An ASSESSMENT of TROPHIC STATUS of 25 LAKES in the MATANUSKA-SUSITNA BOROUGH, ALASKA

by

J. A. Edmundson, V. P. Litchfield, and D. M. Cialek

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AUTHORS

Jim A. Edmundson is a Central Region Limnology Fishery Biologist for the Alaska Department of Fish and Game, Commercial Fisheries Division, 43961 Kalifornsky Beach Road, Suite B, Soldotna, AK 99669.

Virginia P. Litchfield is a Central Region Limnology Fishery Biologist for the Alaska Department of Fish and Game, Commercial Fisheries Division, 43961 Kalifornsky Beach Road, Suite B, Soldotna, AK 99669.

Denise M. Cialek is a Central Region Limnology Fish and Wildlife Technician for the Alaska Department of Fish and Game, Commercial Fisheries Division, 43961 Kalifornsky Beach Road, Suite B, Soldotna, AK 99669.

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ABSTRACT

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. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report No. 2A00-26:41p.

Results of limnological surveys of 25 lakes within the Matanuska-Susitna (Mat-Su) Borough representing 71 lake-year observations are presented. These data were obtained from Alaska Department of Fish and Game's Central Region Limnology databases. Considering all lake-year mean values, total phosphorus concentrations ranged from 2.2 µg L^{-1} to 44.2 µg L^{-1} and chlorophyll *a* standing crop ranged from 0.1 µg L^{-1} to 15.7 µg L^{-1}. Phosphorus appeared to be the primary nutrient limiting algal production based on high total nitrogen to phosphorus molar ratios (>27:1). The Secchi depth, a measure of water clarity, ranged from 1.4 to 13 m. Evaluation of frequency of occurrence histograms of salient trophic state indicators showed values to be distributed asymmetrically; i.e., with median values typically less than the mean. Based on common classification schemes using mean phosphorus concentration and Secchi depth data, the Mat-Su lakes as a group spanned a trophic gradient from oligotrophic (nutrient poor) to eutrophic (nutrient rich). Lakes within the Cottonwood Creek and Fish Creek drainages tended to be of the mesotrophic condition (between oligotrophic and eutrophic). However, the lakes in this study were sorted mostly within the oligotrophic class using chlorophyll criteria. In addition, comparisons of Carlson's trophic state index (TSI) values, revealed that mean phosphorus concentration produced the highest TSI value (median 53), whereas Secchi data yielded an intermediate TSI value (median 41) and mean chlorophyll concentration produced the lowest TSI value (median 28). Results of analysis-of-variance suggested that the change in TSI values between methods differed significantly among clear-water, stained (brown-water), and glacial (turbid) lakes. Thus, trophic state indices based on Secchi or total phosphorus have predictive capabilities for regional classification of trophic status only if lake typology is considered. The summary data and assessment of trophic status for the 25 Mat-Su lakes will be useful in developing meaningful regional nutrient criteria for future water quality goals and perhaps in addressing recent trends in sport and commercial salmon fisheries.

KEY WORDS: trophic status, Carlson's trophic state index, water quality, phosphorus, nitrogen, chlorophyll, color, turbidity, sub-arctic lakes

INTRODUCTION

Eutrophication is the result of nutrient enrichment of a water body that causes an undesirable level of growth of floating plants primarily that of phytoplankton (free-floating algae). Beyond the development of unsightly algal blooms, eutrophication can also lead to severe oxygen depletion within the water column, reduced transparency, offensive odors, and fish kills. Eutrophication is a naturally occurring process; however, many lakes experience the effects of cultural eutrophication; i.e. excessive nutrient (primarily phosphorus) loading from anthropogenic inputs (e.g., agricultural fertilizers, sewage, urban run-off). Excess nutrients and its consequences are a long-standing problem in many northern temperate lakes (Cooke et. al 1993). To deal with the problem, the U.S. Environmental Protection Agency (EPA) proposes to develop regional nutrient criteria using lakes considered largely free from the effects of anthropogenic eutrophication and acidification (USEPA 2000). As part of the EPA National Regional Nutrient Criteria Development Program, lakes within the Matanuska-Susitna (Mat-Su) Borough have been identified as potential candidates for developing such regional criteria.

Lakes comprise one of the Mat-Su Borough's most valuable natural resources and economic assets and they provide for a host of recreational pursuits such as fishing, swimming, boating, and camping as well as specialized uses such as drinking water supply. In addition, many of the lakes considered herein support commercially viable stocks of salmon (Ruesch and Fox 1999). Moreover, these lakes constitute an immeasurable aesthetic resource and as a consequence of rapid population growth, residential development and associated land use activities have increased dramatically over the past two decades. Such changes in land usage can include shoreline alteration, associated problems with storm-water runoff carrying nutrients and pollutants, impacts from fisheries, and changes in hydrology (e.g., channelization and lake level) all of which can influence a lake's water quality or trophic state (Dillon and Rigler 1975).

Much of the known limnological work conducted on individual lakes within the Mat-Su Borough considered the importance of lake physics and chemistry in relation to fish (salmonids) production (e.g., ADF&G 1974; Lebida 1983; Woods 1985a; Chlupach and Kyle 1990; Tarbox and Kyle 1989; Fandrei 1995) rather than water quality or trophic status *per se*. In a more recent study, Kyle et al. (1994) examined nine lakes of different type and trophic state within the Susitna River drainage and ranked these lakes according to various water quality measures to help evaluate potential productivity of sockeye salmon stocks. Maurer and Woods (1987) compiled an excellent index to limnological data for nearly 1,000 lakes in southcentral Alaska including more than 200 lakes in the Mat-Su region. However, in most instances these data represent synoptic surveys and there is a paucity of published information on the chemical and biological aspects relative to trophic status. Thus, it is difficult to address whether eutrophication or oligotrophication (nutrient reduction) is occurring within the Mat-Su Borough on a regional or large-scale watershed basis. Nonetheless, recent changes toward eutrophication have been documented for Lucile Lake (Woods 1985b), Big Lake (Woods 1986), and nearby Finger Lake (Edmundson et al. 1989) within the Mat-Su valley.

To provide a good database for developing regional nutrient criteria requires the selection of multiple lakes representing different typology, origin and morphology, and chemical and biological composition. Comparisons among lakes can assist in developing water quality or nutrient criteria and in formulating management plans for specific water bodies. While there are no ongoing programs for assessing the trophic status of surface waters on a multiple lake basis in this region, some historical and relevant data do exist as part of the former (1979-1997) statewide ADF&G limnology program. Through this program many lakes within the state, including several within the Mat-Su Borough, were inventoried with data collected on physical characteristics, water chemistry, nutrients, and plankton (Kyle et al. 1997; Edmundson et al. 1999). In addition, ADF&G Sport Fisheries Division and ADF&G Commercial Fisheries Division (Central Region Limnology) recently conducted a cooperative two-year study (1998-1999) on six lakes within the Cottonwood Creek drainage (immediately north of the city of Anchorage). However, these data have not been incorporated into a common database nor has a regional perspective on trophic status of surface waters within the Mat-Su region been prepared.

