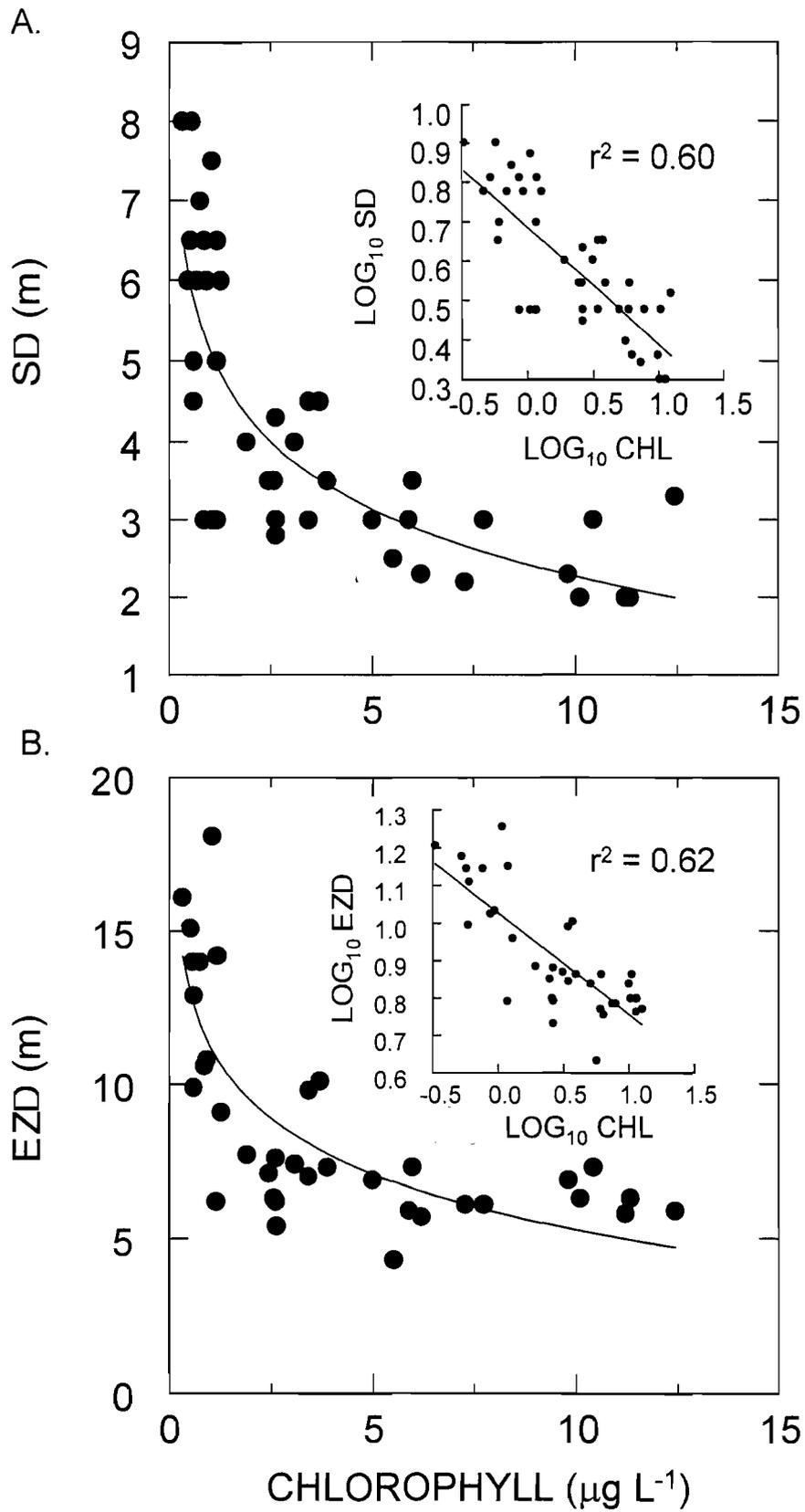
The observed distribution of temperature with depth in the seven lakes over the course of the 2001 season are presented in Figure 12A-I. By the time of the late May survey, the lakes were already quite warm with maximum surface temperatures ranging from 10 °C to 15 °C. In mid-summer, surface temperatures reached nearly 20 °C in Knik, Lorraine, and Threemile lakes. In the other four lakes, maximum temperatures were about 2 °C cooler. Sampling revealed that Big, Cottonwood, Finger, Knik, and Wasilla lakes were strongly stratified with a distinct epilimnion and hypolimnion, at least by mid-summer (31 July-01 August). Generally, the metalimnion extended from about 4 m to 8 m, being slightly deeper (5-10 m) than that in Big Lake. Throughout the summer, hypolimnetic temperatures of these stratified lakes hovered around 5 °C. By the October sampling trip,



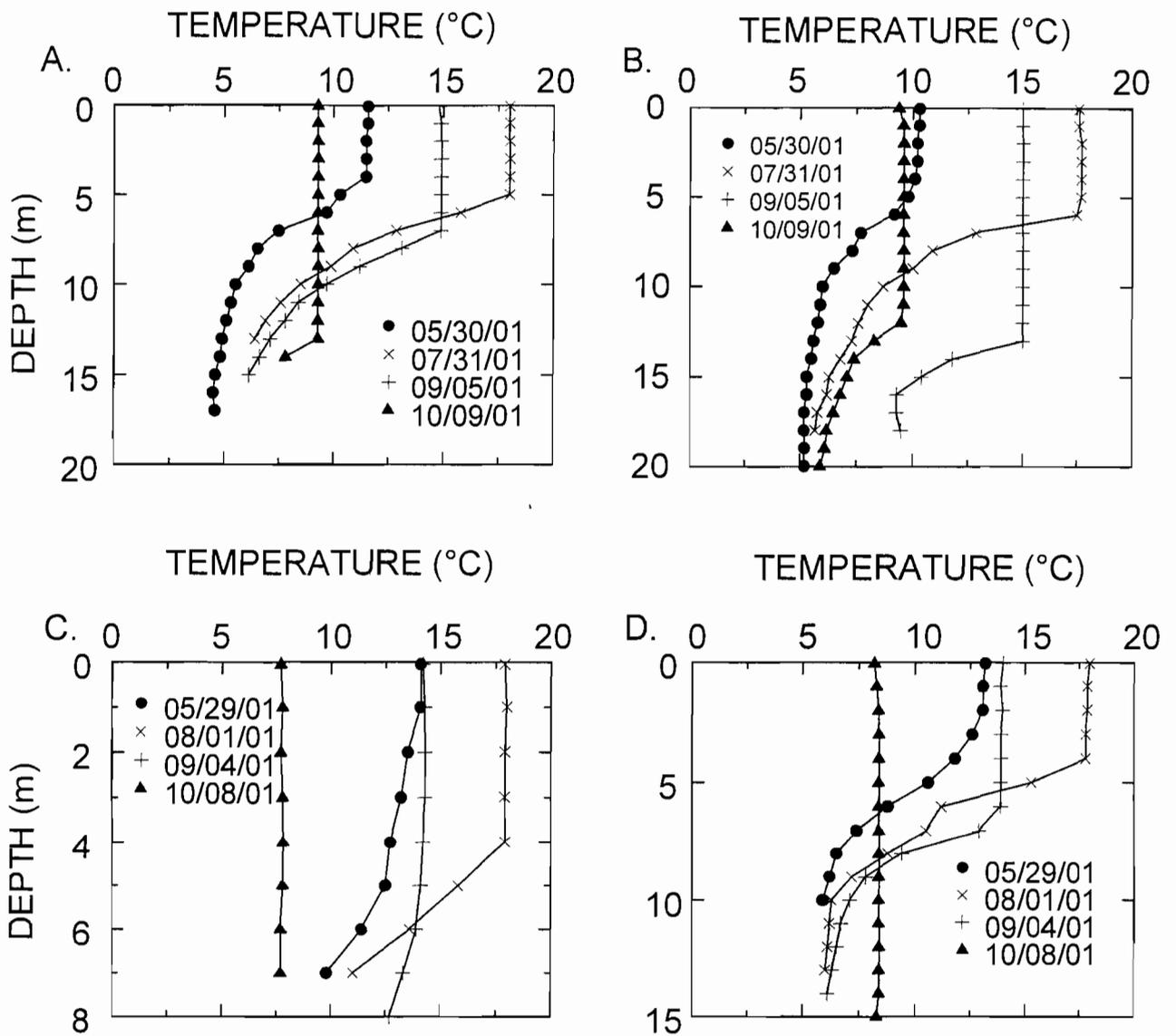
**Figure 9.** Box plots of Secchi depth ( $SD$ ), vertical extinction coefficient ( $K_d$ ), and euphotic zone depth ( $EZD$ ) for the seven study lakes: Big (BG), Cottonwood (CW), Finger (FG), Knik (KN), Lorraine (LR), Three Mile (TM) and Wasilla (WA). Box shows the interquartile range, horizontal line within box is the median, whiskers show range of values within  $\pm 1.5$  times the box edges, and values greater than  $\pm 1.5$  times the box edges are plotted as open circles.



**Figure 10.** The relationship between Secchi depth (*SD*) and (A) euphotic zone depth (*EZD*) and (B) vertical extinction coefficient (*K<sub>d</sub>*).



**Figure 11.** (A) Secchi depth (*SD*) and (B) euphotic zone depth (*EZD*) as a function of chlorophyll *a* (*CHL*) for the seven study lakes. Insets show the relationships after  $\log_{10}$  transformation.



**Figure 12.** Vertical temperature profiles for (A) Big Lake (east), (B) Big Lake (west) (C) Wasilla Lake (east), (D) Wasilla Lake (west), (E) Cottonwood Lake, (F) Finger Lake, (G) Knik Lake, (H) Lorraine Lake, and (I) Threemile Lake, May-October 2001.

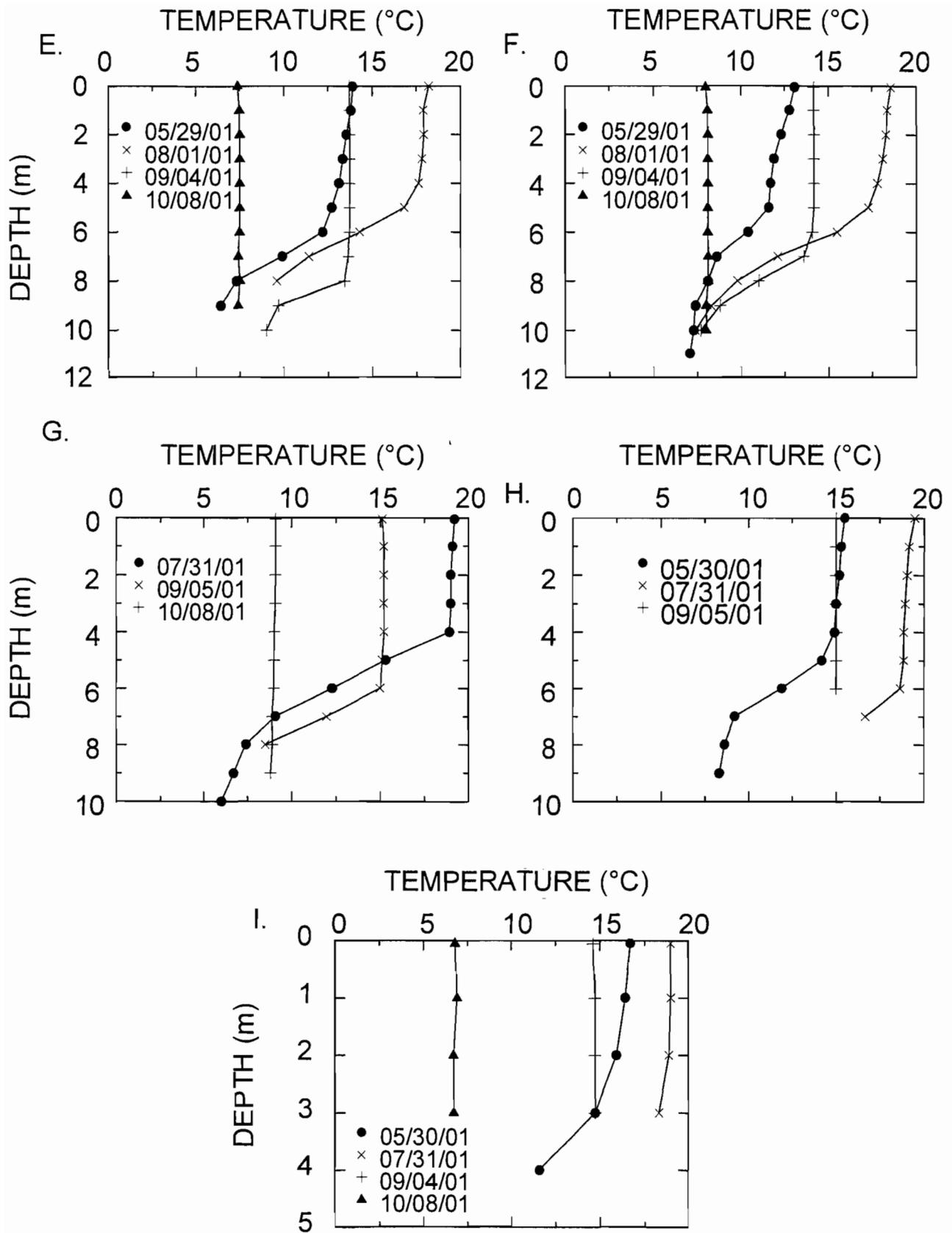


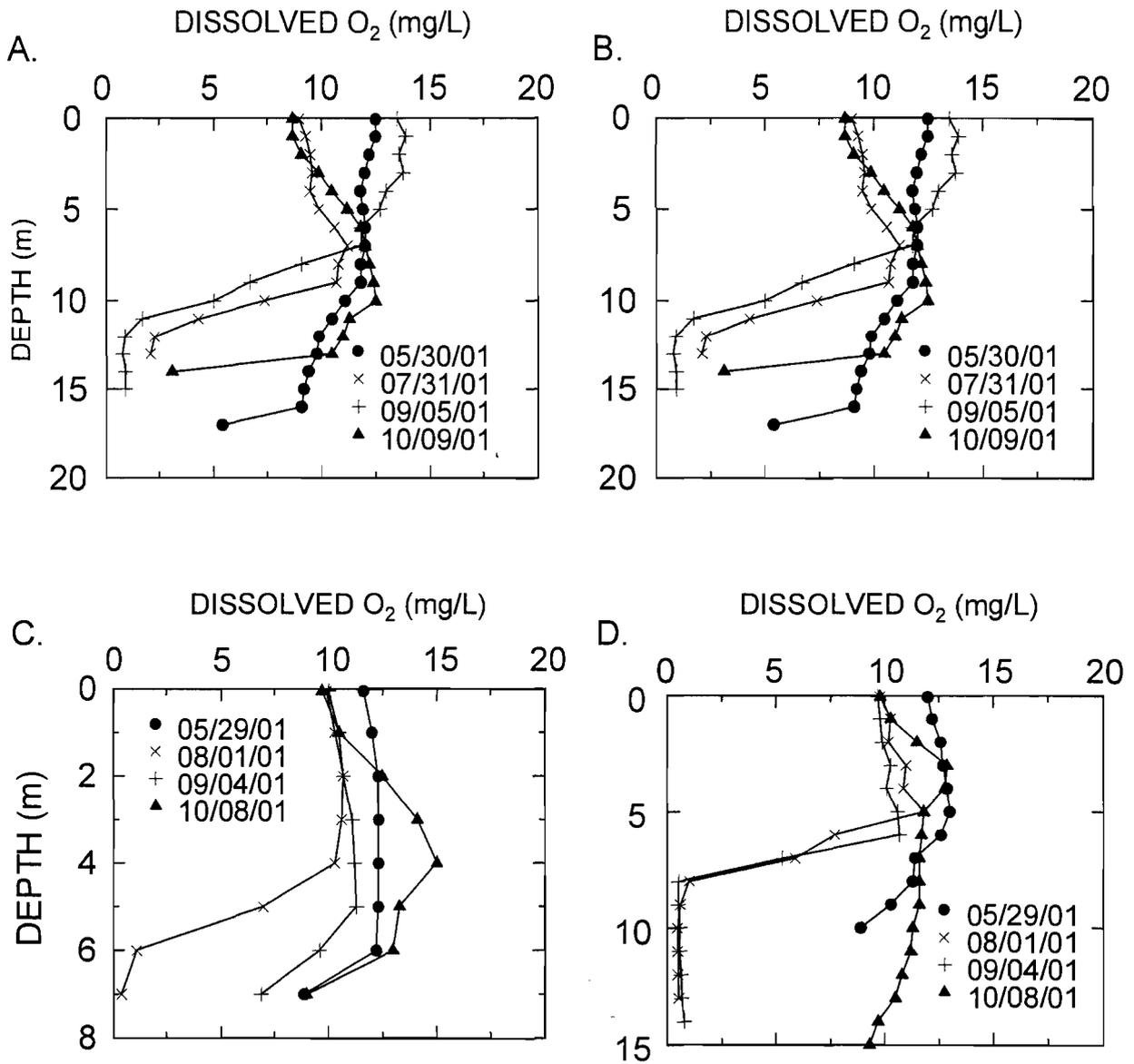
Figure 12. Continued.

and following a period of lower radiation and cooler temperatures, the stratified lakes underwent turnover when the whole water column mixed (i.e., the process of holomixis). Water column temperatures at this time were essentially isothermal at around 8 °C. However, Lorraine and Threemile lakes lacked thermal stratification during summer presumably due to their shallowness and exposure to wind. Between the September and October water column temperatures in all seven lakes decreased from around 15 °C to 5 °C; i.e., at a rate of 1.0 °C every three days.

### *Chemical Characteristics*

When stratified, dissolved oxygen concentrations in some lakes decline rapidly with depth (Wetzel 1983). In the Mat-Su study lakes, summer dissolved-oxygen profiles indicated hypolimnetic anoxia (lack of oxygen) or near anoxic conditions in the bottom layers of the five stratified lakes (Figure 13A-I). Big Lake and Wasilla Lake exhibited positive heterograde oxygen profiles where dissolved oxygen levels are highest in the metalimnion and depleted, due to microbial respiration, in the hypolimnion. Dissolved oxygen levels less than 2 mg L<sup>-1</sup> were observed near the bottom of these lakes in mid-summer. This type of oxygen curve is typical of mesotrophic (intermediate productivity) lakes. Dissolved oxygen levels in Cottonwood, Finger and Knik lakes displayed more of a clinograde profile, where oxygen concentrations decrease with depth which is usually characteristic of more productive or eutrophic lakes. In these lakes, there was no obvious metalimnetic oxygen peak and much of the hypolimnion was anoxic. By October, autumnal re-aeration from turnover was complete as evidenced by oxic conditions throughout the whole water column of these five lakes. In contrast, because Lorraine and Threemile lakes lacked strong thermal stratification, they were well oxygenated during the entire summer period with oxygen levels slightly higher in the near bottom layers indicating more of an orthograde profile. We also measured dissolved oxygen during the winter ice cover in three of the lakes. In March 2002, dissolved oxygen concentration in the near surface layers of Cottonwood, Finger, and Wasilla lakes varied from 17 mg L<sup>-1</sup> to 20 mg L<sup>-1</sup> and decreased with depth. However, the lowest levels, which occurred near the bottom, ranged from 7 mg L<sup>-1</sup> to 10 mg L<sup>-1</sup> (data not graphically displayed). Thus, the late 2001/2002 winter conditions of these lakes were not characteristic of low dissolved oxygen levels associated with partial or complete winterkill. That is, most fish cannot survive dissolved oxygen concentrations less than 3-5 mg L<sup>-1</sup> (Davis et al. 1979).

General water chemistry, nutrients, particulate organic carbon, and algal pigment concentrations within the 1-m stratum of the seven survey lakes are summarized in Table 2, whereas Table 3 summarizes the information obtained from the deeper depths sampled. Measurements of pH, within the 1-m stratum, indicated that all of the seven study lakes were slightly alkaline, with mean pH ranging from 7.4 to 7.9. The lowest individual pH recorded (6.6) was in Big Lake at a depth of 11 m during the September survey; the highest value was at 1 m in Finger Lake on 01 August (8.4). Although high pH (greater than 9) caused by intense photosynthetic activity (e.g., algal bloom) can promote phosphorus release from iron complexes and sediments (Cooke et al. 1993), the pH values we obtained in this study suggest this mechanism of phosphorus release is



**Figure 13.** Vertical profiles of dissolved oxygen concentration for (A) Big Lake (east), (B) Big Lake (west), (C) Wasilla Lake (east), (D) Wasilla Lake (west), (E) Cottonwood Lake, (F) Finger Lake, (G) Knik Lake, (H) Lorraine Lake, and (I) Threemile Lake, May-October 2001.