Objectives

Our objective in this report is to summarize the available historical information on the limnology of 25 lakes within the Mat-Su Borough to provide a database on their trophic condition. Herein, we present data on morphometry, transparency, water chemistry, nutrients, and algal biomass and examine these data from a multi-lake and regional perspective. We also make recommendations regarding future studies relative to lake monitoring and trophic status. It is our intent that this database will be used as part of the national EPA nutrient criteria program to help identify gaps in the data and to develop a cost-effective monitoring program for developing appropriate regional nutrient criteria to protect designated uses of these sub-arctic waters. This information may also be useful in developing lake management goals not only for water quality, but also for fisheries (e.g., sockeye and coho salmon).

Study Site Description

The 25 study lakes are situated in southcentral Alaska (Figure 1), primarily within the Mat-Su River Valleys. The study area is bounded on the north by the Talkeetna Mountains, on the south by Cook Inlet, on the east by the Chugach Mountains, and on the west by the Yentna River. The lakes range in latitude from 61 31° north to 62 44° north and in longitude from 149 05° west to 151 33° west. Lake elevations range from about 1 m to 913 m above sea level. All of the lakes are drainage lakes with outlets. Ten lakes feed into the Susitna River and its major tributaries flowing southward to Cook Inlet (Byers, Caswell, Chelatna, Hewitt, Judd, Larson, Red Shirt, Shell, Stephan, Whiskey); five of the lakes drain into the nearby Little Susitna River flowing to Cook Inlet (Butterfly, Dylindia, Finger [also known as Crooked Lake], Horseshoe, Nancy); seven of the lakes form part of the Cottonwood Creek drainage which empties into Knik Arm (Anderson, Cornelius, Cottonwood, Finger, Mud, Necklason, Wasilla); two lakes are included from the Fish Creek watershed which also drains into Knik Arm (Big, Lucile); and one lake (Monsoon) drains into the west fork of the Gulkana River a tributary of the Copper River that eventually empties into Prince William Sound. The lakes considered in this summary report include clear-water, organically stained (brown water), and glacial (turbid with silt) systems. The lakes range in surface area from 0.2 km^2 to 15.8 km^2, and from 1.0 m to 61 m in average depth (Table 1).

METHODS

Database

Water quality, nutrient, and chlorophyll data were obtained from ADF&G Central Region Limnology (CRL) program's database. These data originated from lake surveys carried out during the 1980s and early 1990s by the former statewide ADF&G limnology program. Since 1998, CRL and various cooperative agencies collected the data. However, the methods used to collect these data prior to and after the creation of CRL were consistent and detailed field and laboratory methods can be found in Koenings et al. (1987). All of the samples were analyzed by ADF&G's centralized laboratory in Soldotna. A general description of the analytical methods is presented in Table 2. Most of the lakes were sampled over a span of years: 15 for two to five and four for six or more years. Hence, our original database comprised a total of 315 individual observations representing 71 lake-year observations and 25 lake observations (Table 3). For analysis purposes, all of the chemistry, nutrients, and chlorophyll data presented in this report were derived from water samples collected near the surface ($\leq$2 m); however, the majority were obtained from the 1-m depth. Water transparency (Secchi disk) measurements were fewer and comprised 57 lake-year observations representing 23 lakes. Secchi data were not available from Horseshoe and Lucile lakes. Data regarding lake morphometry were obtained mostly from Lebida (1983) and Spafard and Edmundson (2000). We took morphometric data for Lucile Lake from Woods (1985a) and for Horseshoe Lake from Woods (1986). All raw data are on file at the ADF&G, CRL laboratory in Soldotna. Access to the electronic file may be made available to the public by contacting the authors.

Statistical Analysis

For each individual lake, we summarized the available limnological data by averaging values within each sample year to obtain lake-year means (N=71). These values represent seasonal water quality and trophic conditions and help illustrate the extent of interannual variability of limnological characteristics. However, to avoid over-weighting individual lakes because of sampling frequency, we summarized the data at the level of lake mean (average of the seasonal means). We generated frequency of occurrence histograms by pooling lake mean values (N=25) for the salient limnological parameters. The histogram density of a sample is the relative concentration of data within prescribed intervals (we selected 10) across the range in distribution. We then plotted a non-parametric density estimator (Kernel) to assess the underlying structure of these distributions. The non-parametric density estimator does not impose a functional (e.g., normal) form on the distribution. We computed trophic state index (TSI) values from Secchi depth, total phosphorus, and chlorophyll data using the equations of Carlson (1977). Because the lake data set contained a mixture of different lake types (i.e., clear, stained, and glacial), we used two-way analysis of variance (ANOVA) to test the main effects of method and lake type on TSI values. A significant ($P<0.05$) interaction term (method × type) suggests a change in TSI between methods is not the same across lake type. All statistical tests were conducted using SYSTAT version 8 (SPSS 1998).

RESULTS and DISCUSSION

Mean values and standard deviation for general water chemistry, nutrients, and chlorophyll *a* at the level of lake year mean are presented in Tables 4-5 and descriptive statistics regarding water transparency are presented in Table 6. For individual lakes, most of this information will not be discussed in detail, but is provided for reference purposes. However, the lakes are categorized at the lake mean level by intervals for the salient physical, chemical, and biological traits (Figures 2-5). In addition, the Mat-Su lakes may be best described by the means, medians, and ranges derived using lake mean as the observational unit (Table 7). These values are important because they represent the seasonal water quality and trophic conditions of the surveyed lakes as a group. Whether these summary statistics represent a "typical" random survey of Mat-Su lakes is difficult to assess since several of the lakes in this data set were surveyed as part of fisheries studies related to sockeye salmon production. By definition, sockeye nursery lakes tend to be of the oligotrophic condition and therefore may not reflect the overall nutrient status of lakes in the Mat-Su region at large. Nonetheless, we examined the data (Figures 2-4; Table 7) from a multiple lake or regional perspective and assessed trophic status based on single parameters and using Carlson's (1977) composite indices of trophic status.

Regional Description

The average size (area) of the Mat-Su lakes in this study was 2.6 km^2 with a median size of 1.3 km^2. Approximately 72% of the lakes were less than 2 km^2 in area, with only two lakes exceeding 6 km^2. The largest lake was Chelatna Lake, a glacially influenced lake draining into the Yentna River, the smallest was Mud Lake within the Cottonwood Creek drainage. The average mean depth for the lakes was 9.4 m with a median mean depth of 6.5 m. Most (76%) of the lakes had a maximum depth less than 30 m, only four lakes exceeded 30 m. The deepest lake was Chelatna Lake and the shallowest was Mud Lake. Considering lakes with a maximum depth of less than 30 m, the maximum to mean depth ratio averaged 2.5. For the data set including all lakes, the ratio was 2.03. Thus, the maximum depth is about twice the mean depth. These ratios will be useful for estimating mean depth for other lakes in the region in the absence detailed bathymetric data. The average volume of the lakes was 68×10^6 m^3 with all but Chelatna Lake and Big Lake having volumes less than 100×10^6 m^3.