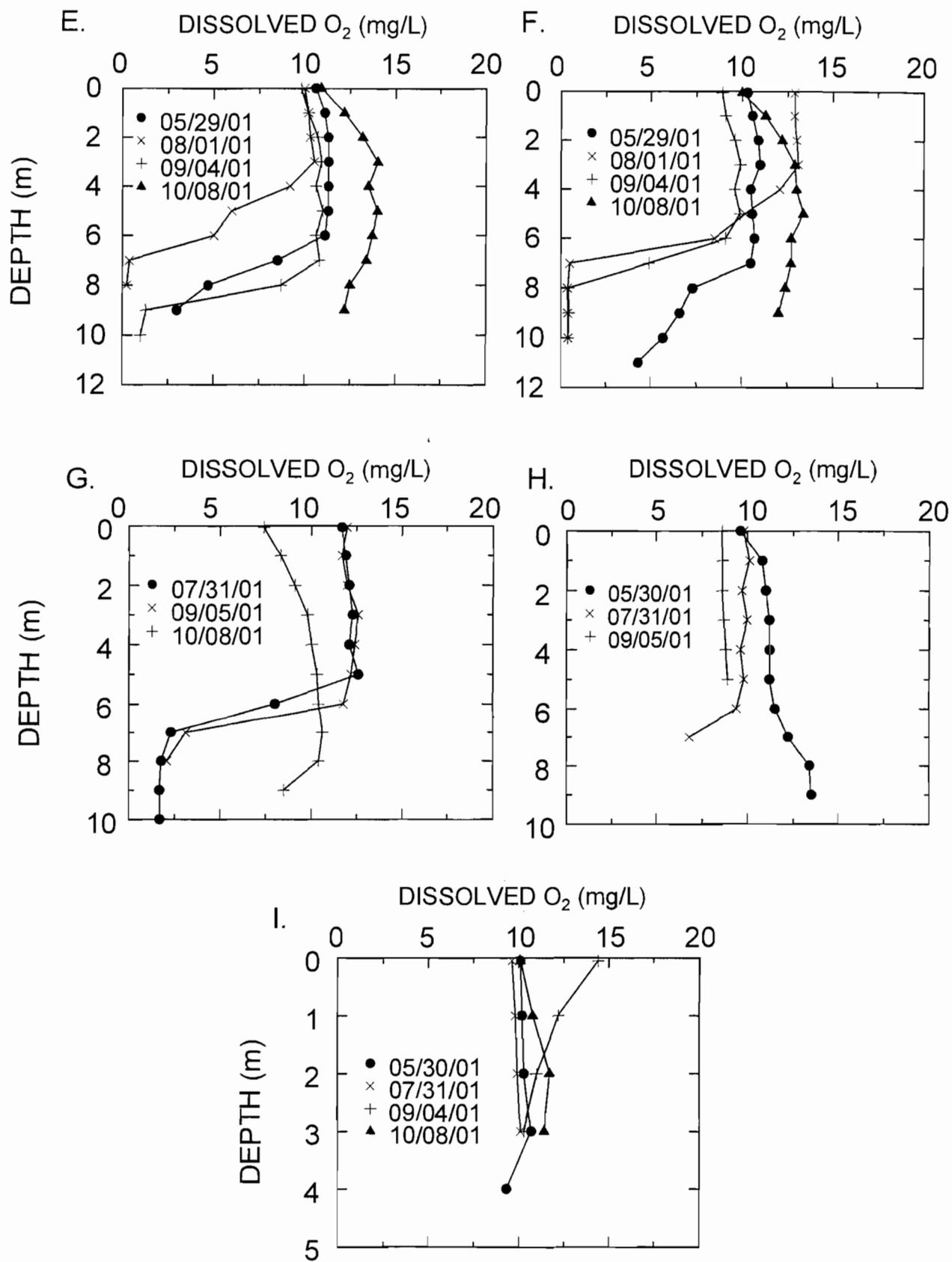


Figure 13. Continued.

**Table 2.** Descriptive statistics of general water chemistry, nutrients, and algal pigments for the seven study lakes.  
Data are derived from samples collected at the 1-m depth.

Parameter	Units	Big			Cottonwood			Finger			Knik		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Conductivity	µmhos/cm	126	132	143	174	192	209	209	222	237	157	166	174
pH	Units	7.3	7.5	7.7	7.7	7.8	8.0	7.6	7.9	8.4	7.4	7.9	8.3
Alkalinity	mg/L	58	60	69	79	90	99	85	93	108	71	76	80
Turbidity	NTU	0.4	1.0	1.5	0.8	1.4	2.5	2.2	3.3	6.7	0.8	1.0	1.4
Color	Pt-Co	5	10	15	14	17	23	10	13	20	10	12	14
Calcium	mg/L	17.8	18.9	20.6	21.3	27.9	33.2	7.9	18.5	23.0	20.0	21.5	22.6
Magnesium	mg/L	2.2	3.4	3.9	3.9	5.1	6.5	6.9	9.0	11.9	3.0	4.3	5.0
Iron	µg/L	18	41	73	38	48	66	30	39	54	18	31	37
Total-P	µg/L	4.6	6.8	12.3	8.8	11.4	13.7	12.8	21.7	31.8	9.9	14.5	22.5
Total filterable-P	µg/L	2.3	3.2	4.8	3.5	4.4	6.2	4.1	5.8	7.0	4.9	6.4	10.3
Filterable reactive-P	µg/L	1.5	2.2	3.0	3.0	3.6	5.0	1.3	2.0	3.1	1.2	2.7	5.0
Kjeldahl-N	µg/L	163	190	220	258	278	289	440	490	530	330	393	488
Ammonia	µg/L	0.4	12.3	27.1	1.7	8.5	16.6	5.0	6.3	7.5	7.5	31.1	90.1
Nitrate+nitrite	µg/L	1	11	27	2	18	52	2	13	35	2	17	32
Total-N	µg/L	166	201	244	260	295	340	442	503	556	354	410	520
N:P ratio	molar	44	69	89	51	58	69	39	55	77	51	67	83
Reactive silicon	µg/L	3059	3280	3507	3245	3736	4297	966	1196	1411	2227	2534	2828
Particulate organic-C	µg/L	126	218	302	349	464	658	566	791	949	296	395	565
Chlorophyll <i>a</i>	µg/L	0.33	0.75	1.27	2.57	5.09	10.41	3.41	8.40	12.44	1.91	3.03	3.69
Phaeophytin	µg/L	0.12	0.24	0.33	0.77	1.06	1.43	0.05	0.54	0.82	0.42	0.60	0.90

**Table 2.** Continued.

Parameter	Units	Lorraine			Three Mile			Wasilla		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Conductivity	µmhos/cm	70	72	73	96	116	128	187	211	240
pH	Units	7.0	7.4	7.9	7.1	7.4	7.6	7.5	7.9	8.2
Alkalinity	mg/L	31	31	32	49	58	66	85	96	113
Turbidity	NTU	0.5	0.7	0.8	0.6	1.2	2.1	1.2	2.6	4.6
Color	Pt-Co	3	6	8	15	19	23	11	19	26
Calcium	mg/L	8.3	8.6	8.9	15.4	17.8	19.8	12.8	22.9	35.6
Magnesium	mg/L	1.6	2.1	2.5	2.0	2.8	3.2	4.7	7.6	10.7
Iron	µg/L	34	41	57	54	118	185	28	49	92
Total-P	µg/L	4.0	5.0	6.1	8.0	9.1	11.2	8.5	15.0	22.4
Total filterable-P	µg/L	2.1	2.7	3.1	3.6	4.8	8.2	3.5	4.9	7.5
Filterable reactive-P	µg/L	0.8	1.4	1.8	2.3	3.4	7.0	2.3	3.7	5.9
Kjeldahl-N	µg/L	401	409	419	286	324	341	311	368	482
Ammonia	µg/L	7.3	29.7	60.0	2.6	8.3	18.1	1.7	22.7	128.8
Nitrate+nitrite	µg/L	4	21	46	2	12	26	2	20	59
Total-N	µg/L	405	430	459	288	336	367	317	388	534
N:P ratio	molar	161	196	254	72	83	94	43	60	83
Reactive silicon	µg/L	82	155	217	2300	2918	3586	1761	3345	4177
Particulate organic-C	µg/L	258	299	355	213	305	400	355	645	966
Chlorophyll <i>a</i>	µg/L	0.46	0.87	1.18	0.86	1.02	1.17	2.45	6.17	11.21
Phaeophytin	µg/L	0.07	0.19	0.33	0.16	0.26	0.41	0.05	0.73	3.79

**Table 3.** Descriptive statistics of general water chemistry, nutrients, and algal pigments for six study lakes. Data were derived for samples collected at depth: Big (8-15 m), Cottonwood (6-8 m), Finger (7-10 m), Knik (6-8 m), Lorraine (5-7 m), and Wasilla lakes (5-11 m).

Parameter	Units	Big			Cottonwood			Finger			Knik		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Conductivity	µmhos/cm	132	138	144	200	216	228	225	251	265	173	187	200
pH	Units	6.6	7.1	7.6	7.0	7.4	7.7	7.0	7.2	7.6	6.9	7.1	7.4
Alkalinity	mg/L	60	63	65	93	101	106	94	107	114	80	86	91
Turbidity	NTU	0.4	1.2	2.0	0.9	2.8	4.3	2.5	4.7	7.3	0.8	2.9	4.2
Color	Pt-Co	5	10	14	9	14	19	8	12	17	11	15	22
Calcium	mg/L	18.6	19.6	20.8	21.8	27.6	31.8	14.8	20.5	34.8	21.1	23.7	28.2
Magnesium	mg/L	2.7	3.5	3.9	3.8	6.0	9.4	5.3	8.7	11.2	5.2	5.3	5.4
Iron	µg/L	23	50	96	37	65	93	44	75	101	19	32	45
Total-P	µg/L	7.2	10.4	13.8	12.6	18.2	24.0	29.2	41.7	57.6	17.4	27.2	41.2
Total filterable-P	µg/L	2.9	4.0	6.3	3.6	4.5	5.6	6.9	9.8	13.1	8.9	10.9	12.7
27 Filterable reactive-P	µg/L	2.1	2.7	4.2	2.7	3.9	4.7	2.2	3.9	7.2	2.9	3.6	4.5
Kjeldahl-N	µg/L	162	201	237	279	332	391	519	552	578	428	559	768
Ammonia	µg/L	1.7	12.5	27.9	1.7	20.8	71.9	6.5	23.6	66.4	57.5	166.8	346.2
Nitrate+nitrite	µg/L	1	14	56	2	17	48	2	13	35	3	18	30
Total-N	µg/L	164	216	260	308	349	394	533	565	601	450	577	771
N:P ratio	molar	41	47	57	33	45	63	20	32	42	41	50	65
Reactive silicon	µg/L	3553	4041	4890	3845	4525	5044	1386	1736	1975	2883	3601	4163
Particulate organic-C	µg/L	222	284	446	471	663	983	614	937	1166	365	632	1010
Chlorophyll <i>a</i>	µg/L	0.49	1.33	4.14	5.70	9.64	14.98	1.55	9.26	15.74	1.34	10.92	23.10
Phaeophytin	µg/L	0.31	0.51	0.74	0.05	1.35	4.32	0.05	15.75	44.66	0.05	0.20	0.29

**Table 3. Continued.**

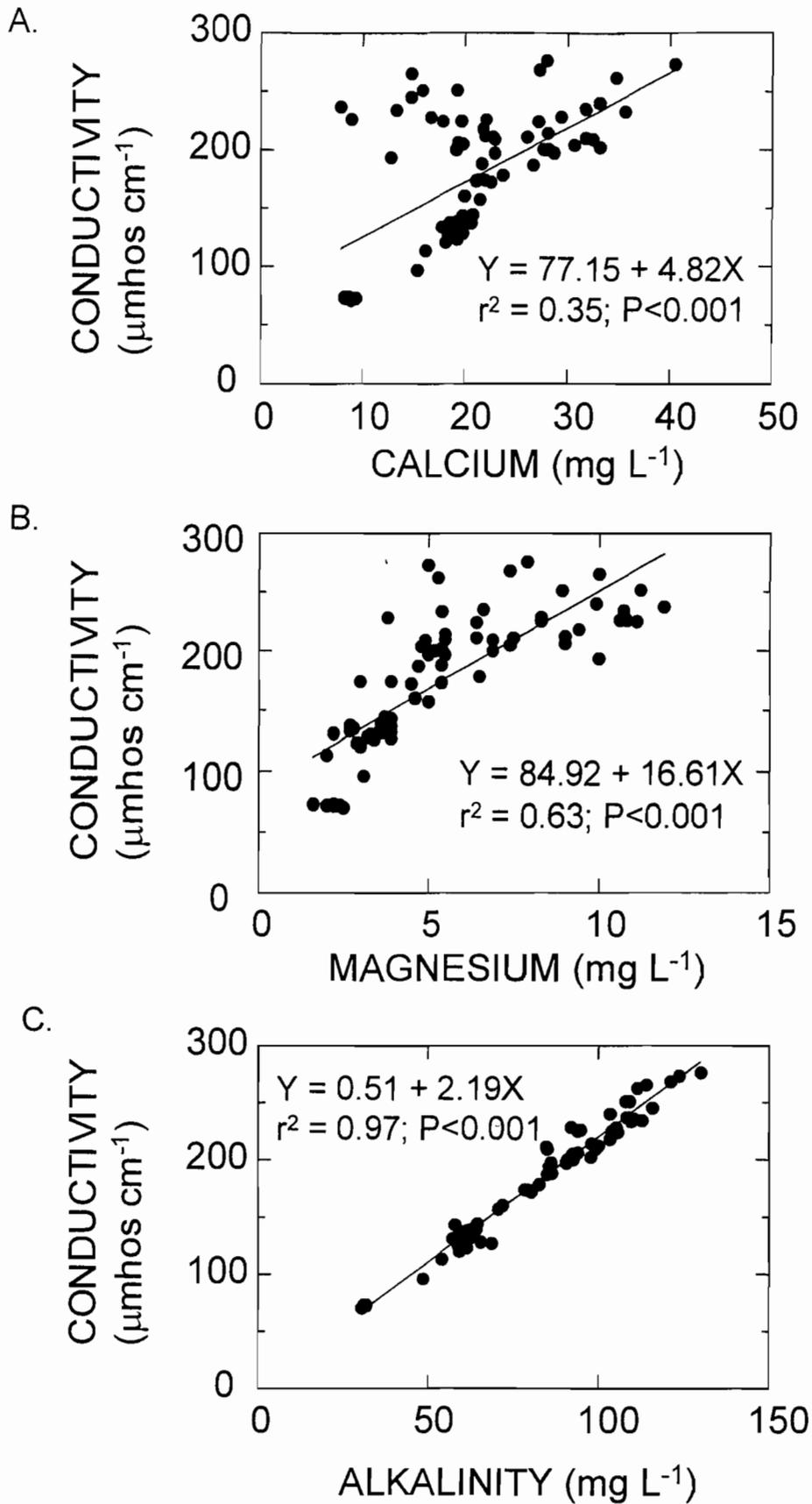
Parameter	Units	Lorraine			Wasilla		
		Min	Mean	Max	Min	Mean	Max
Conductivity	µmhos/cm	72	72	73	204	238	276
pH	Units	7.0	7.4	7.9	7.0	7.5	8.0
Alkalinity	mg/L	31	32	32	92	110	130
Turbidity	NTU	0.8	1.1	1.5	1.7	3.9	6.5
Color	Pt-Co	4	5	6	13	20	28
Calcium	mg/L	8.3	8.8	9.4	8.9	25.2	40.5
Magnesium	mg/L	2.0	2.2	2.4	4.8	8.6	17.8
Iron	µg/L	32	41	55	42	234	997
Total-P	µg/L	5.7	6.3	7.3	15.7	20.1	24.7
Total filterable-P	µg/L	2.2	2.7	2.9	4.2	4.9	6.2
Filterable reactive-P	µg/L	1.0	1.3	1.6	3.0	3.7	5.6
Kjeldahl-N	µg/L	401	418	448	355	505	925
Ammonia	µg/L	10.2	26.6	55.9	1.7	158.7	713.3
Nitrate+nitrite	µg/L	3	18	43	2	43	124
Total-N	µg/L	406	436	491	374	548	947
N:P ratio	molar	142	153	165	46	61	101
Reactive silicon	µg/L	56	145	218	3227	4284	6012
Particulate organic-C	µg/L	326	401	606	516	686	926
Chlorophyll <i>a</i>	µg/L	0.67	1.28	2.09	1.30	7.72	17.01
Phaeophytin	µg/L	0.10	0.40	1.11	0.05	0.87	1.70

probably uncommon in these systems. Alkalinity (or carbonate hardness) is a measure of water's ability to resist changes in pH. Mean alkalinity within the 1-m stratum for our study lakes ranged from 31 mg L<sup>-1</sup> to 96 mg L<sup>-1</sup>, which is characteristic of soft to moderately hard water. Lakes within the Cottonwood Creek (Wasilla, Finger, and Cottonwood lakes) drainage generally had higher alkalinity values (approximately 95 mg L<sup>-1</sup>) than the two lakes we studied in the Fish Creek watershed (Big and Finger lakes) (approximately 60 mg L<sup>-1</sup>). Conductivity is often used as an index of the total amount of dissolved inorganic solids. In a general sense, higher productivity lakes are associated with higher total dissolved solids or TDS (Ryder 1965). However, Prepas (1983) found that TDS did not predict productivity among 25 lakes of the Precambrian Shield because it is primarily phosphorus supply not TDS that regulates algal biomass. However, TDS or its surrogate conductivity can indicate productivity differences between lakes. Average conductivity values within the 1-m stratum ranged from 72 µmhos cm<sup>-1</sup> in Lorraine Lake to 222 µmhos cm<sup>-1</sup> in Finger Lake and are considered low to moderate. For comparison, the conductivity of seawater is around 50,000 µmhos cm<sup>-1</sup> and in some Alaskan lakes conductivity values are less than 10 µmhos cm<sup>-1</sup> (LaPerriere 1997; Edmundson and Carlson 1998). Patterns in conductivity data generally followed those found in the major ions (Figure 14A-C). For example, conductivity was directly related to calcium (Ca<sup>2+</sup>), magnesium (Mg<sup>2+</sup>), and alkalinity (CaCO<sub>3</sub>). The strong correlation between alkalinity and conductivity is expected in lakes that are mainly calcium carbonate systems, wherein the major component of alkalinity is the bicarbonate ion (HCO<sub>3</sub><sup>-</sup>).

### ***Nutrients***

Concentrations of reactive silicon, an important building material of the particulate frustules of diatoms, were considered low to moderate with mean values within the 1-m stratum ranging from 155 µg L<sup>-1</sup> in Lorraine Lake to 3,736 µg L<sup>-1</sup> in Cottonwood Lake. These levels were similar to the average epilimnetic (1-m) concentrations calculated for 25 lakes in the Mat-Su Borough, which ranged from 491 µg L<sup>-1</sup> to 4,824 µg L<sup>-1</sup> with an overall mean of 3,014 µg L<sup>-1</sup> (Edmundson et al. 2000). Among the 5 stratified lakes in our study, reactive silicon levels were notably higher in the hypolimnion compared to the epilimnion with average concentrations ranging from 1,736 µg L<sup>-1</sup> to 4,525 µg L<sup>-1</sup>. There was no indication that reactive silicon was limiting primary productivity in any of these lakes.

Nitrogen occurs in natural waters in the form of numerous compounds as inorganic nitrate, nitrite, and ammonia and as dissolved and particulate organic forms (Wetzel 1983). Nitrate and ammonia are the most important nitrogen compounds in water because they are the main source of nitrogen for photoautotrophic plants (phytoplankton, periphyton, and macrophytes). However, nitrate is much more abundant than ammonia in oligotrophic (well oxygenated) lakes. Mean inorganic nitrogen levels in our study lakes, measured as nitrate+nitrite, were quite low within the 1-m stratum and ranged from 11 to 21 µg L<sup>-1</sup>. All of the lakes exhibited mid-summer nitrate depletion when epilimnetic concentrations decreased to near or below our analytical detection limits

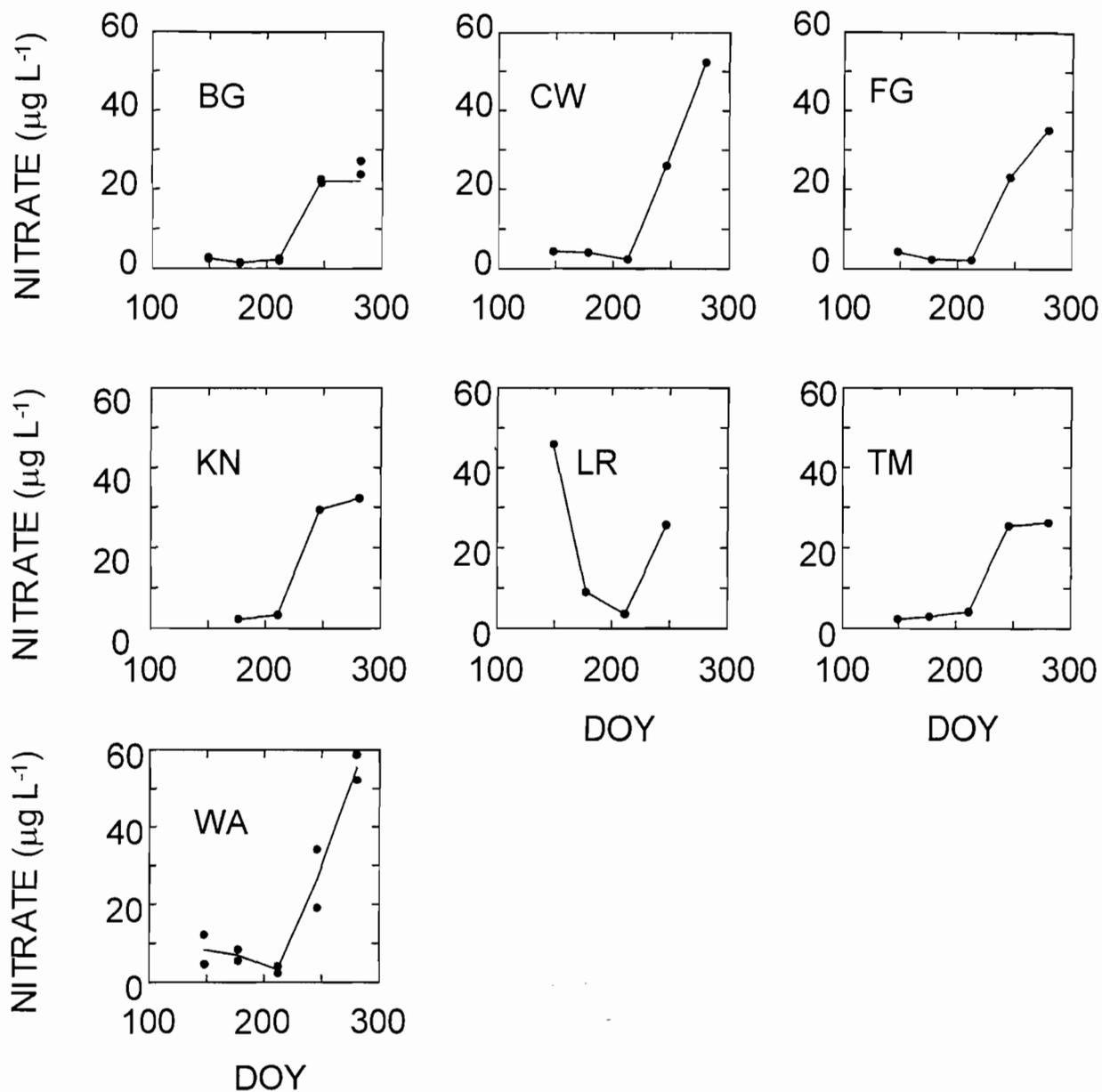


**Figure 14.** The relationship between conductivity and (A) calcium, (B) magnesium and (C) alkalinity for the seven study lakes.

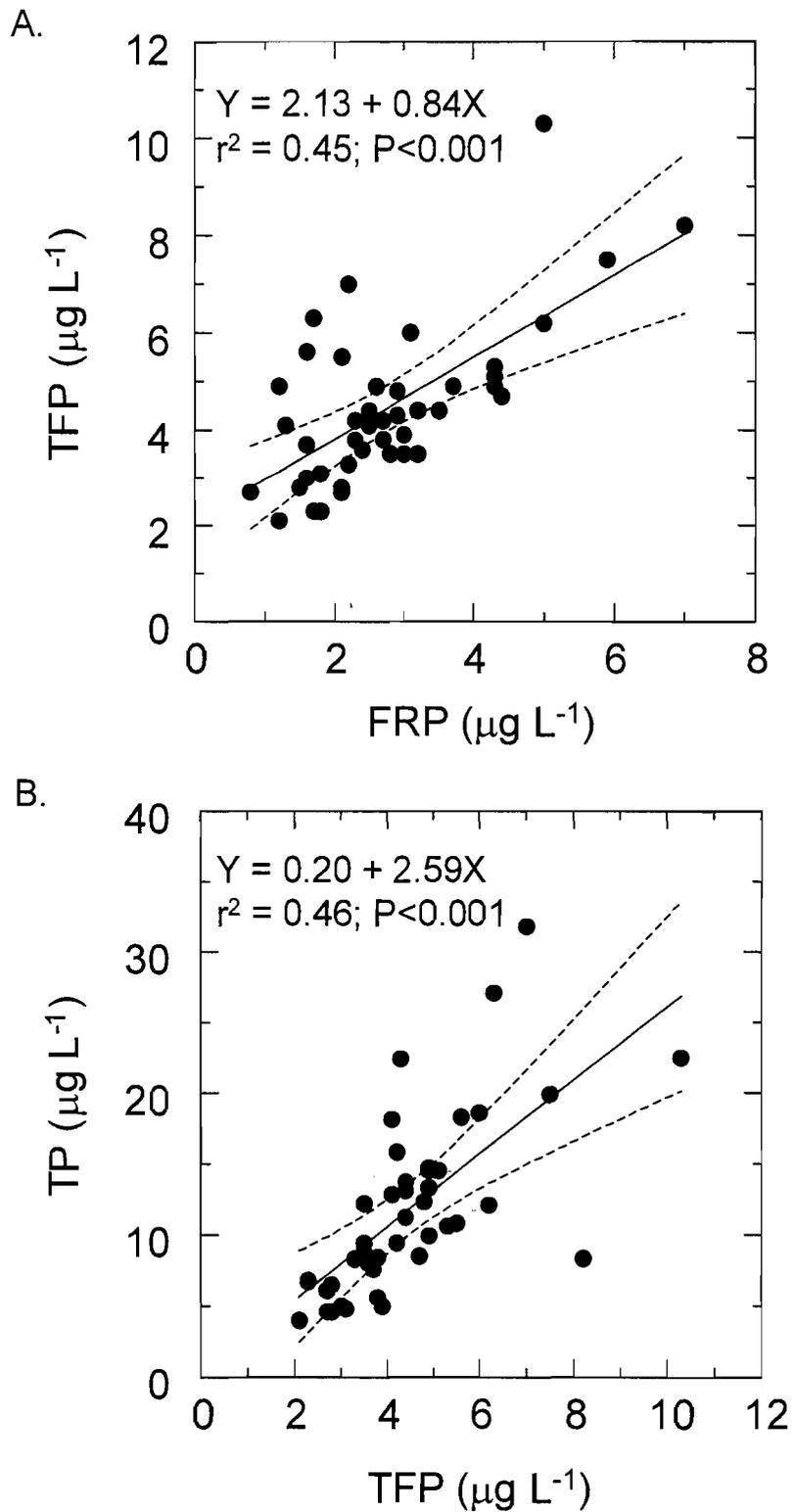
(3  $\mu\text{g L}^{-1}$ ). However, concentrations increased, as expected, to more than 30  $\mu\text{g L}^{-1}$  in the fall following turnover (Figure 15). This seasonal pattern is often present in highly productive lakes. Ammonia nitrogen can be absorbed directly by many kinds of algae and ammonium ions can accumulate in the hypolimnion under conditions of anoxia. The highest ammonia concentrations were found in the hypolimnion of Wasilla Lake during the 01 August (531  $\mu\text{g L}^{-1}$ ) and 04 September (713  $\mu\text{g L}^{-1}$ ) surveys and in Knik Lake (346  $\mu\text{g L}^{-1}$ ) on 31 July (Appendix Table B). All other ammonia values were less than 100  $\mu\text{g L}^{-1}$  with most being less than 20  $\mu\text{g L}^{-1}$  (Appendix Table B). Of the three nitrogen compounds analyzed, TKN (organic + ammonia nitrogen) had the highest concentrations. Mean TKN values for the 1-m stratum ranged from a low of 190  $\mu\text{g L}^{-1}$  in Big Lake to 490  $\mu\text{g L}^{-1}$  in Finger Lake, whereas average hypolimnetic TKN values ranged from 201  $\mu\text{g L}^{-1}$  in Big Lake to 559  $\mu\text{g L}^{-1}$  in Knik Lake. As expected, TKN was strongly related ( $r^2 = 0.97$ ;  $P < 0.001$ ) to total nitrogen (TN), which was computed as the sum of TKN and nitrate+nitrite. The linear regression equation was  $\text{TN} = 13.25 + 1.02\text{TKN}$ . Over all measurements ( $n=80$ ), TN ranged from 164  $\mu\text{g L}^{-1}$  to 947  $\mu\text{g L}^{-1}$  and averaged 382  $\mu\text{g L}^{-1}$ , this range being typical of oligotrophic lakes and reservoirs according to Wetzel (1983). Considering only the stratified lakes, results of ANOVA suggested TN levels were significantly higher ( $P=0.001$ ) in the hypolimnion (least squares mean 339  $\mu\text{g L}^{-1}$ ) compared to the 1-m stratum (least squares mean 422  $\mu\text{g L}^{-1}$ ).

Among three phosphorus fractions, total phosphorus (TP), total filterable phosphorus (TFP), and filterable reactive phosphorus (FRP), there was a moderately strong relationship between TFP and (FRP) ( $r^2 = 0.45$ ;  $P < 0.001$ ) and also between TP and TFP ( $r^2 = 0.46$ ;  $P < 0.001$ ) (Figure 16A-B). In the trophogenic or illuminated zone of the water column, FRP is taken up by algae and converted to organic compounds, which fuel the pelagic food chain. Considering the 1-m stratum, mean values for FRP in our study lakes were generally low and ranged from 1.4  $\mu\text{g L}^{-1}$  to 3.7  $\mu\text{g L}^{-1}$ . In comparison, average TFP levels ranged from 2.7  $\mu\text{g L}^{-1}$  to 6.4  $\mu\text{g L}^{-1}$ . From a lake management perspective, the most important phosphorus constituent in lakes however, is TP because most lake (trophic) evaluations are based on this compound. For 19 lakes in the Yukon Territory TP concentrations ranged from 3.2  $\mu\text{g L}^{-1}$  to 12.9  $\mu\text{g L}^{-1}$  (Shortreed and Stockner 1986), which corresponds well to the 2  $\mu\text{g L}^{-1}$  and 24  $\mu\text{g L}^{-1}$  concentration range found in 52 clearwater Alaskan lakes (Edmundson and Carlson 1998). In our study, mean epilimnetic TP values for the seven lakes ranged from 5.0  $\mu\text{g L}^{-1}$  in Lorraine Lake to 21.7  $\mu\text{g L}^{-1}$  in Finger Lake, which falls within the 2.2  $\mu\text{g L}^{-1}$  to 44.2  $\mu\text{g L}^{-1}$  range observed for 25 lakes in the Mat-Su Borough (Edmundson et al. 2000). The two highest individual TP concentrations in our study occurred within the epilimnion (31.8  $\mu\text{g L}^{-1}$ ) and the hypolimnion (57.6  $\mu\text{g L}^{-1}$ ) of Finger Lake (Appendix Table B). Among the stratified lakes, results of ANOVA suggested that TP concentrations were significantly higher ( $P=0.001$ ) in the hypolimnion (least squares mean 20.8  $\mu\text{g L}^{-1}$ ) compared to levels in the 1-m stratum (least squares mean 13.0  $\mu\text{g L}^{-1}$ ).

Nitrogen is usually available for algal production in much greater concentrations than that of phosphorus. In addition, total nitrogen:total phosphorus (N:P) ratios have been shown to influence the composition of algal communities (Watson et al. 1992). Generally, lakes



**Figure 15.** Temporal pattern of inorganic nitrogen measured as nitrate+nitrite (*NITRATE*) concentration within the 1-m stratum of the seven study lakes: Big (BG), Cottonwood (CW), Finger (FG), Knik (KN), Lorraine (LR), Threemile (TM), and Wasilla (WA) lakes. *DOY* is day of year.



**Figure 16.** Relationship between (A) total filterable phosphorus (*TFP*) and filterable reactive phosphorus (*FRP*); (B) the relationship between total phosphorus (*TP*) and *TFP* for the seven Mat-Su study lakes. Data are derived from the 1-m stratum and dashed lines are 95% confidence intervals.

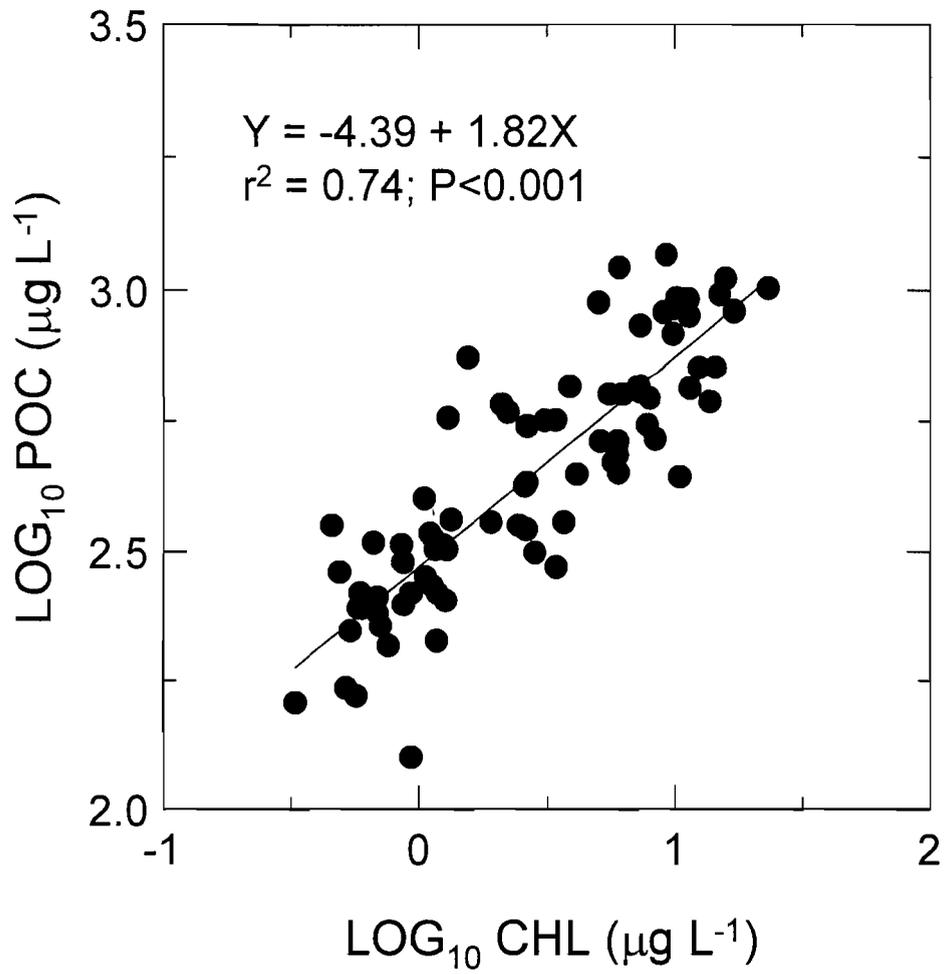
are phosphorus limited when N:P ratios by weight are greater than 15:1 and nitrogen limited when ratios are less than 10:1 (Smith 1982). For N:P ratios between 10:1 and 15:1, either phosphorus or nitrogen may be limiting. Of particular importance is that low N:P ratios less than about 10:1 to 15:1 in a waterbody's nutrient supply create conditions of nitrogen limitation, which favors the production of heterosystous (nitrogen fixing) cyanobacteria or blue-green algae (Smith 1982). Low N:P ratios can contribute to the development of toxic blooms of cyanobacteria such as *Microcystis*. Among our seven study lakes, mean N:P ratios, derived for the 1-m stratum, ranged from 55:1 in Finger Lake to 196:1 in Lorraine Lake and the lowest and highest individual N:P ratios were 39:1 and 254:1, respectively, indicating an adequate supply of nitrogen relative to phosphorus. In comparison, average N:P ratios derived from the hypolimnion in these lakes ranged from 32:1 to 153:1.

### ***Particulate Organic Carbon***

Particulate organic carbon (POC) concentrations provide a measure of the energy stored in particulate organic matter that included both phytoplankton and particulate detritus. In our study lakes, chlorophyll *a* concentration explained 74% of the variance in POC indicating that the content of POC was mostly of phytoplankton origin (Figure 17). POC levels were approximately 50 times the concentration of chlorophyll *a*. Average POC concentrations ranged from 218  $\mu\text{g L}^{-1}$  to 791  $\mu\text{g L}^{-1}$  in the 1-m stratum and from 284  $\mu\text{g L}^{-1}$  to 937  $\mu\text{g L}^{-1}$  within the hypolimnion. POC levels were lowest in Big Lake and highest in Finger Lake. Though absolute concentrations were quite variable among lakes, there were similarities in the temporal development of POC in some of the lakes. For example, epilimnetic POC maxima occurred in the spring (May) and fall (September-October) in Big, Cottonwood, Finger, and Wasilla lakes (Appendix Table B). In contrast, POC peaked in mid-summer (July) in Knik Lake, remained relatively constant throughout the season in Lorraine Lake, and gradually decreased over the course of the season in Threemile Lake (Appendix Table B).