Color and turbidity are important factors affecting light penetration and transparency of the water column (Kirk 1991). Mean values for color were rather evenly distributed among the increments between 3 and 27 Pt units. Other than Chelatna Lake which receives glacial meltwater input, mean turbidity values in the other lakes were all less than 3 nephelometric turbidity units (NTU). The average color was 14 platinum-cobalt (Pt) units and the mean level of turbidity was 1.4

NTU. In comparison, both Koenings and Edmundson (1991) reported a mean color value of 21 Pt units for a set of stained lakes and 8 Pt units for a group of clear lakes in Alaska, whereas turbidity averaged 18 NTU for glacial lakes and <1 NTU for their clear water systems.

The average Secchi reading was 4.3 m and the median value was 3.8 m. Only two lakes (Big and Judd lakes) had a mean Secchi disk reading greater than 6 m, whereas 61% had average readings between 3 and 4.5 m. The maximum Secchi depth recorded was in Judd Lake (13 m) and the minimum reading was in Chelatna Lake (0.8 m). In comparison, LaPerriere and Edmundson (2000) reported a maximum Secchi depth of 18 m in Battle Lake, a remote and pristine lake within the Katmai National Park and Preserve. Given the shallow morphometry of some of the Mat-Su lakes we were concerned about the validity of the Secchi depth, assuming that in some instances the disk might have been visible on the lake bottom and that measurement was reported. However, all of the lakes were sampled at a mid-lake site, assuming it to be the deepest spot. Although the mean Secchi reading was greater than the mean depth in four of the lakes, the maximum depth exceeded the Secchi depth in all cases. On average, the mean and maximum depth were 2.8 and 7.2 times greater than the Secchi depth. Thus we believe the Secchi readings were not constrained by morphometry in any of the study lakes.

Conductivity, and index of dissolved solids, is sometimes used in conjunction with mean depth as a measure of potential productivity and trophic status (Ryder 1965). One-half of the lakes had conductivity values less than 100 $\mu S\ cm^{-1}$ while 28% had conductivity values less than 50 $\mu S\ cm^{-1}$. The mean conductivity was 106 $\mu S\ cm^{-1}$ and nearly twice that reported by Edmundson and Carlson (1998) for a larger Alaskan lake data set. For the most part, the highest seasonal mean conductivity values (>100 $\mu S\ cm^{-1}$) were found in lakes of the Cottonwood Creek drainage and in Big, Horseshoe, and Lucile lakes, whereas Byers, Chelatna, and Shell lakes, which are much deeper, had not surprisingly the lowest conductivity (<50 $\mu S\ cm^{-1}$).

Calcium and magnesium concentrations are often associated with nature of the surrounding geology. For the Mat-Su data set, calcium concentrations (mean = 13.3 mg L^{-1}; median = 10.6 mg L^{-1}) always exceeded that of magnesium concentrations (mean = 2.1 mg L^{-1}; median = 1.8 mg L^{-1}). The mean iron concentration was 71 $\mu g\ L^{-1}$ and the median was 65 $\mu g\ L^{-1}$. Wetzel (1975) reported that concentrations of total iron less than 200 $\mu g\ L^{-1}$ were typical of well-oxygenated waters having a circumneutral pH. Glacially influenced Chelatna Lake had the highest average iron concentrations (range 118-417 $\mu g\ L^{-1}$), but the stained lakes Nancy, Shell and Stephan lakes also had iron concentrations noticeably higher than the other lakes. However, it is known that total iron levels are elevated in waters containing large amounts of glacial silt (inorganic turbidity) or dissolved organic carbon (color) (Edmundson and Koenings 1985).

The hydrogen ion concentration, expressed as pH units, is largely dependent on the dissociation of acid or bases (or their salts) to their respective ions and most chemical and biological reactions in aquatic systems are pH dependent. In addition, the diversity and abundance of biological communities are related to different pH ranges in that both species diversity and abundance tend to decrease sharply at low (<6 units) or high (>8 units) pH levels (Laws 1993). Among the Mat-Su lakes, 68% (17) had mean pH values between 6.5 and 8 units, whereas all of the others exceeded 8 pH units (Figure 2). Alkalinity, expressed as the concentration of calcium carbonate ($CaCO_3$) is a measure of a lake's capacity to resist changes in pH (i.e., it's buffering capacity).

The average alkalinity for the 25 Mat-Su study lakes was 49 mg L^{-1} with the highest values (>150 mg L^{-1}) generally occurring in lakes of the Cottonwood Creek drainage.

Relatively high concentrations of *available* nutrients (phosphorus and nitrogen) cause algal growth that is symptomatic of the eutrophic condition. Among the Mat-Su lakes, the mean total filterable (dissolved) phosphorus content averaged only 4.4 μg L^{-1} and the mean filterable reactive (orthophosphate) concentration was 2.7 μg L^{-1}. Half (52%) of the lakes had total filterable concentrations between 3 and 4.5 μg L^{-1}, whereas 72% of the lakes had average filterable reactive phosphorus concentrations less than 3 μg L^{-1}. Both mean total filterable and filterable reactive phosphorus concentrations were considered to be low suggesting that particulate or colloidal phosphorus is the predominant fraction of total phosphorus in these lakes. Considering lake-year means, total phosphorus ranged from 2.2 to 44.2 μg L^{-1}. The lowest lake mean was derived from Judd Lake and the highest value was from Finger Lake; however, these data represents single surveys conducted in mid-summer, so it is probably not valid to compare these concentrations directly with the other lake-mean values. A high percentage (44%) of lakes exhibited lake-mean total phosphorus values between 10-20 μg L^{-1}, including most of the lakes within the Cottonwood Creek drainage (Anderson, Cottonwood, Mud, Necklason, and Wasilla lakes) as well as Delyndia, Hewitt, Lucile, Monsoon, Nancy, and Stephan lakes. The overall mean total phosphorus concentration for the 25 lakes was 11.3 μg L^{-1} which is considered slightly above the threshold (10 μg L^{-1}) indicative of the mesotrophic (between oligotrophic and eutrophic) condition (Forsberg and Ryding 1980). This concentration is somewhat higher than that reported by Edmundson and Carlson (1998) for 73 clear and stained lakes in Alaska, which was to be expected, since the lakes in our study tend were on average much shallower. That is, a shallower morphometry relative to surface area promotes increased internal phosphorus loading and higher productivity rates (Fee 1979; Osgood 1988).