### ***Phytoplankton***

Chlorophyll *a* (chl *a*) is a measure of the green pigment contained in planktonic algae and therefore is considered a reasonable index of the composite algal biomass in a water body (Wetzel 1983). Algal biomass, on the basis of individual chl *a* measurements in the seven study lakes, ranged from 0.3  $\mu\text{g L}^{-1}$  to 11.2  $\mu\text{g L}^{-1}$  within the 1-m stratum and from 0.5  $\mu\text{g L}^{-1}$  to 23.1  $\mu\text{g L}^{-1}$  in the hypolimnion. Average chl *a* concentrations spanned one order of magnitude and ranged from 0.8  $\mu\text{g L}^{-1}$  to 8.1  $\mu\text{g L}^{-1}$  within the 1-m stratum and from 1.3  $\mu\text{g L}^{-1}$  to 10.9  $\mu\text{g L}^{-1}$  in the hypolimnion. Epilimnetic chl *a* reached peak concentrations in late summer (September) or fall (October) in Cottonwood, Finger, and Knik lakes, whereas chl *a* was relatively constant throughout the season in Big, Lorraine, and Threemile lakes. On the other hand, chl *a* maxima occurred in May and September in Wasilla Lake. Summer (31 July-01 August) values of chl *a* were highest in Finger Lake (9.8  $\mu\text{g L}^{-1}$ ) and lowest in Lorraine Lake (0.7  $\mu\text{g L}^{-1}$ ) (Appendix Table B). In



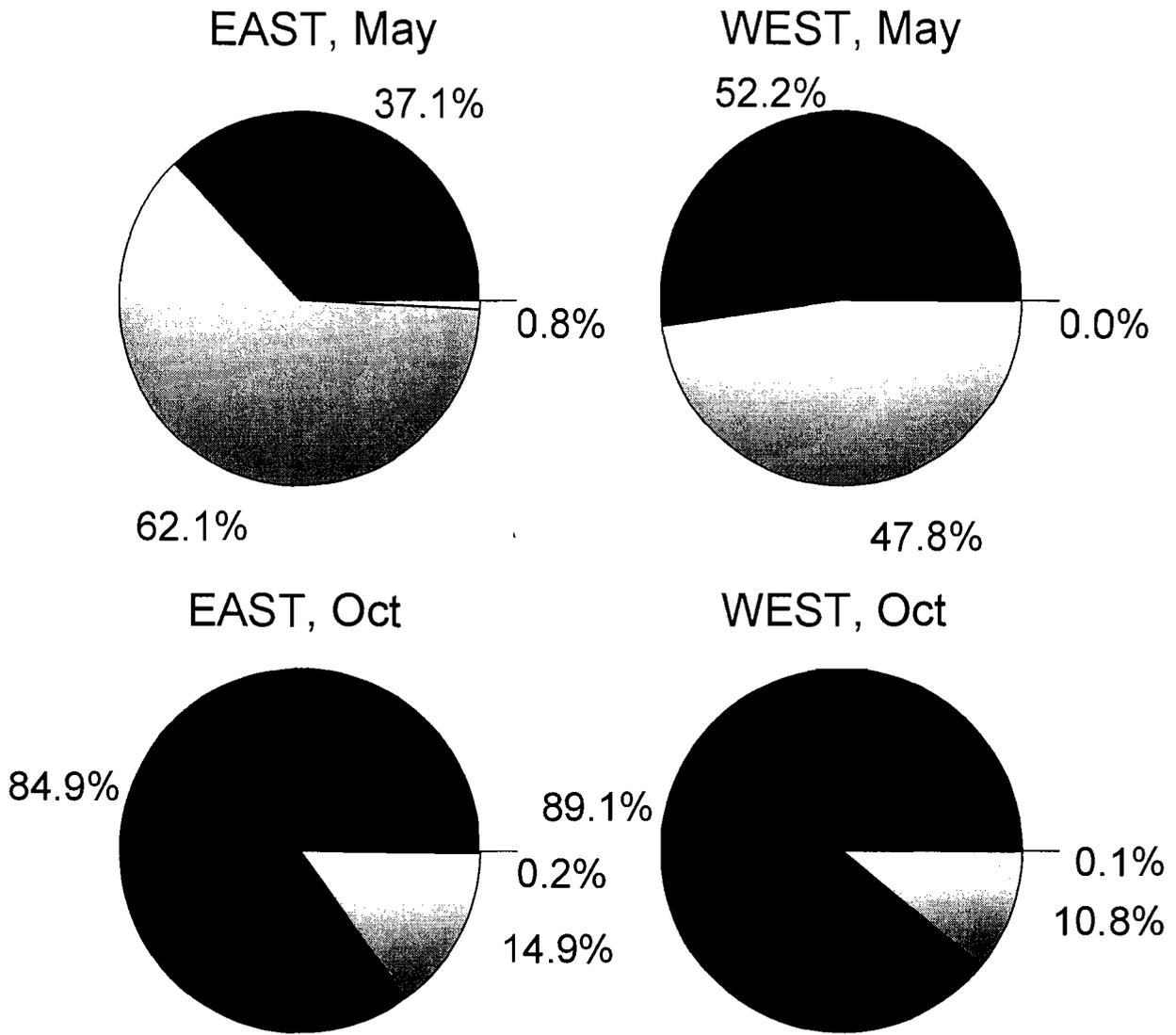
**Figure 17.** Relationship between particulate organic carbon (POC) and chlorophyll *a* (CHL) for the seven study lakes.

comparison, summer chl *a* values for the deeper depths sampled were highest in Knik Lake (23.1  $\mu\text{g L}^{-1}$ ) and lowest in Lorraine Lake (0.7  $\mu\text{g L}^{-1}$ ) (Appendix Table B). Given the vertical heterogeneity in TP and TN among the stratified lakes, we assumed chl *a* levels would also be higher at depth than near the surface. Contrary to our expectations, results of ANOVA suggested there was no differences in chl *a* associated with depth. However, the reported probability value ( $P=0.066$ ) for the testing term was only slightly greater than our prescribed significance level ( $\alpha=0.05$ ). Thus, chl *a* may be affected by depth (stratification).

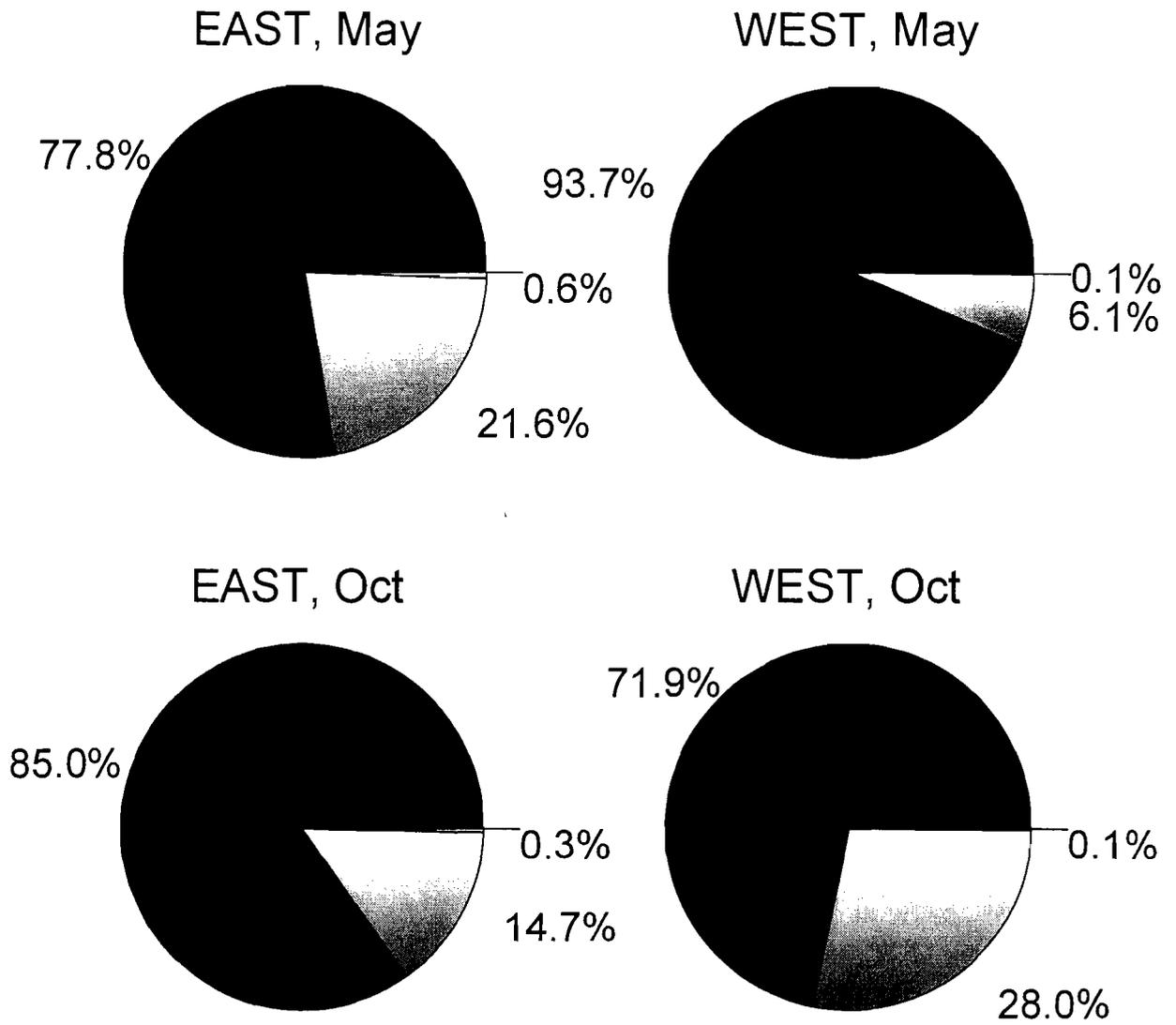
The phytoplankton communities in the seven lakes during May and October were dominated numerically (number of cells per ml) by ultra-algae (2-10  $\mu\text{m}$ ) of unknown species and by cyanobacteria (Figure 18-21). *Microcystis* sp. dominated the cyanobacteria assemblage in Big, Cottonwood, Knik, Lorraine, and Threemile lakes, whereas collectively the species *Microcystis* sp., *Oscillatoria* sp. and *Lyngbya* sp. made up the cyanophyte group in Finger and Wasilla lakes. In terms of biomass (Figure 22), ultra-algae were the most abundant group in Big, Lorraine, Threemile and Wasilla lakes in May, whereas larger micro-algae (>20-64  $\mu\text{m}$ ) composed most of the biomass in Cottonwood Lake. In comparison, the phytoplankton biomass in Finger Lake was made up of approximately equal proportions of cyanophytes, ultra-algae, and nano-algae (10-20  $\mu\text{m}$ ). During the October survey, the deeper west basin of Big Lake was dominated entirely by the cyanobacteria species *Microcystis* sp. This phytoplankton species was also prevalent in Cottonwood and Finger lakes. *Microcystis*, *Lyngbya*, and *Oscillatoria* spp. composed the cyanobacteria biomass component in Wasilla Lake, but both ultra-algae and micro-algae made up most of the total phytoplankton biomass. The algal biomass of Knik Lake was dominated by the dinoflagellates (pyrrophytes) *Chroomonas* sp. and *Cryptomonas* sp. Ultra-algae and the dinoflagellate species *Peridinium* sp. composed the phytoplankton in Threemile Lake. Chlorophytes (green algae) and the classes Chrysophyceae and Bacillariophyceae (diatoms) of the Division Chrysophyta (golden algae) were uncommon in all lakes in terms of their biomasses. A complete list of common and dominant phytoplankton species for each lake are provided in Appendix Table C.

### ***Nutrient-Chlorophyll Models***

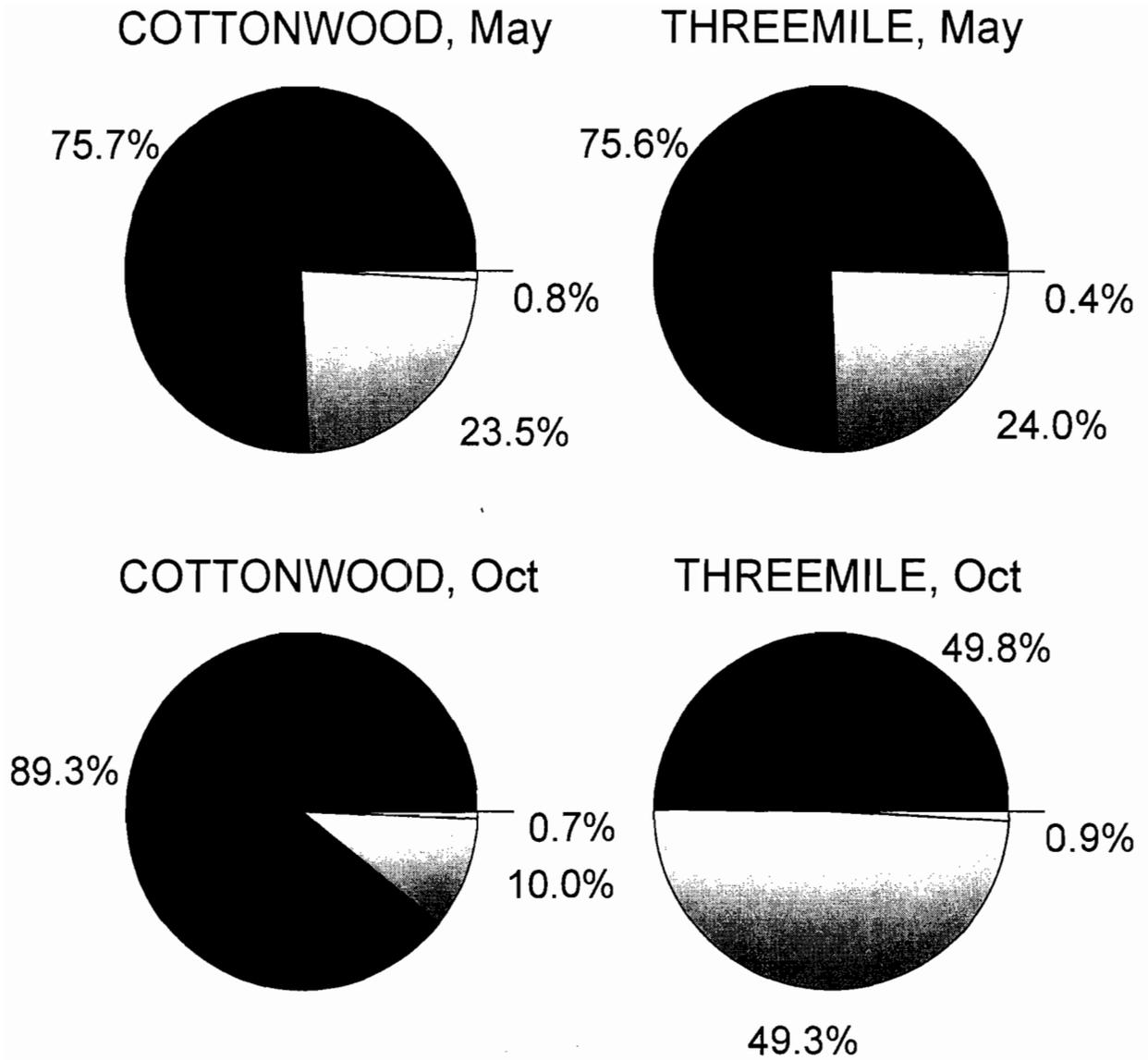
The relationships between chlorophyll *a* (chl *a*) and phosphorus have been well documented for many northern temperate and subarctic lakes (Dillon and Rigler 1974; Stockner and Shortreed 1986; Shortreed and Stockner 1986; Ostrofsky and Rigler 1987; Mazumder 1994ab; Edmundson and Carlson 1998). Considering individual measurements ( $n=43$ ) rather than using seasonal mean values, a significant ( $P<0.001$ ) and strong response ( $r^2 = 0.74$ ) existed between TP and chl *a* for our study lakes (Figure 23A). The slope of the regression (1.79) was similar to that previously derived (1.51) for 25 lakes in the Mat-Su Borough (Edmundson and Todd 2001). There is also empirical evidence that the amount of phytoplankton can be limited by nitrogen (Smith 1982). Although a significant ( $P<0.001$ ) response existed between TN and chl *a* for our study lakes (Figure 23B), the relationship was only moderately strong ( $r^2 = 0.42$ ). We then



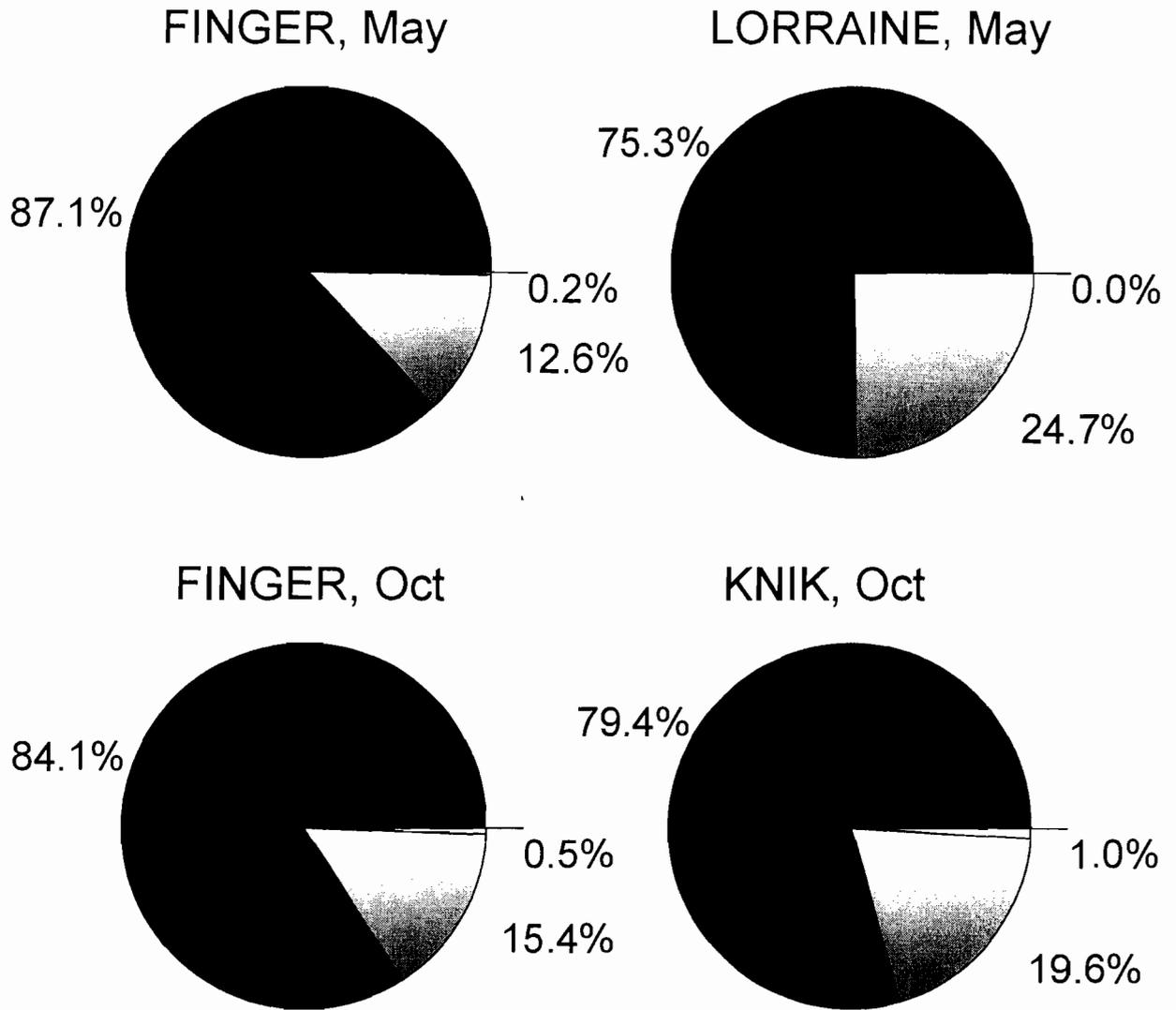
**Figure 18.** Percentage abundance (by density) of cyanophytes (solid slice), ultra-algae (shaded slice), and all other phytoplankton assemblage groups combined (no fill) at two stations in Big Lake. Data are for May and October 2001 survey dates.