Inorganic nitrogen (nitrate + nitrite + ammonia) averaged 105 μg L^{-1}, and most (64%) of the lakes had concentrations less than 60 μg L^{-1}. Relatively high inorganic nitrogen levels (lake-mean range 210-516 μg L^{-1}) were found in Byers, Chelatna, Delyndia, Judd, Larson, and Shell lakes). However, organic nitrogen (Kjeldahl minus ammonia) exceeded inorganic nitrogen in 76% of the lakes. Overall, mean organic nitrogen averaged 75% of the total nitrogen present. Total nitrogen lake-mean values ranged from 143 to 920 μg L^{-1} and 56% of the lakes fell within the 100-300 μg L^{-1} range. The overall mean was 356 μg L^{-1} and the median was 284 μg L^{-1}. In comparison, Edmundson and Carlson (1998) reported mean total nitrogen levels of 214 μg L^{-1} for 52 clear lakes, 195 μg L^{-1} for 21 stained lakes, and 158 μg L^{-1} for glacial lakes in Alaska. Vollenweider (1976) suggested total nitrogen concentrations greater than 300 μg L^{-1} point toward an eutrophication problem; however, it is usually phosphorus that is considered to be the limiting nutrient. Indeed, the total nitrogen to phosphorus (N:P) ratios (by atoms) were generally high indicating phosphorus deficiency relative to nitrogen. For the Mat-Su lakes, 68% of the lake-mean N:P values exceeded 60:1. The overall mean N:P molar ratio was 92:1 and the median was 67:1. In comparison, Smith (1979) suggested N:P molar ratios greater than 15-17:1 indicate phosphorus limitation. Thus, among the Mat-Su study lakes algal growth appeared to be limited by phosphorus shortage.

The pigment chlorophyll is usually used as an index of phytoplankton (algal) biomass and thus, of lake trophic status. Finger Lake had the highest chlorophyll concentration (15.7 $\mu g\ L^{-1}$) which occurred during a summer (1988) algal bloom (Edmundson et al. 1989). However, when lakes having a sample size of one were excluded (Finger, Judd, Lucile, Whiskey), the highest lake-year mean in the data set was 5.9 $\mu g\ L^{-1}$ (Hewitt Lake). Considering all lakes, fifty-two percent of the lake-mean chlorophyll concentrations were less than 1 $\mu g\ L^{-1}$, 30% of the values were between 1 and 2 $\mu g\ L^{-1}$, and only 18% of the lakes had concentrations greater than 3 $\mu g\ L^{-1}$. The overall average chlorophyll concentration (including Finger Lake) was 1.8 $\mu g\ L^{-1}$ and the median was 1.0 $\mu g\ L^{-1}$. These statistics were very similar to that reported for 73 non-glacial lakes in Alaska (Edmundson and Carlson 1998). Generally, average concentrations over the growing season that are less than 3-4 $\mu g\ L^{-1}$ are considered indicative of the oligotrophic condition (Forsberg and Ryding 1980).

Trophic Status

Examining phosphorus concentration, chlorophyll levels, and Secchi depth together typically assesses trophic status depth (e.g., Carlson 1977; Chapra and Roberston 1977; Forsberg and Ryding 1980). The use of these single parameters is a widely accepted method for trophic classification. The Secchi depth is the simplest way to measure trophic status, assuming that phytoplankton is the main source of turbidity (Megard et al. 1980). That is, lower Secchi readings imply higher algal densities. Among natural lakes it is generally assumed that total phosphorus concentrations greater than 20 $\mu g\ L^{-1}$ are evidence of eutrophy (Forsberg and Ryding 1980). However, measurements of phosphorus taken during the spring overturn (de-stratification) period are often sufficient to determine trophic status, with concentrations greater than 10 $\mu g\ L^{-1}$ indicating a potential for eutrophication (Vollenweider 1976). Many traditional trophic classification schemes suggest that chlorophyll concentrations greater than the 5-7 $\mu g\ L^{-1}$ range reflect the eutrophic condition (e.g., Vollenweider 1976; Forsberg and Ryding 1980). Based on the single variable Secchi depth the majority (57%) of the Mat-Su study lakes were considered mesotrophic, whereas mean total phosphorus values indicated more than half of the lakes (52%) were oligotrophic. In contrast, nearly all of these lakes (86%) were considered oligotrophic based on the chlorophyll data (Table 8).

Carlson (1977) proposed a trophic state index (TSI) based on any one of the variables Secchi depth, total P, and chlorophyll assuming that all were inter-correlated. This commonly used method computes a TSI value between 0 and 100 corresponding to the degree of eutrophy rather than assigning trophic classification by name. Rather, an increase in 10 units represents a doubling of algal biomas (chlorophyll). Comparisons of mean TSI values for the Mat-Su lakes and apparent water quality descriptions after Carlson (1977) are presented in Figure 6. TSI values derived from mean total phosphorus produced the highest TSI value (mean 53; median 54), whereas chlorophyll produced the lowest (mean 30; median 28) and the TSI based on the Secchi depth data yielded an intermediate value (mean 39; median 41). Thus, TSI derived from chlorophyll data suggest higher (very good to excellent) water quality than do TSI values based on either total phosphorus or Secchi depth (fair to good). However, researchers have shown that Carlson's (1977) TSI based on Secchi depth is inappropriate (biased toward eutrophy) where large amounts of non-algal material are present in the water column (Brezonik 1978; Megard et al. 1980). That is, lakes differ in regard to physical and chemical characteristics that can uncouple the nutrient-phytoplankton-transparency relationships. Because the Mat-Su data set contains a mixture of different lake types, the overriding effect of color (organic stain) and inorganic turbidity (silt) reduces transparency and decreases primary production, ultimately resulting in lower average chlorophyll standing crop. This explains the apparent differences in TSI values between methods. Thus, when considering lake of different typology, TSI values based upon chlorophyll are a much more meaningful method for assessing or comparing trophic status.

Using criteria based upon color, turbidity, and Secchi depth (Koenings and Edmundson 1991), we classified 21 of the lakes according to type (Table 9). In the case of Butterfly, Delyndia, and Finger (Crooked) lakes, where we lacked information on color and turbidity, we inferred the stained typology based on their low conductivity, pH, alkalinity, and reduced water transparency (Wetzel 1975). Koenings and McDaniel (1983) previously assigned the stained typology to Monsoon Lake. Thus, among the 25 Mat-Su study lakes herein, 16 were classified as stained, 8 were designated clear-water, and one (Chelatna Lake) was considered glacially turbid. We were interested in whether the effect of TSI methods was dependent upon lake type. Considering the lake mean data as the observational unit (N=71), the two-factor interaction plot using fitted values from ANOVA can be seen in Figure 7. Overall, TSI calculated from total phosphorus produced the highest values, followed by the Secchi and chlorophyll methods. More importantly, ANOVA revealed a significant (P=0.0002; F = 5.7; df method = 2; df type = 2; df method × type = 4; df error = 177) interaction (method × type) which suggested that the magnitude of the difference between the three methods for calculating TSI depends on which lake type one examines. That is, the method difference between TSI calculated from Secchi depth and total phosphorus was 16 for clear lakes and 13 for stained lakes, but only 6 for the glacial lakes. In addition, the difference in TSI calculated from Secchi depth and chlorophyll was 1 for both clear and stained lakes, but 16 for glacial lakes. Between the phosphorus and chlorophyll method the difference in TSI was 16 for the clear lakes and 14 for the stained lakes, whereas the methods difference was 22 for the glacial lakes. Thus, the overall conclusion is that TSI based on Secchi depth, total phosphorus, and chlorophyll *a* has predictive capabilities for regional classification of trophic status only if lake typology is considered or when the data set is restricted to exclude lakes in which the extinction of light by non-algal substances is high.