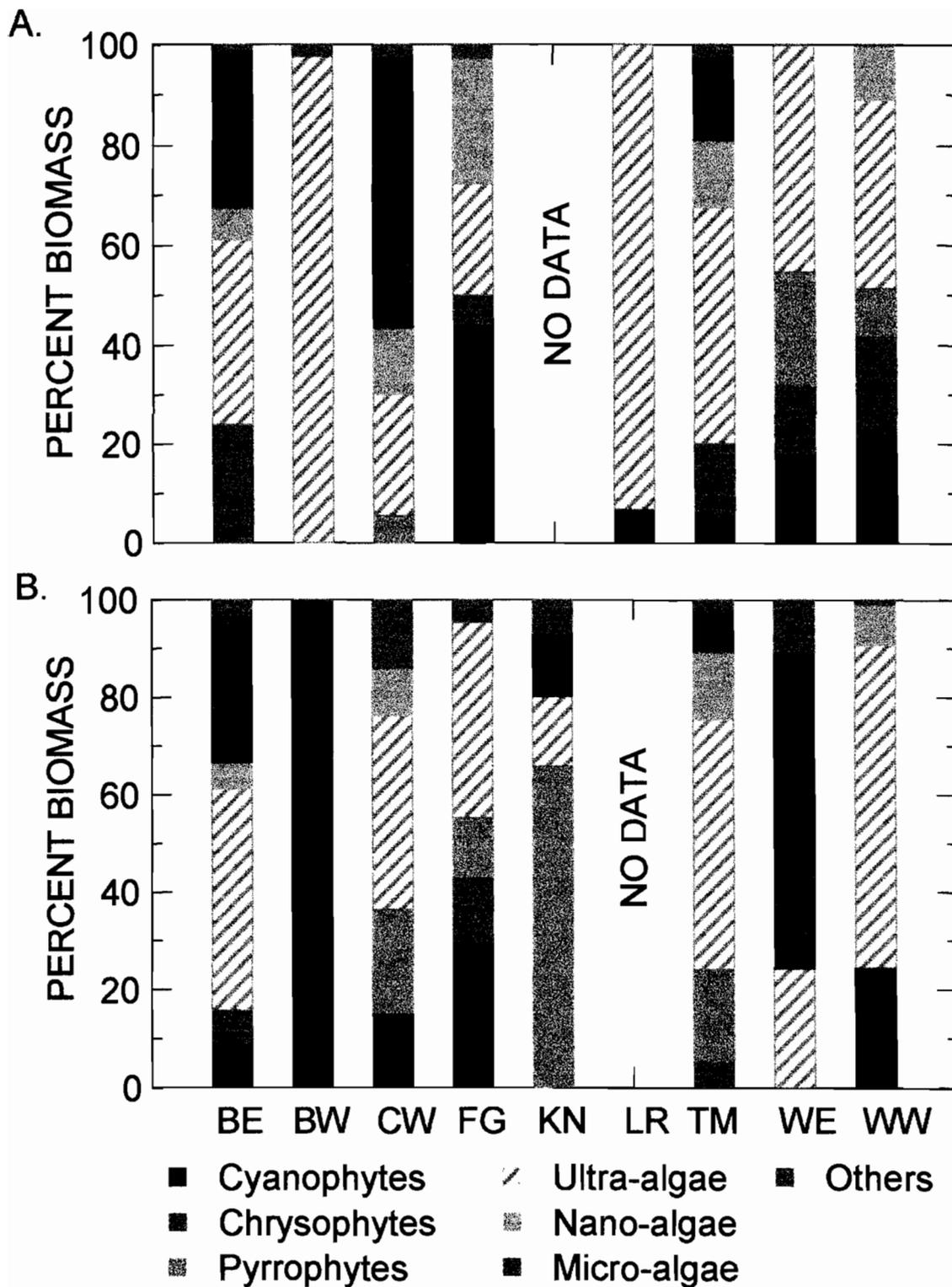
**Figure 19.** Percentage abundance (by density) of cyanophytes (solid slice), ultra-algae (shaded slice), and all other phytoplankton assemblage groups combined (no fill) at two stations in Wasilla Lake. Data are for May and October 2001 survey dates.



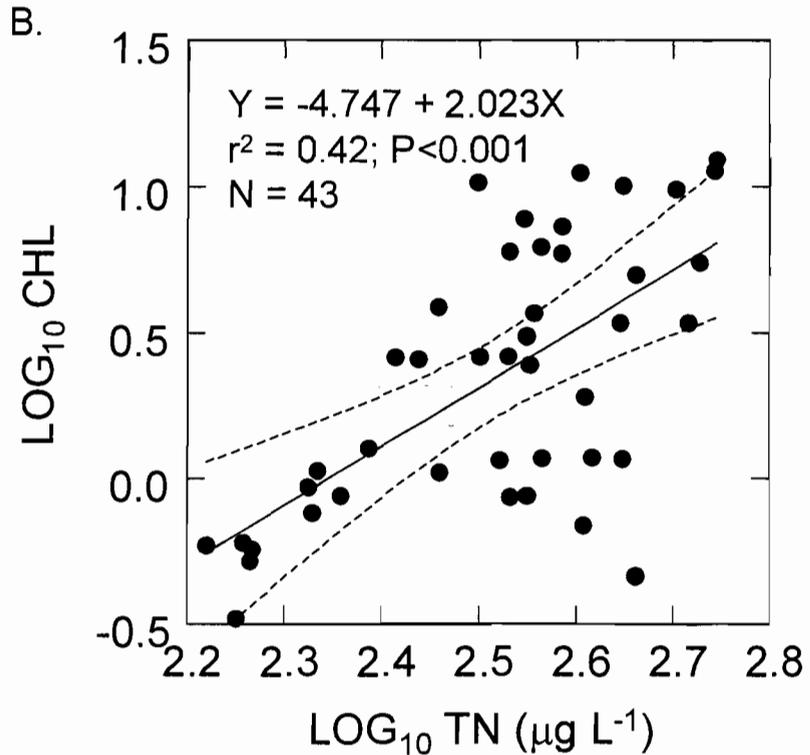
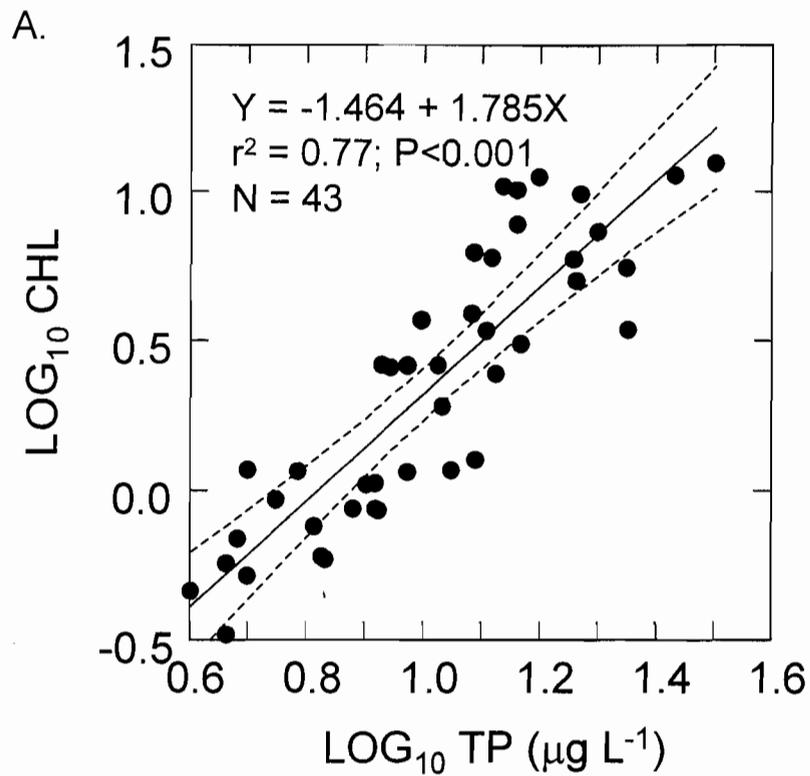
**Figure 20.** Percentage abundance (by density) of cyanophytes (solid slice), ultra-algae (shaded slice), and all other phytoplankton assemblage groups combined in Cottonwood and Threemile lakes. Data are for May and October survey dates.



**Figure 21.** Percentage abundance (by density) of cyanophytes (solid slice), ultra-algae (shaded slice), and all other phytoplankton assemblage groups combined (no fill) in Finger Lake (May and October), Lorraine Lake (May), and Knik Lake (October), 2001.



**Figure 22.** Percentage wet biomass ( $\mu\text{g L}^{-1}$ ) of major phytoplankton assemblages. Data are for (A) May and (B) October, 2001 survey dates: Big Lake (east) (BE), Big Lake (west) (BW), Cottonwood Lake (CW), Finger Lake (FG), Knik Lake (KN), Lorraine Lake (LR), Threemile Lake (TM), Wasilla Lake (east) (WE), and Wasilla Lake (west) (WW).



**Figure 23.** The relationship between (A) total phosphorus (TP) and chlorophyll *a* (*CHL*); and (B) total nitrogen (TN) and *CHL* for the seven study lakes. Dashed lines are 95% confidence intervals.

considered both TP and TN together as predictors of chl *a* concentration in a multiple regression. Both variables were selected using the backward elimination procedure. However, TP and TN together accounted for only an additional 4% of the variation in chl *a* than did TP alone. The multiple regression equation was:

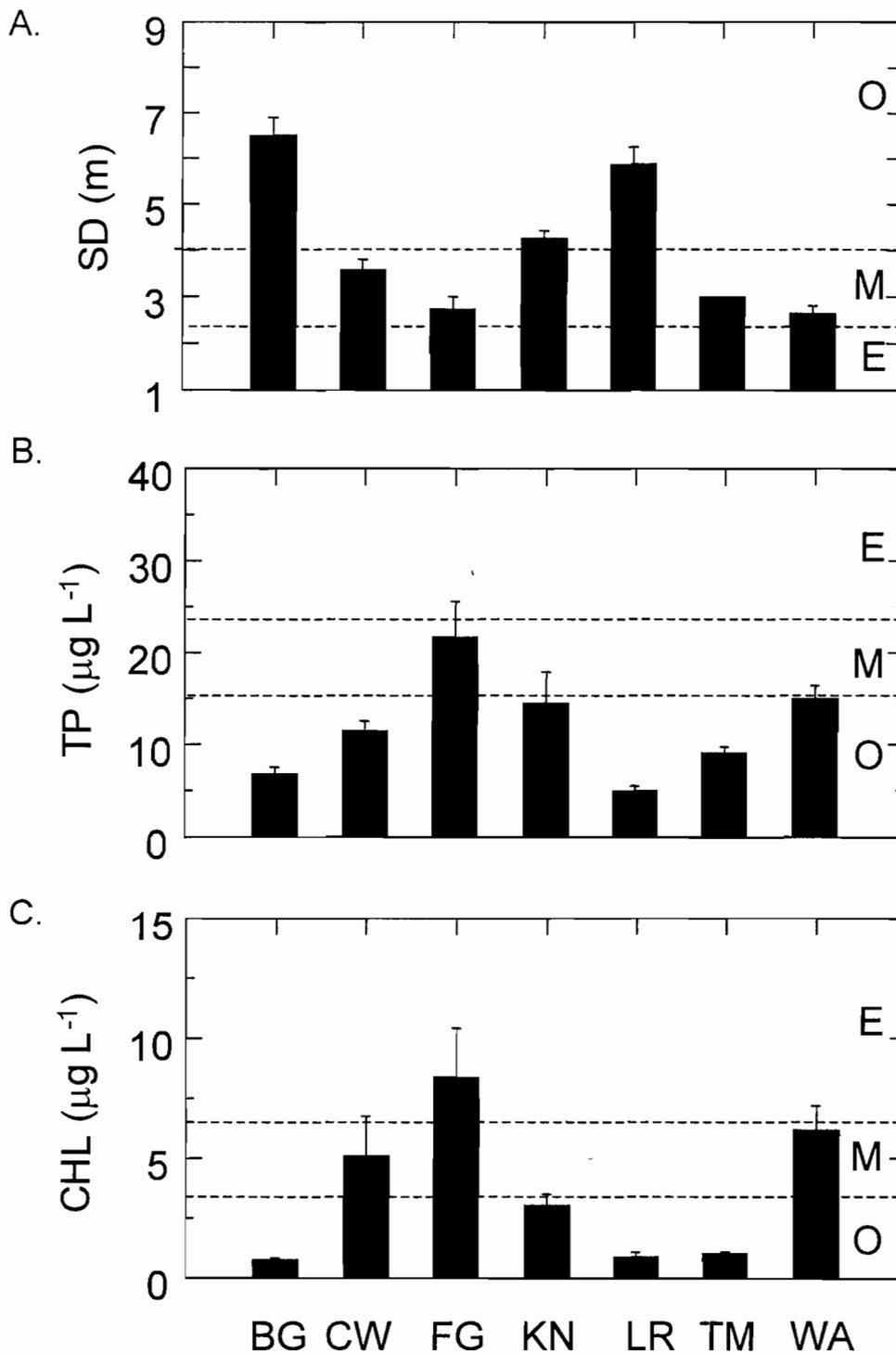
$$\text{Chl } a = -2.472 + 1.586\text{TP} + 0.480\text{TN} \quad (r^2 = 0.78; P < 0.001).$$

### ***Trophic Status***

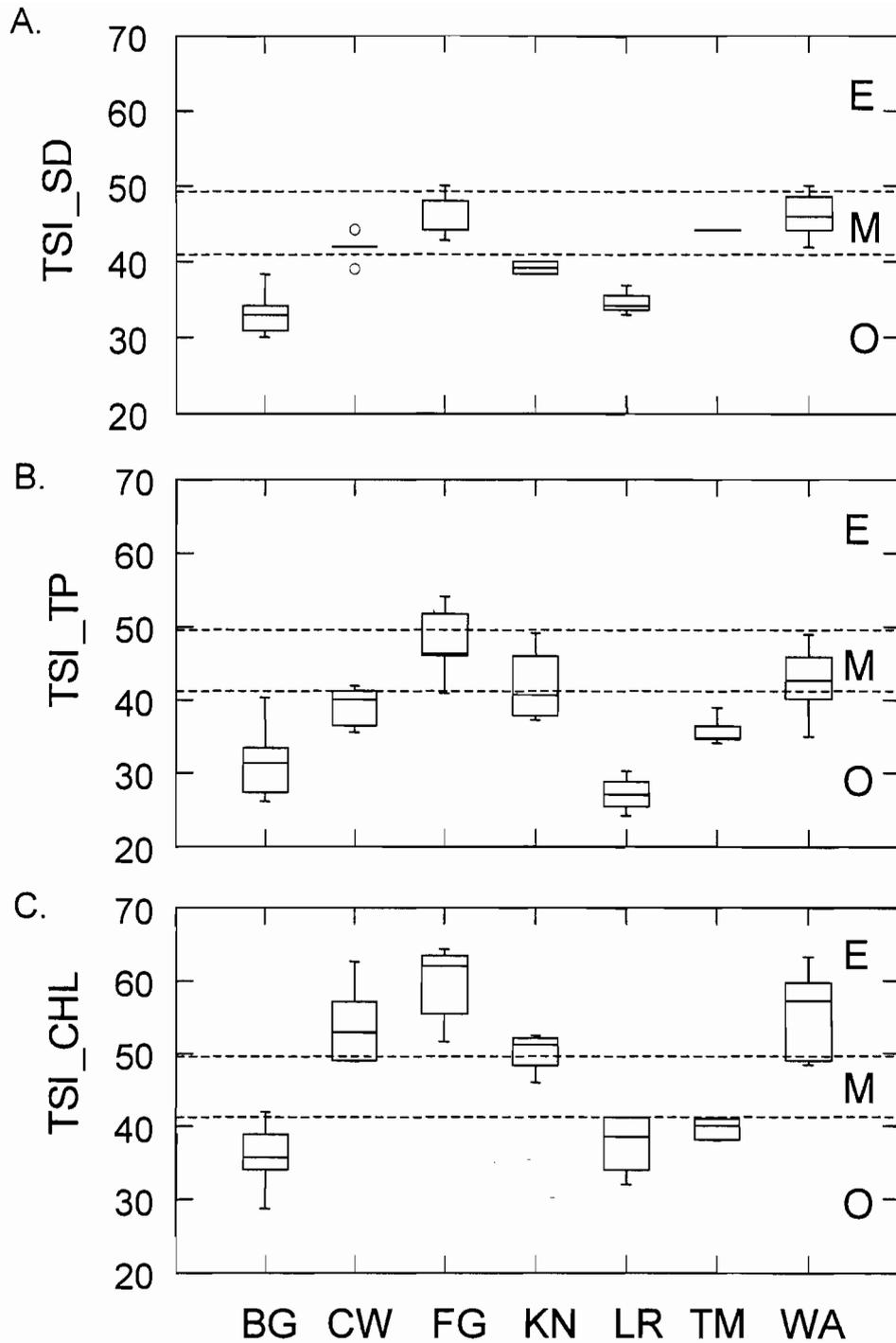
The present trophic status of a lake is determined by its original or intrinsic characteristics and by its history since formation. For all lakes, the natural tendency is to become shallower and more productive as it gradually fills with sediment (Wetzel 1983). Nutrient loading and productivity of algae and macrophytes increases in response to more nutrients. By using mean values for one or more of the variables SD, TP, TN, and chl *a*, a lake can be classified from nutrient rich (eutrophic) to nutrient poor (oligotrophic) (Cooke et al. 1993; Nürnberg 1996). Although classification schemes have been applied to many different lakes spanning broad geographic regions, the threshold values are fairly similar. Based on the Forsberg and Ryding (1980) criteria for classifying lakes into trophic states (Figure 24A-C), Big, Knik, and Lorraine lakes were oligotrophic and Wasilla Lake was classified as mesotrophic. In comparison, Threemile Lake was oligotrophic based on TP and chl *a*, but mesotrophic with respect to SD. Cottonwood Lake was classified as oligotrophic based on TP and mesotrophic relative to mean SD and chl *a*. Finger Lake was assigned the mesotrophic condition based on SD and TP, but was classified as eutrophic in terms of chl *a*. Cottonwood and Wasilla lakes fell on the mesoeutrophic boundary relative to chl *a*.

Carlson's (1977) trophic state index (TSI) is another commonly used method to evaluate trophic state in lakes and reservoirs. The basic idea is that changes in phosphorus cause changes in algal biomass, which affects water clarity. However, TSI is not a useful index in those lakes with high non-algal turbidity or color (Brezonik 1978; Megard et al. 1980; Lind 1986) or those with extensive rooted plant populations (Canfield et al. 1984). When used appropriately, TSI removes some of the subjectivity inherent in trophic classification terms such as oligotrophic, mesotrophic and eutrophic. The TSI model converts SD, TP, and chl *a* values to a standardized numerical scale ranging from 1 to 100. An increase in 10 TSI units represents a doubling of algal biomass. The general rule is that TSI values less than 40 are associated with the oligotrophic conditions; values between 40 and 50 are commonly interpreted as mesotrophic and values greater than 50 are considered to represent the eutrophic condition (Carlson 1977). That is, TSI defines the degree of eutrophication within each classification in a more objective appraisal.

We constructed box plots to conveniently summarize the TSI data for the Mat-Su study lakes. As seen from the median TSI values (Figure 25A-C), Big Lake and Lorraine Lake were classified as oligotrophic based on all three indices. TSI values based on SD and TP indicated Knik Lake was oligotrophic, but the lake was considered eutrophic using TSI values derived from chl *a*. In comparison, TSI values derived from either TP or chl *a*



**Figure 24.** Average values for (A) Secchi depth (*SD*), (B) total phosphorus (*TP*), and (C) chlorophyll *a* (*CHL*) for the seven study lakes relative to the Forsberg and Ryding (1980) trophic criteria (O = oligotrophic, M = mesotrophic, and E = eutrophic): Big (BG), Cottonwood (CW), Finger (FG), Knik (KN), Lorraine (LR), Thremile (TM), and Wasilla (WA). Vertical lines are one standard error.



**Figure 25.** Box plots of Carlsons's (1977) trophic state index (TSI) based on (A) Secchi depth (SD), (B) total phosphorus (TP), and (C) chlorophyll *a* for the seven study lakes: Big (BG), Cottonwood (CW), Finger (FG), Knik (KN), Lorraine (LR), Threemile (TM), and Wasilla (WA). Box shows the interquartile range, horizontal line within box is the median, whiskers show range of values within  $\pm 1.5$  times the box edges, and values greater than  $\pm 1.5$  times the box edges are shown as open circles. Dashed lines indicate the boundaries between oligotrophic (O), mesotrophic (M), and eutrophic (E) states.

suggested Threemile Lake was oligotrophic, but the lake was mesotrophic based on SD. On the other hand, TSI values for Cottonwood Lake were classified as oligotrophic when computed from TP, but was mesotrophic based on SD and eutrophic based on chl *a* levels. Both Finger and Wasilla lakes were classified as mesotrophic with respect to SD or TP, but they were considered eutrophic systems when TSI was computed from chl *a* data. The overall conclusion is that reliable information of lake trophic state requires consideration of all key variables together because it is the dynamics of the whole system that are important. Collectively, the spread (data availability) around the medians for each of the three TSI indices suggested that Big Lake and Lorraine Lake are probably oligotrophic, Knik Lake is oligo-mesotrophic, and Cottonwood, Finger, and Wasilla lakes are mesoeutrophic, which is similar to our other findings based on examination of mean phosphorus concentration, chl *a* levels, and Secchi depth.