Other Considerations

Although we lack information on the extent of macrophyte (rooted sub-surface and surface plants) growth in these lakes, it is known that abundant populations of rooted plants can also greatly influence (reduce) water transparency (Canfield et al. 1983). Given that many of the Mat-Su lakes in this study are relatively shallow, it is possible that the presence of macrophytes in some of these systems may also limit water transparency expressed as Secchi depth and thus infer a higher trophic state. However, nutrient "over enrichment" does not always cause nuisance growth of macrophyte populations. It should be stated that the presence of abundant weed growth is usually the result of shallow morphometry, clear water, and nutrient rich sediments. When water column nutrients are high, algal blooms reduce transparency, which often limits the growth of rooted plants. Nonetheless, decomposition of submersed aquatic macrophytes under winter ice cover can lead to severe depletion of dissolved oxygen, particularly in shallow stratified lakes as documented for Lucile Lake, near the city of Wasilla (Woods 1985a). In addition, a thick covering of ice and snow prevents diffusion from the atmosphere and with too little light for active photosynthesis, oxygen is consumed but cannot be regenerated effectively. As a result, oxygen concentrations at the end of long winters can become so low that fish do not survive, a phenomenon known as "winter kill". We do not know the extent (if any) of winter kill occurring in lakes of the Mat-Su Borough. However, gathering baseline data on macrophyte coverage, the existence or potential for hypolimnetic oxygen depletion, and wintertime dissolved oxygen conditions are important aspects relevant to trophic status and should be considered in future water quality monitoring programs.

Conclusions

Phosphorus is the primary nutrient limiting productivity in the 25 Mat-Su lakes based on nutrient concentrations and N:P ratios. Frequency of occurrence histograms and density curves for salient trophic state indicators showed the pattern of distribution to be largely asymmetrical (right-skewed). Trophic status evaluation using Secchi depth and total phosphorus criteria revealed an oligotrophic to eutrophic gradient; however, when trophic status was evaluated from chlorophyll criteria developed for natural lakes nearly all of them were classified as oligotrophic. This apparent discrepancy was attributed to the inclusion of stained and silty lakes where light attenuation from non-algal material is high; in contrast with clear-water lakes where phytoplankton dominates the underwater light climate. That is, inorganic turbidity from glacial silt and high color from organic stain decreases transparency (Secchi depth) independent of algal cell densities. In addition, much of the total phosphorus pool in stained and glacial (turbid) lakes are comprised of phosphorus fractions that are less available or non-available (e.g., inorganic particulate or colloidal phosphorus) for assimilation by phytoplankton (Edmundson and Carlson 1998) so there is less chlorophyll being expressed per unit of phosphorus. For comparative purposes, when assessing the trophic status among a mixture of different lake types, chlorophyll criteria should be used rather than phosphorus or Secchi data to characterize the trophic state. Moreover, it should be stated that chlorophyll expressed as a function of nutrients (total phosphorus) tended to be lower in western Canadian lakes (Ostrofsky and Rigler 1987) and in subarctic Alaskan lakes (Edmundson and Carlson 1998) compared to north temperate lakes. Although the influence of lake typology on nutrient-chlorophyll relationships has been demonstrated, lower chlorophyll yield per unit of phosphorus may also be due to the shorter growing season in lakes of higher latitudes or other regional climatic and meteorological forces. Thus, direct comparisons of nutrient levels and their potential for eutrophication across different ecoregions may yield an "overstated" or "understated" trophic state. To develop meaningful nutrient criteria for lakes in this region requires an understanding of nutrient levels relative to the definition and process of eutrophication in cold regions.

Recommendations

Although the information presented here provides baseline data on trophic conditions for a select group of 25 lakes, these lakes were not all sampled consistently across years. Hence, interannual variation due to climatic factors could confound between-lake comparisons of nutrient/chlorophyll concentrations and trophic status. In addition, most of the longer-term time series of data in this summary were generated more than a decade ago. In developing regional nutrient criteria for Alaskan lakes, we recommend implementing a multi-lake limnological monitoring program to examine water chemistry, nutrient concentrations, and algal biomass levels over a period of at least 2-3 years. The selection of candidate lakes for further study should include those lakes known to be largely free of the effects of cultural eutrophication and acidification, which could include several from this study (e.g., Larson, Judd, and Shell lakes), as well as those where the potential effects of growing urban development are many or where changes toward eutrophication have already been documented (Woods 1985b; Woods 1986; Edmundson et al. 1989). If we compare these kinds of lakes with natural lakes that are remote or protected, there should be noticeable differences that can be used to develop appropriate regional nutrient criteria for water quality goals. A logical extension of this work would be to acquire a further understanding of lakes as rearing habitat for fish and other aquatic life. For example, there is genuine concern among fishery resource managers surrounding the recent decline in sockeye salmon production in Big Lake (Reusch and Fox 1999) as it could be linked to changes in freshwater rearing conditions or degradation of spawning habitat brought about by landscape perturbations and perhaps cultural eutrophication.

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Table 1. Geographic and morphometric information for the 25 Matanuska-Susitna area study lakes.