## CONCLUSIONS and RECOMMENDATIONS

Although there is ample empirical evidence for the role of phosphorus and nitrogen in limiting productivity of lakes (Canfield 1983), the combination of relatively high (greater than 15:1) N:P ratios (Table 2) and the strong dependence of algal biomass (chl *a*) on TP (Figure 23A) suggest that phosphorus is more limiting than nitrogen in the seven Mat-Su study lakes. However, the availability of light energy can be another important limiting factor. For example, reservoirs often have inorganic turbidities from suspended clay particles (Hoyer and Jones 1983). In Alaska, sockeye salmon lakes that have elevated turbidities from glacial meltwater or yellowish color derived from humic acids in the watershed exhibited significantly lower chl *a* yield per unit TP compared to clear lakes (Edmundson and Carlson 1998). For the Mat-Su study lakes, our data show that transparency and light penetration are largely a function of algal turbidity (chl *a*) rather than inorganic sediment or color. Thus, nutrients (phosphorus) rather than light limits algal biomass in these lakes. Nonetheless, identifying lake typology is critical in developing appropriate nutrient criteria for different lake types (Edmundson et al. 2000); e.g., clear, stained, and glacial lakes (Koenings and Edmundson 1991; Edmundson and Carlson 1998). *For future water research, we recommend continuing the collection of water samples for both turbidity and color along with paired measurements of transparency (Secchi depth) and light penetration (photometer readings) because together these data impart additional information about the nature of the principal light-attenuating component in natural lakes that is not interpretable by either Secchi disk or photometer readings alone.*

Traditionally, limnologists examine near-surface values of SD, TP, TN, and chl *a* as indicators of lake water quality and trophic state. The general implication of the foregoing results is that the lakes in our study are generally considered oligomesotrophic, with the exception of Finger Lake and perhaps Wasilla Lake, which are symptomatic of a

mesoeutrophic system based on measurements obtained from the 1-m stratum. However, in some lakes stratification may result in physical, chemical, and biological differences between the surface and bottom waters (Wetzel 1983). In the stratified lakes in this study, TN, TP, and chl *a* showed a consistent vertical pattern in that concentrations were higher in the hypolimnion than the near surface (Tables 2-3). The occurrence of deep-lying chlorophyll maxima was discovered in Big Lake and Wasilla Lake (Woods 1985a) and in four of nine other lakes in the Mat-Su Borough (Woods 1985b), which yielded a much higher trophic ranking than chl *a* levels derived from their surface waters. A hypolimnetic chlorophyll maxima has also been documented in Bear Lake, near the city of Seward, Alaska (Kyle 1994). We agree with Woods (1985a) that reconnaissance type surveys based only on near-surface concentrations of TP, TN, and chl *a* may underestimate trophic status. *Therefore, to obtain meaningful information on the vertical distribution of water quality parameters, we recommend continuing taking bottom water samples in any future water quality-monitoring or trophic assessment program. Alternatively, it may be appropriate to collect a vertical column of water using standardized integrated (e.g., tube) sampling.*

The mixing action of spring and fall overturn distributes oxygen and nutrients throughout the water column. Capturing conditions at turnover, particularly in the spring, is critical in assessing phosphorus (P) loading and a lake's response to P inputs (Vollenweider 1976). Predicting how a lake will respond to a change in nutrient loading rate can be useful to lake managers in determining how to best to reduce nutrient inputs to improve water quality. Use of specific P-loading models developed for different lake types or ecoregions can also provide insight into the sensitivity of lakes to changes in P inputs. Such models require information on watershed delineation, annual precipitation, and good estimates of water inputs and outputs to determine hydraulic residence time (the time a water molecule spends in a lake). *Future research should include model development of nutrient loading and budgets relative to in-lake nutrient concentrations and conditions because application of the models aids in water resources planning.*

In terms of water quality, dense macrophyte growths rather than free-floating algae can also impair a lake's aesthetic appeal and hinder its recreational use including swimming, boating, fishing, and operating floatplanes. Shallow, warm, nutrient-rich systems have the potential to produce nuisance growths of aquatic rooted plants. In our study, we did not obtain quantitative data on macrophytes; however, previous research showed that dense beds of macrophytes dominated shallow Lucille Lake (Woods 1985a) in the Palmer-Wasilla area (Alaska) and in Robe Lake near the city of Valdez (Alaska) (Koenings et al. 1987), which caused major water quality problems. Nearly two decades ago, a synoptic limnology survey of nine lakes in the Mat-Su Borough revealed that rooted aquatic plants were prevalent during the summer months along some of the area's lake shorelines (Woods 1985b). Given the rapid development in and around the Mat-Su region over the past and commensurate increase in population and number of lake shore residences (BLCAC 1998), a potential negative impact on water quality exists including a greater abundance and distribution of macrophytes. *Therefore, a comprehensive water quality program to develop nutrient criteria should also attempt to quantify the extent of*

*macrophytes by mapping the distribution of plants at the surface and collecting above-ground (sediment) samples to estimate community composition, density, and biomass.*

There is also substantial evidence that abundance and kinds of herbivorous zooplankton can regulate the biomass and structure of the phytoplankton community. For example, it has been observed that when large herbivorous zooplankton (e.g., *Daphnia*) populations are abundant, as happens when the density of zooplanktivorous fish is low, algal biomass decreases and transparency increases (Northcote 1988). Conversely, small algae tend to increase and water transparency decreases when planktivorous fish are abundant. Put another way, when planktivorous fish are less abundant, systems tend to move in the direction of relative oligotrophy, whereas increasing planktivory moves the system toward relative eutrophy. Thus, it is important to understand whether foodweb structure is affecting the abundance, seasonality, and kinds of phytoplankton. *As many of the lakes in this study, as well as others within the Mat-Su Borough, contain juvenile salmonids (i.e., planktivorous fry) (Woods 1985ab), we recommend collecting additional information on zooplankton abundance and species composition as part of future lake-monitoring efforts aimed at developing nutrient criteria.*

Finally, development of nutrient criteria for subarctic Alaskan lakes is beyond the scope of this study. Rather, our intention was to initiate a lake monitoring program and report on water quality and specific conditions for a set of seven urban lakes within the Mat-Su Borough. Originally, this was to be a three-year study; however, funding for continued monitoring was curtailed due to budget constraints following the 2001 field season. A problem common to many of these types of limnological surveys is the short-term duration of the work and paucity of data, which makes it difficult when interpreting results and assessing natural variability. Nonetheless, we have constructed a database containing 100 individual measurements of water chemistry, nutrient concentrations, and algal biomass for developing nutrient criteria in subarctic Alaskan lakes considered to be within a more urban type of setting. These data can also be concatenated with a larger historical data set previously derived for 25 lakes in the Mat-Su Borough (Edmundson et al. 2000), as all limnological surveys and laboratory analysis were conducted in a consistent fashion (Koenings et al. 1987) in both studies. Together, these databases comprise 415 individual observations representing 78 lake-year observations from a total of 32 lakes. *Nonetheless, we strongly encourage a multi-year (2-3 year) sampling protocol for lakes in order to help identify sources of spatial and temporal variability in water quality and trophic conditions. Future research should be devoted to assessing the spatial and temporal distribution of water quality data throughout the designated ecoregion, establishment of reference values, and further modeling of data to develop appropriate nutrient criteria.*

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## REFERENCES

- American Public Health Association (AHAP), American Water Works Association and Water Pollution Control Federation. 1985. Standard methods for the examination for water and wastewater. 16<sup>th</sup> edition, New York, NY. 1268p.
- Big Lake Citizen's Advisory Committee (BLCAC). 1998. Big Lake, lake management plan. Prepared by Unwin Scheben Korynta Huetti, Inc. (USKH) and Dames and Moore Group.
- Brezonik, P. L. 1978. Effect of organic color and turbidity on Secchi disk transparency. *J. Fish. Res. Bd. Can.* 35:1410-1416.
- Carlson, E. E. 1977. A trophic index for lakes. *Limnol. Oceanogr.* 22:361-369.
- Canfield, D. E. Jr., 1983. Prediction of chlorophyll *a* concentrations in Florida lakes: the importance of phosphorus and nitrogen. *Water Res. Bull.* 19:255-262.
- Canfield, D. E. Jr., J. V. Shireman, D. E. Colle, W. T. Haller, C. Watkins, and M. J. Maceina. 1984. Prediction of chlorophyll *a* concentrations in Florida lakes: importance of macrophytes. *Can. J. Fish. Aquat. Sci.* 41:497-501.
- Cooke, G. D., E. B. Welch, S. A. Peterson, and P. R. Newroth. 1991. Restoration and management of lakes and reservoirs. Lewis Publishers, Ann Arbor, MI.
- Davis, J. C. and eight others. 1979. Dissolved oxygen. Pages 169-174 *In* A review of the EPA Red Book: quality criteria for water, R.V. Thurston, R.C. Russo, C.M. Fellerolf, T.A. Edsall, and Y.M. Barber, Jr. [eds.]. Water Quality Section, American Fisheries Society, Bethesda, MD.
- Dillon, P. J. and F. H. Rigler. 1974. The phosphorus-chlorophyll *a* relationship in lakes. *Limnol. Oceanogr.* 19:767-773.

- Dillon, P. J. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. *J. Fish. Res. Board Can.* 32:1519-1531.
- Edmundson, J. A. and S. R. Carlson. 1998. Lake typology influences on the phosphorus-chlorophyll relationship in subarctic, Alaskan lakes. *Lake and Reserv. Managt.* 14:440-450.
- Edmundson, J. A. and G. L. Todd. 2001. Central region limnology 2001 annual report of progress. Ak. Dept. Fish and Game, Division of Commercial Fisheries, Regional Information report No. 2A01-16:48p.
- Edmundson, J. A., J. P. Koenings, and T.C. Wilson. 1989. Finger Lake water quality: August 1988. Ak. Dept. Fish and Game, FRED Division Technical Report Series 92:31p.
- Edmundson, J. A., V. P. Litchfield, and D. M. Cialek. 2000. An assessment of trophic status of 25 lakes in the Matanuska-Susitna Borough, Alaska. Ak. Dept. Fish and Game, Division of Commercial Fisheries, Regional Information Report No.2A00-26:41p.
- Eisenreich, S. T., R. T. Bannerman, and D. E. Armstrong. 1978. A simplified phosphorus analysis technique. *Environ, Lett.* 9:43-53.
- Forsberg, C. and S. Ryding. 1980. Eutrophication parameters and trophic state indices in 30 Swedish waste-receiving wastes. *Arch. Hydrobiol.* 80:189-207.
- Gibson, G. and eight others. 2000. Nutrient criteria technical guidance manual, lakes and reservoirs. U.S. EPA Report 8222-B00-001.
- Hoyer, M. V. and J. R. Jones. 1983. Factors affecting the relationship between phosphorus and chlorophyll *a* in Midwestern reservoirs. *Can. J. Fish. Aquat. Sci.* 40:192-199.
- Kirk, J. T. O. 1994. Light and photosynthesis in aquatic ecosystems 2<sup>nd</sup> edition. Cambridge University Press, Cambridge, UK.
- Koenings, J. P. and J. A. Edmundson. 1991. Secchi disk and photometer estimates of light regimes in Alaskan lakes: effects of yellow color and turbidity. *Limnol. Oceanogr.* 36:91-105.
- Koenings, J. P., J. A. Edmundson, G. B. Kyle, and J. M. Edmundson. 1987. Limnology field and laboratory manual: methods for assessing aquatic production. Ak. Dept. Fish and Game, FRED Division Technical Report Series 71:212p.

- Koenings, J. P., D. Barto, and G. Perkins. 1987. Assessing the water quality of Robe Lake, Alaska, 1981-1982. Ak. Dept. Fish and Game, FRED Division Technical Report Series 77:82p.
- Kyle, G. B. 1994. Assessment of trophic level responses and coho salmon (*Oncorhynchus kisutch*) production following nutrient treatment (1981-1986) of Bear Lake, Alaska. *Fish. Res.* 20:243-261.
- LaPerriere, J. D. 1997. Limnology of two lake systems of Katmai National Park and Preserve, Alaska: physical and chemical profiles, major ions and trace elements. *Hydrobiol.* 354:89-99.
- Lind, O. T. 1986. The effect of non-algal turbidity on the relationship of Secchi depth to chlorophyll *a*. *Hydrobiol.* 140:27-35.
- Mazumder, A. 1994a. Phosphorus-chlorophyll relationships under contrasting herbivory and thermal stratification: predictions and patterns. *Can. J. Fish. Aquat. Sci.* 51:390-400.
- Mazumder, A. 1994b. Phosphorus-chlorophyll relationships under contrasting zooplankton community structure. *Can. J. Fish. Aquat. Sci.* 51:456-466.
- Mazumder, A. and K. E. Havens. 1998. Nutrient-chlorophyll-Secchi relationships under contrasting grazer communities of temperate versus tropical lakes. *Can. J. Fish. Aquat. Sci.* 55:1652-1662.
- McCauley, E., J. A. Downing, and S. Watson. 1989. Sigmoid relationships between nutrients and chlorophyll among lakes. *Can. J. Fish. Aquat. Sci.* 46:1171-1175.
- Megard, R. O., J. C. Settles, H. A. Boyer, and W. S. Combs, Jr. 1980. Light, Secchi disks, and trophic states. *Limnol. Oceanogr.* 25:373-377.
- Neter, J., W. Wasserman, and M. H. Kunter. 1990. Applied linear statistical models: regression, analysis of variance, and experimental designs. Iwrin Press, Burr Ridge, IL.
- Newel, R. I. E. 1982. An evaluation of the wet oxidation technique for use in determining the energy content of seston samples. *Can. J. Fish. Aquat. Sci.* 39:1383-1388.
- Northcote, T. E. 1988. Fish in the structure and function of freshwater ecosystems: a "top-down" view. *Can. J. Fish. Aquat. Sci.* 45:361-379.

- Nürnberg, G. K. 1996. Trophic state of clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. *Lake and Reserv. Managmt.* 12:432-447.
- Ostrofsky, M. L. and F. H. Rigler. 1987. Chlorophyll-phosphorus relationships for subarctic lakes in western Canada. *Can. J. Fish. Aquat. Sci.* 44:775-781.
- Prepas, E. E. 1983. Total dissolved solids as a predictor of lake biomass and productivity. *Can. J. Fish. Aquat. Sci.* 40:92-95.
- Reimann, B. 1978. Carotenoid interference in the spectrophotometric determination of chlorophyll degradation products from natural populations of phytoplankton. *Limnol. Oceanogr.* 23:1059-1066.
- Riley, E. T. and E. E. Prepas. 1985. Comparisons of the phosphorus-chlorophyll relationships in mixed and stratified lakes. *Can. J. Fish. Aquat. Sci.* 42:831-835.
- Ryder, R. A. 1965. A method for estimating the potential fish production of northern-temperate lakes. *Trans. Amer. Fish. Soc.* 94:214-218.
- Sakamoto, M. 1966. Primary production by phytoplankton community in some Japanese lakes and its dependence on lake depth. *Arch. Hydrobiol.* 62:1-28.
- Shortreed, K. S. and J. G. Stockner. 1986. Trophic status of 19 subarctic lakes in the Yukon Territory. *Can. J. Fish. Aquat. Sci.* 43:797-805.
- Smith, V. H. 1982. The nitrogen and phosphorus dependence of algal biomass in lakes: an empirical and theoretical analysis. *Limnol. Oceanogr.* 27:1101-1112.
- Spafard, M. A. and J. A. Edmundson. 2000. A morphometric atlas of Alaskan lakes: Cook Inlet, Prince William Sound, and Bristol Bay areas. Ak. Dept. Fish and Game, Division of Commercial Fisheries, Regional Information Report No.2A00-23:13p. +82 maps.
- Vollenweider, R. A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. *Mem. Inst. Ital. Idrobiol.* 33:53-83.
- Watson, S., E. McCauley, and J. A. Downing. 1992. Sigmoidal relationships between phosphorus, algal biomass, and algal community structure. *Can. J. Fish. Aquat. Sci.* 49:2605-2610.
- Wetzel, R. G. 1983. Limnology 2<sup>nd</sup> edition. Saunders College Publishing, Philadelphia, PA.

- Woods, P. F. 1985a. Potential for circumventing internal nutrient-recycling in Lucile Lake at Wasilla, Alaska, Pages 39-49 *In* Dwight, L. P. [ed.] resolving Alaska's water resources conflicts: Proceedings, Alaska Section, American Water Resources Association, Institute of Water resources/Engineering Experiment Station, University of Alaska Fairbanks, report IWR-108.
- Woods, P. F. 1985b. Limnology of nine small lakes, Matanuska-Susitna Borough, Alaska, and the survival and growth rates of rainbow trout. U.S. Geological Survey. Water-Resources Investigations report 85-4292:32p.
- Woods. P. F. 1986. Deep-lying chlorophyll maxima in Big lake: implications for trophic state classification of Alaskan lakes, Pages 195-200 *In* Kane, D. L. [ed] Proceedings of the Symposium: Cold regions Hydrology, University of Alaska Fairbanks. American Water Resources Association, Bethesda, MD.

**APPENDIX A**

**GENERAL WATER QUALITY BY SURVEY DATE, STATION, AND DEPTH FOR THE  
SEVEN STUDY LAKES**

**Appendix A.** General water chemistry by survey date, station, and depth for the seven study lakes.

Lake	Date	Sta	Depth (m)	Conductivity ( $\mu\text{mhos cm}^{-1}$ )	pH (Units)	Alkalinity ( $\text{mg L}^{-1}$ )	Turbidity (NTU)	Color (Pt units)	Calcium ( $\text{mg L}^{-1}$ )	Magnesium ( $\text{mg L}^{-1}$ )	Iron ( $\mu\text{g L}^{-1}$ )
Big	5/30/2001	E	1	143	7.4	58.2	1.2	10	20.6	3.9	73
Big	5/30/2001	E	5	.	.	.	.	.	.	.	.
Big	5/30/2001	E	8	137	7.3	62.4	2.0	14	20.6	3.9	96
Big	5/30/2001	W	1	127	7.5	69.0	1.4	14	18.9	3.9	36
Big	5/30/2001	W	5	.	.	.	.	.	.	.	.
Big	5/30/2001	W	12	132	7.6	62.8	1.2	13	18.8	3.9	46
Big	6/27/2001	E	1	131	7.5	57.6	1.4	9	18.6	2.2	38
Big	6/27/2001	E	6	.	.	.	.	.	.	.	.
Big	6/27/2001	E	8	135	7.2	61.2	1.4	10	19.1	2.8	32
Big	6/27/2001	W	1	133	7.6	59.0	1.3	15	17.8	2.7	30
Big	6/27/2001	W	6	.	.	.	.	.	.	.	.
Big	6/27/2001	W	10	137	7.2	60.3	1.0	13	18.6	2.7	29
Big	7/31/2001	E	1	131	7.6	58.8	0.8	12	18.5	3.5	50
Big	7/31/2001	E	5	.	.	.	.	.	.	.	.
Big	7/31/2001	E	10	143	7.0	64.5	1.2	9	19.8	3.8	50
Big	7/31/2001	W	1	130	7.7	58.8	0.5	10	18.6	3.3	27
Big	7/31/2001	W	10	.	.	.	.	.	.	.	.
Big	7/31/2001	W	14	139	7.1	62.8	0.4	8	19.6	3.6	27
Big	9/5/2001	E	1	134	7.3	59.6	0.6	10	19.0	3.7	46
Big	9/5/2001	E	11	144	6.6	64.6	1.5	9	20.8	3.7	80
Big	9/5/2001	W	1	126	7.5	59.0	0.4	6	18.4	3.4	32
Big	9/5/2001	W	15	138	6.8	61.8	0.6	5	19.7	3.6	32
Big	10/9/2001	E	1	135	7.4	62.5	1.5	11	19.2	3.6	55
Big	10/9/2001	E	11	138	7.3	63.9	1.6	9	19.3	3.6	83
Big	10/9/2001	W	1	132	7.3	61.5	0.6	5	19.4	3.7	18
Big	10/9/2001	W	15	139	6.9	64.3	0.9	6	19.9	3.7	23
Cottonwood	5/29/2001	M	1	202	7.7	97.8	2.5	23	33.2	5.4	46
Cottonwood	5/29/2001	M	8	218	7.5	103.4	4.3	13	21.8	9.4	69
Cottonwood	6/28/2001	M	1	174	8.0	78.5	1.6	15	21.3	3.9	42
Cottonwood	6/28/2001	M	3	.	.	.	.	.	.	.	.
Cottonwood	6/28/2001	M	6	228	7.0	105.1	4.2	9	29.4	3.8	37
Cottonwood	8/1/2001	M	3	.	.	.	.	.	.	.	.