Lake	Latitude (°N)	Longitude (°W)	Location by drainage	Elevation (m)	Area ($\times 10^6$ m^2)	Mean depth (m)	Maximum depth (m)	Volume ($\times 10^6$ m^3)
Anderson	61 37	149 20	Cottonwood Creek	137	0.5	3.2	8.5	1.7
Big	61 31	149 59	Fish Creek	43	12.1	9.0	27.0	111.9
Butterfly	61 35	150 07	Little Susitna River	61	1.2	6.5	22.9	7.6
Byers	62 44	150 06	Susitna River	249	1.3	20.0	54.0	26.7
Caswell	62 01	149 57	Susitna River	92	0.4	4.0	8.2	1.8
Chelatna	62 29	151 27	Yentna River	422	15.8	61.0	125.0	970.5
Cornelius	61 37	149 15	Cottonwood Creek	122	0.2	6.9	16.5	1.3
Cottonwood	61 35	149 19	Cottonwood Creek	100	1.1	3.3	12.0	3.5
Delyndia	61 36	150 05	Little Susitna River	61	1.2	6.5	22.8	7.7
Finger[a]	61 31	150 03	Little Susitna River	46	1.0	4.2	10.7	4.2
Finger	61 37	149 15	Cottonwood Creek	337	1.5	4.7	13.4	6.9
Hewitt	62 00	151 21	Yentna River	44	2.3	13.5	34.0	38.0
Horseshoe	61 22	150 09	Little Susitna River	25	0.7	2.9	7.5	1.9
Judd	61 34	151 33	Yentna River	299	1.3	na[b]	na	na
Larson	62 20	149 53	Susitna River	186	1.8	16.4	42.6	29.1
Lucile	61 34	149 28	Fish Creek	na	1.5	1.7	6.5	2.5
Monsoon	62 39	146 49	Gulkana River	913	0.3	8.5	19.0	2.6
Mud	61 35	149 20	Cottonwood Creek	100	0.2	1.0	5.2	0.2
Nancy	61 41	150 00	Little Susitna River	77	3.1	7.7	19.8	23.6
Neklason	61 37	149 16	Cottonwood Creek	0.9	0.3	4.8	17.3	1.4
Red Shirt	61 37	150 10	Susitna River	37	5.5	5.3	15.2	28.8
Shell	61 58	151 33	Yentna River	123	5.2	11.9	28.7	62.3
Stephan	62 42	148 54	Susitna River	256	4.0	7.0	27.7	33.7
Wasilla	61 35	149 24	Cottonwood Creek	98	1.5	5.2	14.6	7.9
Whiskey	61 59	151 24	Yentna River	na	1.1	na	na	na

a/ also known as Crooked Lake (Maurer and Woods 1987)

b/ na indicates data not available

Table 2. Analytical methods used in the lake sampling program.

Parameter	Method[a]
Transparency	Secchi disk
Conductivity	Electrometric
pH	Electrometric
Alkalinity	Titration (0.02 N H_2SO_4)
Turbidity	Nephelometric
Color	Absorption 400 nm
Calcium	Titration (EDTA)
Magnesium	Titration (EDTA)
Iron	Colorimetric (HCL digestion, ferrozine)
Total P	Colorimetric (persulfate digestion, ascorbic acid reduction)
Total Filterable P	Colorimetric (persulfate digestion, ascorbic acid reduction)
Filterable Reactive P	Colorimetric (ascorbic acid reduction)
Total N	Summation (Kjeldahl + nitrate + nitrite)
Kjeldahl N	Colorimetric (block digestion, phenate)
Ammonia N	Colorimetric (phenal-hypochorite)
Nitrate + Nitrite N	Colorimetric (cadmium reduction)
Reactive Silicon	Colorimetric (heteropoly blue)
Chlorophyll a	Fluorometric and Spectrophotmetic (acetone extraction)
Phaeophytin	Fluorometric and Spectrophotmetric (acetone extraction)
Total Pigment	Summation (chlorophyll + phaeophytin)

a/ Reference: Koenings et al. (1987)

Table 3. Number of limnological surveys conducted annually during the open-water period for the 25 study lakes.

Lake	Year	Frequency	Lake	Year	Frequency
Anderson	1998	4	Larson	1981	3
	1999	4		1984	3
Big	1983	10		1985	4
	1984	9		1986	6
	1985	4		1987	6
	1999	2		1988	4
Butterfly	1981	3		1993	1
Byers	1981	3	Lucile	1984	1
	1983	2	Monsoon	1982	3
	1984	2	Mud	1998	4
	1993	1		1999	4
Caswell	1983	3	Nancy	1983	3
	1984	2		1984	2
Chelatna	1990	3	Neklason	1998	4
	1991	3		1999	4
	1992	3	Red Shirt	1984	3
	1993	3		1993	1
	1994	5	Shell	1981	3
	1995	4		1984	4
	1996	3		1985	4
Cornelius	1983	3		1986	4
	1984	2		1987	2
	1998	4		1993	1
	1999	4	Stephan	1984	2
Cottonwood	1983	3		1985	3
	1984	2		1986	1
	1998	4		1993	1
	1999	4	Wasilla	1983	3
Delyndia	1981	3		1984	3
Finger[a]	1981	4		1986	6
Finger	1988	1		1993	1
Hewitt	1984	3		1998	4
	1985	4		1999	4
	1993	1	Whiskey	1993	1
Horseshoe	1985	7			
	1986	6			
Judd	1993	1			

a/ also known as Crooked Lake (Mauer and Woods 1987)

Table 4. Mean values (**bold**) and standard deviation (*italics*) for general water chemistry parameters for the 25 study lakes. Data are derived for near-surface (0-2 m) waters. Nd = not determined; decimal indicates standard deviation cannot be calculated (i.e., sample size ≤1).

Lake	Year	Conductivity (μS cm^{-1})	pH (Units)	Alkalinity (mg L^{-1})	Turbidity (NTU)	Color (Pt units)	Calcium (mg L^{-1})	Magnesium (mg L^{-1})	Iron (μg L^{-1})
Anderson	98	**144**	**8.0**	**61.0**	**1.7**	**12**	**nd**	**nd**	**nd**
		4	*0.2*	*2.4*	*1.0*	*3*	.	.	.
Anderson	99	**146**	**8.1**	**59.3**	**1.6**	**10**	**nd**	**nd**	**73**
		6	*0.3*	*2.2*	*1.1*	*1*	.	.	.
Big	83	**106**	**7.8**	**54.9**	**nd**	**nd**	**15.2**	**2.6**	**24**
		3	*0.2*	*3.2*	.	.	*0.5*	*0.7*	*10*
Big	84	**109**	**7.6**	**56.7**	**1.1**	**8**	**13.6**	**2.8**	**29**
		3	*0.2*	*5.3*	*1.4*	*3*	*4.5*	*1.1*	*20*
Big	85	**111**	**7.3**	**55.3**	**0.9**	**9**	**15.1**	**3.2**	**66**
		5	*0.1*	*4.4*	*0.2*	*1*	*0.2*	*0.2*	*27*
Big	99	**126**	**7.8**	**60.3**	**2.7**	**9**	**nd**	**nd**	**nd**
		6	*0.1*	*2.6*	*2.4*	*3*	.	.	.
Butterfly	81	**43**	**6.3**	**20.0**	**nd**	**nd**	**5.7**	**0.4**	**77**
		10	*0.6*	*5.4*	.	.	*1.3*	*0.4*	*66*
Byers	81	**29**	**6.6**	**14.8**	**nd**	**nd**	**4.6**	**0.6**	**89**
		7	*0.3*	*3.0*	.	.	*0.6*	*0.5*	*71*
Byers	83	**37**	**7.0**	**15.3**	**nd**	**nd**	**8.9**	**1.8**	**56**
		1	*0.2*	*0.6*	.	.	*5.7*	*2.7*	*27*
Byers	84	**40**	**7.0**	**17.0**	**0.6**	**11**	**4.8**	**0.4**	**71**
		1	*0.1*	*1.4*	*0.1*	*1*	*0.6*	*0.1*	*16*
Byers	93	**32**	**6.8**	**15.0**	**0.5**	**9**	**6.0**	**1.0**	**43**
		.	.	.	.	.	.	.	.

Table 4. (continued)

Lake	Year	Conduct-ivity (μS cm^{-1})	pH (Units)	Alkalinity (mg L^{-1})	Turbidity (NTU)	Color (Pt units)	Calcium (mg L^{-1})	Magnesium (mg L^{-1})	Iron (μg L^{-1})
Caswell	83	**41**	**7.1**	**20.7**	**nd**	**nd**	**8.6**	**0.8**	**60**
		2	*0.1*	*1.2*	.	.	*5.0*	*0.5*	*25*
Caswell	84	**45**	**7.0**	**23.5**	**0.6**	**8**	**5.6**	**0.8**	**64**
		1	*0.0*	*3.5*	*0.1*	*3*	*1.1*	*0.6*	*43*
Chelatna	90	**24**	**7.0**	**9.0**	**5.4**	**10**	**3.7**	**0.2**	**417**
		2	*0.3*	*1.0*	*2.2*	*9*	*0.3*	*0.1*	*218*
Chelatna	91	**27**	**7.1**	**13.3**	**3.5**	**5**	**3.8**	**0.7**	**239**
		3	*0.1*	*5.8*	*0.6*	*2*	*0.9*	*0.5*	*73*
Chelatna	92	**25**	**6.7**	**7.3**	**1.5**	**3**	**4.1**	**0.4**	**127**
		1	*0.2*	*0.6*	*0.9*	*0*	*0.8*	*0.3*	*107*
Chelatna	93	**27**	**6.8**	**8.7**	**4.0**	**8**	**3.7**	**0.4**	**242**
		2	*0.5*	*0.6*	*4.7*	*2*	*0.6*	*0.3*	*278*
Chelatna	94	**27**	**6.6**	**9.2**	**2.1**	**5**	**3.5**	**0.4**	**118**
		1	*0.3*	*1.6*	*0.5*	*3*	*0.5*	*0.2*	*47*
Chelatna	95	**25**	**6.4**	**8.8**	**4.8**	**5**	**3.4**	**0.8**	**300**
		2	*0.1*	*0.5*	*4.6*	*4*	*0.6*	*0.2*	*337*
Chelatna	96	**26**	**6.7**	**9.7**	**5.3**	**5**	**3.6**	**0.4**	**252**
		0	*0.3*	*1.2*	*3.7*	*1*	*0.1*	*0.3*	*169*
Cornelius	83	**195**	**8.0**	**102.0**	**nd**	**nd**	**32.3**	**2.3**	**37**
		6	*0.2*	*4.4*	.	.	*2.5*	*1.8*	*25*
Cornelius	84	**190**	**8.1**	**96.0**	**nd**	**21**	**28.2**	**3.7**	**21**
		1	*0.2*	*1.4*	.	*1*	*4.0*	*0.4*	*1*
Cornelius	98	**207**	**8.1**	**101.3**	**1.3**	**19**	**nd**	**nd**	**nd**
		7	*0.0*	*8.4*	*0.8*	*3*	.	.	.

Table 4. (continued)

Lake	Year	Conductivity (μS cm^{-1})	pH (Units)	Alkalinity (mg L^{-1})	Turbidity (NTU)	Color (Pt units)	Calcium (mg L^{-1})	Magnesium (mg L^{-1})	Iron (μg L^{-1})
Cornelius	99	**193**	**8.0**	**97.3**	**2.0**	**14**	**nd**	**nd**	**29**
		10	*0.3*	*7.3*	*2.7*	*6*	.	.	.
Cottonwood	83	**167**	**7.9**	**86.3**	**nd**	**nd**	**26.2**	**4.0**	**58**
		14	*0.2*	*7.4*	.	.	*4.4*	*0.2*	*41*
Cottonwood	84	**176**	**8.6**	**95.0**	**0.9**	**24**	**25.7**	**3.7**	**34**
		8	*0.9*	*2.8*	*0.4*	*3*	*1.5*	*0.4*	*1*
Cottonwood	98	**191**	**8.1**	**92.0**	**1.3**	**23**	**nd**	**nd**	**nd**
		23	*0.1*	*11.5*	*0.6*	*3*	.	.	.
Cottonwood	99	**194**	**8.1**	**92.5**	**1.8**	**18**	**nd**	**nd**	**38**
		19	*0.2*	*8.2*	*1.5*	*4*	.	.	.
Delyndia	81	**39**	**6.6**	**13.7**	**nd**	**nd**	**5.9**	**0.7**	**64**
		17	*0.3*	*1.4*	.	.	*0.8*	*0.6*	*34*
Finger[\a]	81	**53**	**6.7**	**27.4**	**nd**	**nd**	**9.7**	**1.3**	**40**
		4	*0.3*	*2.7*	.	.	*0.4*	*0.7*	*23*
Finger	88	**201**	**8.4**	**95.5**	**1.5**	**15**	**28.3**	**5.9**	**35**
		6	*0.1*	*0.7*	*0.7*	*1*	*0.6*	*0.5*	*0*
Hewitt	84	**89**	**7.1**	**37.3**	**2.1**	**8**	**11.8**	**2.1**	**89**
		6	*0.3*	*5.1*	*1.0*	*2*	*1.6*	*0.4*	*65*
Hewitt	85	**84**	**7.2**	**48.5**	**1.8**	**5**	**10.4**	**1.4**	**98**
		7	*0.4*	*16.0*	*0.7*	*3*	*0.4*	*0.2*	*55*
Hewitt	93	**86**	**7.3**	**38.0**	**3.1**	**3**	**12.5**	**2.4**	**115**
		.	.	.	.	.	.	.	.
Horseshoe	85	**158**	**7.8**	**83.5**	**1.1**	**12**	**25.6**	**2.3**	**69**
		16	*0.3*	*24.7*	*0.3*	*5*	*3.4*	*0.9*	*74*

Table 4. (continued)