## Appendix A. Continued.

Lake	Date	Sta	Depth (m)	Conductivity ( $\mu\text{mhos cm}^{-1}$ )	pH (Units)	Alkalinity ( $\text{mg L}^{-1}$ )	Turbidity (NTU)	Color (Pt units)	Calcium ( $\text{mg L}^{-1}$ )	Magnesium ( $\text{mg L}^{-1}$ )	Iron ( $\mu\text{g L}^{-1}$ )
Cottonwood	8/1/2001	M	7	224	7.1	105.5	2.9	13	27.2	6.4	82
Cottonwood	9/4/2001	M	1	197	7.7	90.5	1.3	14	28.7	5.0	66
Cottonwood	9/4/2001	M	8	200	7.5	92.6	1.8	14	27.7	5.1	93
Cottonwood	10/8/2001	M	1	209	7.7	99.1	0.8	15	32.5	4.9	38
Cottonwood	10/8/2001	M	8	210	7.7	99.4	0.9	19	31.8	5.5	42
Finger	5/29/2001	M	1	237	7.7	108.2	6.7	20	7.9	11.9	36
Finger	5/29/2001	M	3	.	.	.	.	.	.	.	.
Finger	5/29/2001	M	10	251	7.5	109.0	7.3	8	15.9	11.2	73
Finger	6/28/2001	M	1	228	8.0	92.0	2.2	11	16.7	8.3	30
Finger	6/28/2001	M	4	.	.	.	.	.	.	.	.
Finger	6/28/2001	M	7	262	7.0	111.3	2.5	8	34.8	5.3	82
Finger	8/1/2001	M	1	209	8.4	85.1	2.3	13	23.0	6.9	38
Finger	8/1/2001	M	4	.	.	.	.	.	.	.	.
Finger	8/1/2001	M	8	265	7.0	114.0	5.6	17	14.8	10.0	101
Finger	9/4/2001	M	1	211	7.8	84.8	2.4	12	22.8	7.5	54
Finger	9/4/2001	M	8	251	7.0	107.9	4.9	15	19.3	8.9	73
Finger	10/8/2001	M	1	226	7.6	94.7	2.7	10	22.1	10.6	35
Finger	10/8/2001	M	8	225	7.6	93.9	3.0	10	17.9	8.3	44
Knik	6/27/2001	M	1	174	8.3	79.0	1.4	14	22.0	3.0	37
Knik	7/31/2001	M	1	157	8.3	70.9	0.9	10	21.5	5.0	33
Knik	7/31/2001	M	3	.	.	.	.	.	.	.	.
Knik	7/31/2001	M	5	.	.	.	.	.	.	.	.
Knik	7/31/2001	M	8	200	6.9	91.0	3.6	22	28.2	5.2	33
Knik	9/5/2001	M	1	160	7.7	72.1	0.8	12	20.0	4.6	35
Knik	9/5/2001	M	7	188	6.9	86.3	4.2	13	21.7	5.4	45
Knik	10/9/2001	M	1	172	7.4	80.4	0.8	10	22.6	4.5	18
Knik	10/9/2001	M	6	173	7.4	79.9	0.8	11	21.1	5.4	19
Lorraine	5/30/2001	M	1	70	7.2	30.6	0.5	8	8.9	2.5	37
Lorraine	5/30/2001	M	6	72	7.1	31.6	1.1	6	9.4	2.4	39
Lorraine	6/27/2001	M	1	73	7.9	31.2	0.8	8	8.3	1.6	35
Lorraine	6/27/2001	M	3	.	.	.	.	.	.	.	.
Lorraine	6/27/2001	M	5	72	7.9	31.4	1.5	5	8.6	2.0	32

Appendix A. Continued.

Lake	Date	Sta	Depth (m)	Conductivity ( $\mu\text{mhos cm}^{-1}$ )	pH (Units)	Alkalinity ( $\text{mg L}^{-1}$ )	Turbidity (NTU)	Color (Pt units)	Calcium ( $\text{mg L}^{-1}$ )	Magnesium ( $\text{mg L}^{-1}$ )	Iron ( $\mu\text{g L}^{-1}$ )
Lorraine	7/31/2001	M	1	72	7.5	31.8	0.7	6	8.5	2.2	34
Lorraine	7/31/2001	M	6	73	7.4	31.8	0.8	5	8.7	2.2	36
Lorraine	9/5/2001	M	1	72	7.0	31.8	0.7	3	8.8	2.2	57
Lorraine	9/5/2001	M	7	72	7.0	31.4	0.8	4	8.3	2.3	55
Threemile	5/30/2001	M	1	96	7.4	48.6	2.1	18	15.4	3.1	120
Threemile	6/27/2001	M	1	113	7.6	54.5	1.2	15	16.2	2.0	94
Threemile	7/31/2001	M	1	120	7.4	59.5	0.9	19	18.2	3.0	135
Threemile	9/4/2001	M	1	123	7.1	61.5	1.1	23	19.3	2.9	185
Threemile	10/9/2001	M	1	128	7.3	65.7	0.6	22	19.8	3.2	54
Wasilla	5/29/2001	E	1	240	7.6	103.4	4.6	24	33.2	9.9	38
Wasilla	5/29/2001	E	3	.	.	.	.	.	.	.	.
Wasilla	5/29/2001	E	6	225	7.6	104.0	3.9	18	19.7	11.1	63
Wasilla	5/29/2001	W	1	234	7.7	112.8	3.6	26	13.3	10.7	38
Wasilla	5/29/2001	W	3	.	.	.	.	.	.	.	.
Wasilla	5/29/2001	W	8	245	7.7	115.8	4.6	18	14.8	17.8	42
Wasilla	6/28/2001	E	1	193	8.1	85.6	3.5	18	12.8	10.0	47
Wasilla	6/28/2001	E	3	.	.	.	.	.	.	.	.
Wasilla	6/28/2001	E	5	226	8.0	104.5	4.8	18	8.9	10.8	42
Wasilla	6/28/2001	W	1	205	8.1	92.5	2.6	24	19.8	7.4	36
Wasilla	6/28/2001	W	5	.	.	.	.	.	.	.	.
Wasilla	6/28/2001	W	9	273	7.2	123.5	3.3	18	40.5	5.0	68
Wasilla	8/1/2001	E	1	187	8.1	85.0	1.2	21	26.7	4.7	50
Wasilla	8/1/2001	E	3	.	.	.	.	.	.	.	.
Wasilla	8/1/2001	E	5	214	7.6	98.0	3.1	22	28.1	5.5	47
Wasilla	8/1/2001	W	1	197	8.2	86.2	1.2	22	23.0	5.5	28
Wasilla	8/1/2001	W	5	.	.	.	.	.	.	.	.
Wasilla	8/1/2001	W	11	268	7.0	121.1	6.0	24	27.3	7.4	822
Wasilla	9/4/2001	E	1	200	7.7	91.3	1.6	15	19.2	6.9	92
Wasilla	9/4/2001	E	6	204	7.5	92.2	2.1	24	30.7	4.8	111
Wasilla	9/4/2001	W	1	206	7.9	94.0	3.0	18	19.4	9.0	38
Wasilla	9/4/2001	W	11	276	7.0	129.8	6.5	28	28.0	7.9	997
Wasilla	10/8/2001	E	1	211	7.7	99.2	1.6	14	26.1	6.4	45

Appendix A. Continued.

Lake	Date	Sta	Depth (m)	Conductivity ( $\mu\text{mhos cm}^{-1}$ )	pH (Units)	Alkalinity ( $\text{mg L}^{-1}$ )	Turbidity (NTU)	Color (Pt units)	Calcium ( $\text{mg L}^{-1}$ )	Magnesium ( $\text{mg L}^{-1}$ )	Iron ( $\mu\text{g L}^{-1}$ )
Wasilla	10/8/2001	E	6	212	7.7	100.1	1.7	13	22.0	9.0	50
Wasilla	10/8/2001	W	1	233	7.5	109.6	2.9	11	35.6	5.4	81
Wasilla	10/8/2001	W	11	235	7.5	110.4	3.0	17	31.8	6.6	97

## APPENDIX B

NUTRIENTS AND ALGAL PIGMENT CONCENTRATIONS BY SURVEY DATE,  
STATION, AND DEPTH FOR THE SEVEN STUDY LAKES

Appendix B. Nutrients and algal pigment concentrations by survey date, station, and depth for the seven study lakes

Lake	Date	Sta	Depth (m)	Total-P ( $\mu\text{g L}^{-1}$ )	Total filter- able-P ( $\mu\text{g L}^{-1}$ )	Filterable reactive-P ( $\mu\text{g L}^{-1}$ )	Kjeldahl nitrogen ( $\mu\text{g L}^{-1}$ )	Ammonia nitrogen ( $\mu\text{g L}^{-1}$ )	Nitrate+ nitrite ( $\mu\text{g L}^{-1}$ )	Reactive silicon ( $\mu\text{g L}^{-1}$ )	Particulate organic carbon ( $\mu\text{g L}^{-1}$ )	Chloro- phyll <i>a</i> ( $\mu\text{g L}^{-1}$ )	Phaeo- phytin ( $\mu\text{g L}^{-1}$ )
Big	5/30/2001	E	1	6.8	2.3	1.7	163	11.0	2.4	3,507	263	0.59	0.29
Big	5/30/2001	E	5	.	.	.	.	.	.	.	.	1.21	0.42
Big	5/30/2001	E	8	11.2	3.4	2.4	237	5.3	2.7	3,980	446	4.14	0.67
Big	5/30/2001	W	1	6.7	2.3	1.8	178	15.4	2.8	3,129	246	0.60	0.29
Big	5/30/2001	W	5	.	.	.	.	.	.	.	.	0.83	0.31
Big	5/30/2001	W	12	11.1	2.9	2.1	204	4.2	0.9	3,554	315	2.83	0.64
Big	6/27/2001	E	1	5.0	3.9	3.0	183	11.8	1.3	3,223	172	0.52	0.19
Big	6/27/2001	E	6	.	.	.	.	.	.	.	.	0.58	0.32
Big	6/27/2001	E	8	8.5	3.4	2.2	193	1.7	1.8	3,771	320	1.29	0.52
Big	6/27/2001	W	1	4.6	2.7	2.1	177	19.0	1.6	3,486	161	0.33	0.12
Big	6/27/2001	W	6	.	.	.	.	.	.	.	.	0.48	0.22
Big	6/27/2001	W	10	7.2	3.8	2.3	162	22.9	2.4	3,844	240	0.69	0.37
Big	7/31/2001	E	1	5.6	3.8	2.7	208	27.1	2.4	3,059	126	0.93	0.27
Big	7/31/2001	E	5	.	.	.	.	.	.	.	.	0.89	0.20
Big	7/31/2001	E	10	12.6	3.5	2.3	229	10.6	2.6	4,070	263	0.93	0.46
Big	7/31/2001	W	1	4.6	2.8	2.1	183	17.9	1.9	3,219	166	0.57	0.19
Big	7/31/2001	W	10	.	.	.	.	.	.	.	.	0.96	0.27
Big	7/31/2001	W	14	9.4	3.5	2.3	196	23.7	2.6	4,047	246	0.58	0.54
Big	9/5/2001	E	1	7.6	3.7	1.6	205	3.3	22.5	3,404	302	0.87	0.20
Big	9/5/2001	E	11	12.2	6.3	4.2	205	16.8	21.0	4,890	227	0.71	0.48
Big	9/5/2001	W	1	6.5	2.8	1.5	192	4.3	21.5	3,151	208	0.76	0.22
Big	9/5/2001	W	15	8.3	3.5	2.6	183	7.5	29.3	4,413	289	0.49	0.35
Big	10/9/2001	E	1	12.3	4.8	2.9	220	12.4	23.6	3,351	255	1.27	0.33
Big	10/9/2001	E	11	13.8	5.3	3.1	237	27.9	23.6	3,553	272	1.13	0.74
Big	10/9/2001	W	1	8.3	3.3	2.2	189	0.4	27.0	3,270	283	1.06	0.33
Big	10/9/2001	W	15	9.8	4.0	3.1	169	4.6	55.7	4,290	222	0.54	0.31
Cottonwood	5/29/2001	M	1	12.1	6.2	5.0	283	1.7	4.2	3,245	658	3.88	0.77
Cottonwood	5/29/2001	M	8	20.4	5.5	4.7	391	1.7	3.0	4,384	983	14.98	0.05
Cottonwood	6/28/2001	M	1	8.8	3.5	3.0	270	1.7	4.0	3,495	423	2.57	0.96
Cottonwood	6/28/2001	M	3	.	.	.	.	.	.	.	.	2.25	1.02
Cottonwood	6/28/2001	M	6	20.6	4.0	3.8	304	1.7	4.4	4,988	658	7.19	4.32

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Appendix B. Continued.

Lake	Date	Sta	Depth (m)	Total-P ( $\mu\text{g L}^{-1}$ )	Total filter- able-P ( $\mu\text{g L}^{-1}$ )	Filterable reactive-P ( $\mu\text{g L}^{-1}$ )	Kjeldahl nitrogen ( $\mu\text{g L}^{-1}$ )	Ammonia nitrogen ( $\mu\text{g L}^{-1}$ )	Nitrate+ nitrite ( $\mu\text{g L}^{-1}$ )	Reactive silicon ( $\mu\text{g L}^{-1}$ )	Particulate organic carbon ( $\mu\text{g L}^{-1}$ )	Chloro- phyll <i>a</i> ( $\mu\text{g L}^{-1}$ )	Phaeo- phytin ( $\mu\text{g L}^{-1}$ )
Cottonwood	8/1/2001	M	1	9.4	3.5	3.2	258	16.3	2.3	3,740	349	2.61	1.43
Cottonwood	8/1/2001	M	3	.	.	.	.	.	.	.	.	2.89	1.40
Cottonwood	8/1/2001	M	7	24.0	3.6	3.6	352	11.3	2.2	5,044	715	14.39	0.31
Cottonwood	9/4/2001	M	1	13.7	4.4	3.2	289	6.4	25.9	4,297	440	10.41	0.77
Cottonwood	9/4/2001	M	8	12.6	3.9	2.7	333	71.9	25.9	4,363	486	5.92	1.57
Cottonwood	10/8/2001	M	1	13.1	4.4	3.5	288	16.6	52.3	3,905	449	5.98	1.37
Cottonwood	10/8/2001	M	8	13.3	5.6	4.5	279	17.4	48.3	3,845	471	5.70	0.49
Finger	5/29/2001	M	1	18.3	5.6	1.6	455	5.6	4.2	1,264	949	4.99	0.42
Finger	5/29/2001	M	3	.	.	.	.	.	.	.	.	9.22	0.05
Finger	5/29/2001	M	10	29.8	9.4	3.8	554	6.9	4.0	1,727	1,052	15.74	0.05
Finger	6/28/2001	M	1	12.8	4.1	1.3	440	5.0	2.3	966	566	3.41	0.82
Finger	6/28/2001	M	4	.	.	.	.	.	.	.	.	6.76	4.39
Finger	6/28/2001	M	7	57.6	13.1	7.2	531	26.9	1.6	1,975	1,166	9.22	44.66
Finger	8/1/2001	M	1	18.6	6.0	3.1	503	6.9	2.1	1,036	829	9.81	0.79
Finger	8/1/2001	M	4	.	.	.	.	.	.	.	.	11.36	0.40
Finger	8/1/2001	M	8	50.2	10.3	3.5	576	11.2	2.4	1,886	1,105	6.02	22.39
Finger	9/4/2001	M	1	27.1	6.3	1.7	530	7.5	23.1	1,303	897	11.33	0.62
Finger	9/4/2001	M	8	41.8	9.4	3.0	578	66.4	23.0	1,707	750	1.55	11.60
Finger	10/8/2001	M	1	31.8	7.0	2.2	521	6.4	35.1	1,411	714	12.44	0.05
Finger	10/8/2001	M	8	29.2	6.9	2.2	519	6.5	35.4	1,386	614	13.75	0.05
Knik	6/27/2001	M	1	10.8	5.5	2.1	403	17.7	2.3	2,227	360	1.91	0.42
Knik	7/31/2001	M	1	14.7	4.9	2.6	351	9.0	3.3	2,439	565	3.08	0.55
Knik	7/31/2001	M	3	.	.	.	.	.	.	.	.	1.18	0.41
Knik	7/31/2001	M	5	.	.	.	.	.	.	.	.	3.70	1.22
Knik	7/31/2001	M	8	41.2	12.7	3.5	768	346.2	2.5	4,163	1,010	23.10	0.26
Knik	9/5/2001	M	1	9.9	4.9	1.2	330	7.5	29.4	2,642	360	3.69	0.90
Knik	9/5/2001	M	7	23.1	11.1	2.9	428	57.5	21.7	3,758	520	8.31	0.05
Knik	10/9/2001	M	1	22.5	10.3	5.0	488	90.1	32.2	2,828	296	3.42	0.52
Knik	10/9/2001	M	6	17.4	8.9	4.5	481	96.6	30.4	2,883	365	1.34	0.29
Lorraine	5/30/2001	M	1	4.0	2.1	1.2	413	60.0	45.7	82	355	0.46	0.13
Lorraine	5/30/2001	M	6	7.3	2.2	1.2	448	55.9	43.0	56	606	2.09	1.11

## Appendix B. Continued.

Lake	Date	Sta	Depth (m)	Total-P ( $\mu\text{g L}^{-1}$ )	Total filter- able-P ( $\mu\text{g L}^{-1}$ )	Filterable reactive-P ( $\mu\text{g L}^{-1}$ )	Kjeldahl nitrogen ( $\mu\text{g L}^{-1}$ )	Ammonia nitrogen ( $\mu\text{g L}^{-1}$ )	Nitrate+ nitrite ( $\mu\text{g L}^{-1}$ )	Reactive silicon ( $\mu\text{g L}^{-1}$ )	Particulate organic carbon ( $\mu\text{g L}^{-1}$ )	Chloro- phyll <i>a</i> ( $\mu\text{g L}^{-1}$ )	Phaeo- phytin ( $\mu\text{g L}^{-1}$ )
Lorraine	6/27/2001	M	1	5.0	3.0	1.6	404	7.3	9.0	144	263	1.18	0.07
Lorraine	6/27/2001	M	3	.	.	.	.	.	.	.	.	1.65	0.14
Lorraine	6/27/2001	M	5	5.7	2.8	1.5	401	10.2	5.0	137	326	1.25	0.10
Lorraine	7/31/2001	M	1	4.8	3.1	1.8	401	27.0	3.6	175	258	0.69	0.24
Lorraine	7/31/2001	M	6	6.5	2.9	1.6	413	15.6	2.8	167	329	0.67	0.19
Lorraine	9/5/2001	M	1	6.1	2.7	0.8	419	24.4	25.6	217	320	1.16	0.33
Lorraine	9/5/2001	M	7	5.8	2.9	1.0	409	24.8	22.5	218	343	1.11	0.19
Threemile	5/30/2001	M	1	8.0	3.6	2.4	286	2.6	2.3	2,300	400	1.05	0.29
Threemile	6/27/2001	M	1	8.4	3.8	2.3	337	10.3	3.0	2,537	326	0.86	0.18
Threemile	7/31/2001	M	1	9.4	4.2	2.7	328	4.8	4.1	2,951	334	1.15	0.41
Threemile	9/4/2001	M	1	11.2	4.4	2.5	341	5.9	25.5	3,586	213	1.17	0.16
Threemile	10/9/2001	M	1	8.3	8.2	7.0	328	18.1	26.2	3,215	250	0.87	0.26
Wasilla	5/29/2001	E	1	19.9	7.5	5.9	380	13.6	4.5	1,761	857	7.29	0.05
Wasilla	5/29/2001	E	3	.	.	.	.	.	.	.	.	7.83	0.05
Wasilla	5/29/2001	E	6	20.5	5.6	4.3	446	12.2	2.4	3,284	926	9.94	0.51
Wasilla	5/29/2001	W	1	14.5	5.1	4.3	433	5.2	12.2	3,295	966	10.10	0.05
Wasilla	5/29/2001	W	3	.	.	.	.	.	.	.	.	10.65	0.05
Wasilla	5/29/2001	W	8	24.6	4.7	3.5	440	1.7	124.2	3,943	914	17.01	0.05
Wasilla	6/28/2001	E	1	8.5	4.7	4.4	311	1.7	5.6	3,251	429	2.62	0.59
Wasilla	6/28/2001	E	3	.	.	.	.	.	.	.	.	4.19	0.85
Wasilla	6/28/2001	E	5	19.9	4.2	3.5	413	7.1	2.7	3,453	909	9.02	0.91
Wasilla	6/28/2001	W	1	12.2	3.5	2.8	358	6.7	8.4	2,988	635	6.22	3.79
Wasilla	6/28/2001	W	5	.	.	.	.	.	.	.	.	4.63	1.71
Wasilla	6/28/2001	W	9	21.9	4.2	3.3	428	69.7	112.2	4,854	623	7.91	1.44
Wasilla	8/1/2001	E	1	13.3	4.9	4.3	355	1.7	2.2	3,586	355	2.45	0.86
Wasilla	8/1/2001	E	3	.	.	.	.	.	.	.	.	2.48	0.85
Wasilla	8/1/2001	E	5	15.7	6.2	5.6	371	1.7	2.7	4,286	652	11.45	0.05
Wasilla	8/1/2001	W	1	10.6	5.3	4.3	335	16.6	4.0	3,322	550	2.62	0.53
Wasilla	8/1/2001	W	5	.	.	.	.	.	.	.	.	28.75	0.05
Wasilla	8/1/2001	W	11	17.0	5.1	3.9	773	530.5	3.2	5,669	586	2.21	1.45
Wasilla	9/4/2001	E	1	14.5	4.9	3.7	317	24.0	34.1	4,177	553	7.75	0.05

Appendix B. Continued.

Lake	Date	Sta	Depth (m)	Total-P ( $\mu\text{g L}^{-1}$ )	Total filter- able-P ( $\mu\text{g L}^{-1}$ )	Filterable reactive-P ( $\mu\text{g L}^{-1}$ )	Kjeldahl nitrogen ( $\mu\text{g L}^{-1}$ )	Ammonia nitrogen ( $\mu\text{g L}^{-1}$ )	Nitrate+ nitrite ( $\mu\text{g L}^{-1}$ )	Reactive silicon ( $\mu\text{g L}^{-1}$ )	Particulate organic carbon ( $\mu\text{g L}^{-1}$ )	Chloro- phyll <i>a</i> ( $\mu\text{g L}^{-1}$ )	Phaeo- phytin ( $\mu\text{g L}^{-1}$ )
Wasilla	9/4/2001	E	6	16.1	4.3	3.0	421	98.7	36.0	4,228	516	5.09	0.94
Wasilla	9/4/2001	W	1	15.8	4.2	2.3	382	2.3	19.2	3,963	962	11.21	0.05
Wasilla	9/4/2001	W	11	22.4	5.0	3.9	925	713.3	22.4	6,012	572	1.30	1.70
Wasilla	10/8/2001	E	1	18.1	4.1	2.5	326	26.1	58.7	3,147	509	5.90	0.79
Wasilla	10/8/2001	E	6	17.8	4.6	3.3	355	25.1	67.2	3,227	516	5.94	0.78
Wasilla	10/8/2001	W	1	22.4	4.3	2.9	482	128.8	52.4	3,955	635	5.51	0.51
Wasilla	10/8/2001	W	11	24.7	4.8	3.0	482	126.5	52.0	3,880	641	7.33	0.91

## APPENDIX C

### PHYTOPLANKTON SPECIES LIST FOR THE SEVEN STUDY LAKES

**Appendix C.** Phytoplankton species list for the seven study lakes.

LAKE	DIVISION	CLASS	GENUS/SPECIES
Big	CHLOROPHYTA	Chlorophyceae	<i>Oocystis sp.</i>
Big	CHLOROPHYTA	Chlorophyceae	<i>Ankyra sp.</i>
Big	CHLOROPHYTA	Chlorophyceae	<i>Scenedesmus sp.</i>
Big	CHLOROPHYTA	Chlorophyceae	<i>Crucigenia tetrapedia</i>
Big	CHLOROPHYTA	Chlorophyceae	<i>Crucigenia quadrata</i>
Big	CHLOROPHYTA	Chlorophyceae	<i>Tetraedron minimum</i>
Big	CHLOROPHYTA	Chlorophyceae	<i>Pediastrum sp.</i>
Big	CHLOROPHYTA	Chlorophyceae	<i>Elakatothrix gelatinosa</i>
Big	CHRYSOPHYTA	Bacillariophyceae	<i>Cymbella sp.</i>
Big	CHRYSOPHYTA	Bacillariophyceae	<i>Unknown pennate diatom (&gt;10-20 microns)</i>
Big	CHRYSOPHYTA	Bacillariophyceae	<i>Unknown pennate diatom (&gt;20-64 microns)</i>
Big	CHRYSOPHYTA	Bacillariophyceae	<i>Cyclotella sp.</i>
Big	CHRYSOPHYTA	Bacillariophyceae	<i>Fragilaria sp.</i>
Big	CHRYSOPHYTA	Bacillariophyceae	<i>Dinobryon cysts/Cyclotella sp.</i>
Big	CHRYSOPHYTA	Chrysophyceae	<i>Kephyrion sp.</i>
Big	CHRYSOPHYTA	Chrysophyceae	<i>Halobryon sp.</i>
Big	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon sociale</i>
Big	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon cylindricum v. palustre</i>
Big	CYANOPHYTA	Myxophyceae	<i>Dactylococcopsis sp.</i>
Big	CYANOPHYTA	Myxophyceae	<i>Microcystis sp. A</i>
Big	CYANOPHYTA	Myxophyceae	<i>Chroococcus sp.</i>
Big	CYANOPHYTA	Myxophyceae	<i>Gomphosphaeria lacustris</i>
Big	CYANOPHYTA	Myxophyceae	<i>Microcystis sp. C</i>
Big	CYANOPHYTA	Myxophyceae	<i>cf Lyngbya sp.</i>
Big	CYANOPHYTA	Myxophyceae	<i>cf Lyngbya sp./Schizothrix tinctoria</i>
Big	CYANOPHYTA	Myxophyceae	<i>Nostoc sp.</i>
Big	EUGLENOPHYTA	Euglenophyceae	<i>Trachelomonas sp.</i>
Big	PYRRHOPHYTA	Cryptophyceae	<i>Chroomonas spp.</i>

Appendix C. Continued

LAKE	DIVISION	CLASS	GENUS/SPECIES
Big	PYRRHOPHYTA	Cryptophyceae	<i>Cryptomonas ovata/erosa</i>
Big	PYRRHOPHYTA	Cryptophyceae	<i>Cryptomonas spp.</i>
Big	PYRRHOPHYTA	Cryptophyceae	<i>Chroomonas cf acuta/caudata</i>
Big	PYRRHOPHYTA	Dinophyceae	<i>Unknown Dinoflagellates (&gt;10-20 microns)</i>
Big	Unknown		<i>Unknown ultraplankton (&gt;2-10 microns)</i>
Big	Unknown		<i>Unknown nanoplankton (&gt;10-20 microns)</i>
Big	Unknown		<i>Unknown microplankton (&gt;20-64 microns)</i>
Big	Unknown		<i>Unknown Eukaryote ball</i>
Cottonwood	CHLOROPHYTA	Chlorophyceae	<i>Elakatothrix gelatinosa</i>
Cottonwood	CHLOROPHYTA	Chlorophyceae	<i>Cosmarium sp.</i>
Cottonwood	CHLOROPHYTA	Chlorophyceae	<i>Ankistrodesmus/ Schroederia sp.</i>
Cottonwood	CHLOROPHYTA	Chlorophyceae	<i>Nephrocytium sp.</i>
89 Cottonwood	CHLOROPHYTA	Chlorophyceae	<i>Ulothrix sp./Stichococcus sp.</i>
Cottonwood	CHRYSOPHYTA	Bacillariophyceae	<i>Asterionella formosa</i>
Cottonwood	CHRYSOPHYTA	Bacillariophyceae	<i>Unknown pennate diatom (&gt;10-20 microns)</i>
Cottonwood	CHRYSOPHYTA	Bacillariophyceae	<i>Unknown pennate diatom (&gt;20-64 microns)</i>
Cottonwood	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon bavaricum</i>
Cottonwood	CHRYSOPHYTA	Chrysophyceae	<i>Epipyxis sp.</i>
Cottonwood	CHRYSOPHYTA	Chrysophyceae	<i>Kephyrion sp.</i>
Cottonwood	CHRYSOPHYTA	Chrysophyceae	<i>Halobryon sp.</i>
Cottonwood	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon cylindricum v. palustre/Dinobryon divergens</i>
Cottonwood	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon spp.</i>
Cottonwood	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon cysts</i>
Cottonwood	CHRYSOPHYTA	Xanthophyceae	<i>Ophiocytium sp.</i>
Cottonwood	CYANOPHYTA	Myxophyceae	<i>Microcystis sp. A</i>
Cottonwood	CYANOPHYTA	Myxophyceae	<i>cf Oscillatoria sp./Phormidium sp.</i>
Cottonwood	CYANOPHYTA	Myxophyceae	<i>Unknown Cyanophyte filament</i>

Appendix C. Continued

LAKE	DIVISION	CLASS	GENUS/SPECIES
Cottonwood	CYANOPHYTA	Myxophyceae	<i>Microcystis sp. B/H</i>
Cottonwood	CYANOPHYTA	Myxophyceae	<i>cf Phormidium sp.</i>
Cottonwood	CYANOPHYTA	Myxophyceae	<i>cf Oscillatoria sp.</i>
Cottonwood	EUGLENOPHYTA	Euglenophyceae	<i>Trachelomonas sp.</i>
Cottonwood	PYRRHOPHYTA	Cryptophyceae	<i>Chroomonas cf acuta</i>
Cottonwood	PYRRHOPHYTA	Cryptophyceae	<i>Cryptomonas ovata/erosa</i>
Cottonwood	PYRRHOPHYTA	Cryptophyceae	<i>Chroomonas cf acuta/caudata</i>
Cottonwood	PYRRHOPHYTA	Cryptophyceae	<i>Cryptomonas spp.</i>
Cottonwood	Unknown		<i>Unknown ultraplankton (&gt;2-10 microns)</i>
Cottonwood	Unknown		<i>Unknown nanoplankton (&gt;10-20 microns)</i>
Cottonwood	Unknown		<i>Unknown microplankton (&gt;20-64 microns)</i>
Cottonwood	Unknown		<i>Unknown colonial balls</i>
Cottonwood	Unknown		<i>Unknown Eukaryote filament</i>
67 Finger	CHLOROPHYTA	Chlorophyceae	<i>Tetraedron minimum</i>
Finger	CHLOROPHYTA	Chlorophyceae	<i>Ankistrodesmus falcatus</i>
Finger	CHLOROPHYTA	Chlorophyceae	<i>Elakatothrix gelatinosa</i>
Finger	CHLOROPHYTA	Chlorophyceae	<i>Stichococcus sp.</i>
Finger	CHLOROPHYTA	Chlorophyceae	<i>Micractinium sp.</i>
Finger	CHLOROPHYTA	Myxophyceae	<i>Microcystis sp. A</i>
Finger	CHLOROPHYTA	Myxophyceae	<i>cf Lyngbya sp.</i>
Finger	CHLOROPHYTA	Myxophyceae	<i>cf Oscillatoria sp./Phormidium sp.</i>
Finger	CHLOROPHYTA	Myxophyceae	<i>Anabaena sp.</i>
Finger	CHLOROPHYTA	Myxophyceae	<i>cf Oscillatoria sp. 1</i>
Finger	CHLOROPHYTA	Myxophyceae	<i>cf Oscillatoria sp. 2</i>
Finger	CHRYSOPHYTA	Bacillariophyceae	<i>Unknown pennate diatom (&gt;10-20 microns)</i>
Finger	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon spp.</i>
Finger	PYRRHOPHYTA	Cryptophyceae	<i>Cryptomonas ovata/erosa</i>

Appendix C. Continued

LAKE	DIVISION	CLASS	GENUS/SPECIES
Finger	PYRRHOPHYTA	Cryptophyceae	<i>Chroomonas cf acuta/caudata</i>
Finger	PYRRHOPHYTA	Cryptophyceae	<i>Cryptomonas spp./Chroomonas spp.</i>
Finger	Unknown		<i>Unknown ultraplankton (&gt;2-10 microns)</i>
Finger	Unknown		<i>Unknown nanoplankton (&gt;10-20 microns)</i>
Knik	CHRYSOPHYTA	Chrysophyceae	<i>Mallomonas akrokomos</i>
Knik	CHRYSOPHYTA	Chrysophyceae	<i>Synura sp.</i>
Knik	CYANOPHYTA	Myxophyceae	<i>Chroococcus sp.</i>
Knik	CYANOPHYTA	Myxophyceae	<i>Dactylococcopsis sp.</i>
Knik	CYANOPHYTA	Myxophyceae	<i>Aphanothece sp.</i>
Knik	CYANOPHYTA	Myxophyceae	<i>Microcystis sp. A</i>
Knik	EUGLENOPHYTA	Euglenophyceae	<i>Trachelomonas sp.</i>
Knik	PYRRHOPHYTA	Cryptophyceae	<i>Chroomonas cf acuta/caudata</i>
89 Knik	PYRRHOPHYTA	Cryptophyceae	<i>Cryptomonas ovata/erosa</i>
Knik	Unknown		<i>Ultraplankton (&gt;2-10 microns)</i>
Knik	Unknown		<i>Nanoplankton (&gt;10-20 microns)</i>
Knik	Unknown		<i>Microplankton (&gt;20-64 microns)</i>
Lorraine	CYANOPHYTA	Myxophyceae	<i>Microcystis sp. A</i>
Lorraine	Unknown		<i>Unknown ultraplankton (&gt;2-10 microns)</i>
Threemile	CHLOROPHYTA	Chlorophyceae	<i>Tetraedron minimum</i>
Threemile	CHLOROPHYTA	Chlorophyceae	<i>Oocystis sp.</i>
Threemile	CHLOROPHYTA	Chlorophyceae	<i>Ankistrodesmus falcatus</i>
Threemile	CHLOROPHYTA	Chlorophyceae	<i>Scenedesmus sp.</i>
Threemile	CHLOROPHYTA	Chlorophyceae	<i>Crucigenia tetrapedia</i>
Threemile	CHLOROPHYTA	Chlorophyceae	<i>Planktosphaeria sp.</i>
Threemile	CHLOROPHYTA	Chlorophyceae	<i>Nephrocytium sp.</i>

Appendix C. Continued

LAKE	DIVISION	CLASS	GENUS/SPECIES
Threemile	CHLOROPHYTA	Chlorophyceae	<i>Cosmarium sp.</i>
Threemile	CHRYSOPHYTA	Bacillariophyceae	<i>Achnanthes minutissima</i>
Threemile	CHRYSOPHYTA	Bacillariophyceae	<i>cf Epithemia sp.</i>
Threemile	CHRYSOPHYTA	Bacillariophyceae	<i>Cymbella sp.</i>
Threemile	CHRYSOPHYTA	Bacillariophyceae	<i>Unknown pennate diatom (&gt;20-64 microns)</i>
Threemile	CHRYSOPHYTA	Bacillariophyceae	<i>Fragilaria crotonensis</i>
Threemile	CHRYSOPHYTA	Bacillariophyceae	<i>Dinobryon cysts/Cyclotella sp.</i>
Threemile	CHRYSOPHYTA	Chrysophyceae	<i>Kephyrion sp.</i>
Threemile	CHRYSOPHYTA	Chrysophyceae	<i>Halobryon sp.</i>
Threemile	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon sociale</i>
Threemile	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon cysts</i>
Threemile	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon cf sociale</i>
Threemile	CHRYSOPHYTA	Xanthophyceae	<i>Ophiocytium sp.</i>
Threemile	CYANOPHYTA	Myxophyceae	<i>Chroococcus sp.</i>
⊗ Threemile	CYANOPHYTA	Myxophyceae	<i>Dactylococcopsis sp.</i>
Threemile	CYANOPHYTA	Myxophyceae	<i>Aphanothece sp./Rhabdoderma sp.</i>
Threemile	CYANOPHYTA	Myxophyceae	<i>Microcystis sp. A</i>
Threemile	CYANOPHYTA	Myxophyceae	<i>cf Nostoc sp.</i>
Threemile	CYANOPHYTA	Myxophyceae	<i>cf Oscillatoria sp.</i>
Threemile	CYANOPHYTA	Myxophyceae	<i>Aphanothece sp.</i>
Threemile	CYANOPHYTA	Myxophyceae	<i>Unknown Cyanophyte filament</i>
Threemile	PYRRHOPHYTA	Cryptophyceae	<i>Chroomonas cf acuta/caudata</i>
Threemile	PYRRHOPHYTA	Cryptophyceae	<i>Cryptomonas ovata/erosa</i>
Threemile	PYRRHOPHYTA	Cryptophyceae	<i>Chilamonas spp.</i>
Threemile	PYRRHOPHYTA	Dinophyceae	<i>Peridinium sp.</i>
Threemile	PYRRHOPHYTA	Dinophyceae	<i>Unknown Dinoflagellates (&gt;20-64 microns)</i>
Threemile	Unknown		<i>Unknown ultraplankton (&gt;2-10 microns)</i>

Appendix C. Continued

LAKE	DIVISION	CLASS	GENUS/SPECIES
Threemile	Unknown		<i>Unknown nanoplankton (&gt;10-20 microns)</i>
Threemile	Unknown		<i>Unknown microplankton (&gt;20-64 microns)</i>
Threemile	Unknown		<i>Unknown Eukaryote filament</i>
Wasilla	CHLOROPHYTA	Chlorophyceae	<i>Scenedesmus sp.</i>
Wasilla	CHLOROPHYTA	Chlorophyceae	<i>Ankistrodesmus falcatus</i>
Wasilla	CHLOROPHYTA	Chlorophyceae	<i>Crucigenia tetrapedia</i>
Wasilla	CHLOROPHYTA	Chlorophyceae	<i>Geminella sp./Stichococcus sp.</i>
Wasilla	CHLOROPHYTA	Chlorophyceae	<i>Scenedesmus sp.</i>
Wasilla	CHLOROPHYTA	Chlorophyceae	<i>Ankistrodesmus sp.</i>
Wasilla	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon bavaricum</i>
Wasilla	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon sociale</i>
Wasilla	CHRYSOPHYTA	Chrysophyceae	<i>Kephyrion sp.</i>
Wasilla	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon elegantissimum</i>
Wasilla	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon divergens</i>
70 Wasilla	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon cysts</i>
Wasilla	CHRYSOPHYTA	Chrysophyceae	<i>Dinobryon cysts/Cyclotella sp.</i>
Wasilla	CYANOPHYTA	Myxophyceae	<i>Dactylococcopsis sp.</i>
Wasilla	CYANOPHYTA	Myxophyceae	<i>Microcystis sp. A</i>
Wasilla	CYANOPHYTA	Myxophyceae	<i>cf Lyngbya sp./cf Schizothrix tinctoria</i>
Wasilla	CYANOPHYTA	Myxophyceae	<i>cf Oscillatoria sp./Phormidium sp.</i>
Wasilla	CYANOPHYTA	Myxophyceae	<i>cf Lyngbya sp.</i>
Wasilla	CYANOPHYTA	Myxophyceae	<i>Anabaena sp.</i>
Wasilla	CYANOPHYTA	Myxophyceae	<i>cf Lyngbya sp./Schizothrix sp.</i>
Wasilla	CYANOPHYTA	Myxophyceae	<i>cf Oscillatoria sp.</i>
Wasilla	CYANOPHYTA	Myxophyceae	<i>Unknown Cyanophyte filament</i>
Wasilla	PYRRHOPHYTA	Cryptophyceae	<i>Chroomonas cf acuta</i>
Wasilla	PYRRHOPHYTA	Cryptophyceae	<i>Cryptomonas ovata/erosa</i>

**Appendix C. Continued**

<b>LAKE</b>	<b>DIVISION</b>	<b>CLASS</b>	<b>GENUS/SPECIES</b>
Wasilla	PYRRHOPHYTA	Cryptophyceae	<i>Chroomonas cf spp.</i>
Wasilla	PYRRHOPHYTA	Cryptophyceae	<i>Chroomonas spp.</i>
Wasilla	Unknown		<i>Unknown ultraplankton (&gt;2-10 microns)</i>
Wasilla	Unknown		<i>Unknown nanoplankton (&gt;10-20 microns)</i>
Wasilla	Unknown		<i>Unknown microplankton (&gt;20-64 microns)</i>
Wasilla	Unknown		<i>Unknown Eukaryote filament</i>

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