Lake	Year	Conduct-ivity (μS cm^{-1})	pH (Units)	Alkalinity (mg L^{-1})	Turbidity (NTU)	Color (Pt units)	Calcium (mg L^{-1})	Magnesium (mg L^{-1})	Iron (μg L^{-1})
Horseshoe	86	**151**	**7.9**	**76.1**	**1.0**	**16**	**25.6**	**2.5**	**67**
		15	*0.3*	*8.6*	*0.3*	*5*	*4.8*	*1.0*	*68*
Judd	93	**18**	**6.5**	**6.0**	**0.3**	**3**	**2.0**	**0.2**	**40**
		.	.	.	.	.	.	.	.
Larson	81	**51**	**6.6**	**13.2**	**nd**	**nd**	**6.1**	**0.3**	**52**
		19	*0.2*	*3.2*	.	.	*0.9*	*0.0*	*23*
Larson	84	**68**	**6.7**	**12.4**	**1.5**	**10**	**6.4**	**2.9**	**40**
		3	*0.1*	*1.3*	*0.7*	*1*	*0.5*	*3.5*	*15*
Larson	85	**68**	**6.7**	**12.3**	**5.3**	**8**	**6.5**	**0.3**	**24**
		4	*0.3*	*1.3*	*6.3*	*5*	*1.7*	*0.0*	*14*
Larson	86	**70**	**7.0**	**12.0**	**1.0**	**10**	**nd**	**nd**	**42**
		6	*0.5*	*2.2*	*0.5*	*4*	.	.	*30*
Larson	87	**66**	**6.8**	**11.2**	**0.6**	**12**	**nd**	**nd**	**32**
		3	*0.3*	*1.1*	*0.4*	*2*	.	.	*23*
Larson	88	**79**	**7.0**	**14.0**	**1.1**	**14**	**nd**	**nd**	**15**
		12	*0.4*	*2.0*	*0.3*	*6*	.	.	*8*
Larson	93	**69**	**7.0**	**12.0**	**0.5**	**9**	**8.0**	**0.2**	**15**
		.	.	.	.	.	.	.	.
Lucile	84	**169**	**8.4**	**76.5**	**1.2**	**16**	**19.8**	**3.6**	**87**
		13	*0.2*	*6.4*	*0.4*	*4*	*2.3*	*0.6*	*7*
Monsoon	82	**99**	**7.7**	**51.7**	**nd**	**nd**	**14.7**	**2.9**	**70**
		16	*0.1*	*3.2*	.	.	*3.2*	*0.9*	*63*
Mud	98	**203**	**8.1**	**97.3**	**1.4**	**27**	**nd**	**nd**	**nd**
		17	*0.2*	*10.0*	*0.5*	*8*	.	.	.

Table 4. (continued)

Lake	Year	Conductivity (μS cm^{-1})	pH (Units)	Alkalinity (mg L^{-1})	Turbidity (NTU)	Color (Pt units)	Calcium (mg L^{-1})	Magnesium (mg L^{-1})	Iron (μg L^{-1})
Mud	99	**203**	**8.0**	**97.5**	**2.1**	**20**	**nd**	**nd**	**80**
		12	*0.1*	*5.4*	*1.7*	*4*	.	.	.
Nancy	83	**98**	**7.3**	**38.0**	**nd**	**nd**	**13.0**	**1.7**	**88**
		9	*0.1*	*3.9*	.	.	*3.1*	*0.8*	*109*
Nancy	84	**86**	**7.1**	**36.2**	**0.9**	**25**	**10.5**	**1.1**	**133**
		13	*0.1*	*7.1*	*0.3*	*5*	*1.3*	*0.8*	*104*
Neklason	98	**200**	**8.2**	**98.5**	**1.9**	**17**	**nd**	**nd**	**nd**
		13	*0.2*	*5.9*	*1.2*	*2*	.	.	.
Neklason	99	**192**	**8.1**	**95.8**	**1.8**	**16**	**nd**	**nd**	**23**
		16	*0.2*	*5.6*	*2.1*	*3*	.	.	.
Red Shirt	84	**82**	**7.2**	**34.7**	**1.4**	**17**	**7.9**	**4.5**	**39**
		4	*0.2*	*0.6*	*0.9*	*1*	*3.2*	*5.1*	*10*
Red Shirt	93	**87**	**7.0**	**38.0**	**0.5**	**12**	**12.5**	**1.6**	**31**
		.	.	.	.	.	.	.	.
Shell	81	**29**	**6.2**	**15.7**	**nd**	**nd**	**4.4**	**0.3**	**133**
		4	*0.7*	*5.1*			*0.6*	*0.0*	*60*
Shell	84	**35**	**6.8**	**13.4**	**0.7**	**20**	**4.1**	**0.8**	**69**
		1	*0.2*	*1.8*	*0.5*	*1*	*0.6*	*0.7*	*27*
Shell	85	**37**	**6.8**	**15.0**	**1.3**	**18**	**4.6**	**1.0**	**94**
		5	*0.1*	*2.4*	*0.6*	*3*	*0.7*	*0.2*	*39*
Shell	86	**33**	**6.7**	**12.8**	**0.5**	**12**	**4.3**	**0.3**	**102**
		2	*0.7*	*1.6*	*0.2*	*3*	.	.	*56*
Shell	87	**31**	**6.8**	**10.3**	**0.7**	**22**	**nd**	**nd**	**170**
		0	*0.0*	*0.5*	*0.3*	*2*	.	.	*17*

Table 4. (continued)

Lake	Year	Conductivity (μS cm^{-1})	pH (Units)	Alkalinity (mg L^{-1})	Turbidity (NTU)	Color (Pt units)	Calcium (mg L^{-1})	Magnesium (mg L^{-1})	Iron (μg L^{-1})
Shell	93	**38**	**6.8**	**11.0**	**0.7**	**14**	**4.8**	**0.8**	**110**
		.	.	.	.	.	.	.	.
Stephan	84	**104**	**7.5**	**36.0**	**1.1**	**19**	**8.6**	**2.0**	**60**
		8	*0.1*	*4.2*	*0.5*	*1*	*4.5*	*0.6*	*4*
Stephan	85	**98**	**7.2**	**38.0**	**2.3**	**14**	**11.1**	**2.3**	**118**
		9	*0.3*	*2.6*	*0.1*	*1*	*1.4*	*0.7*	*60*
Stephan	86	**96**	**7.4**	**30.0**	**2.0**	**29**	**10.2**	**2.4**	**143**
		.	.	.	.	.	.	.	.
Stephan	93	**110**	**7.5**	**40.0**	**0.8**	**10**	**14.0**	**3.9**	**60**
		.	.	.	.	.	.	.	.
Wasilla	83	**173**	**7.9**	**89.7**	**nd**	**nd**	**28.8**	**4.0**	**57**
		10	*0.2*	*5.0*			*5.9*	*0.3*	*32*
Wasilla	84	**167**	**7.9**	**94.3**	**1.1**	**20**	**27.6**	**3.7**	**42**
		24	*0.2*	*2.9*	*0.2*	*10*	*1.9*	*0.9*	*14*
Wasilla	86	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**
		.	.	.	.	.	.	.	.
Wasilla	93	**227**	**8.2**	**107.3**	**1.3**	**27**	**35.5**	**5.4**	**64**
		3	*0.0*	*1.5*	*0.3*	*4*	*1.0*	*0.7*	*23*
Wasilla	98	**213**	**8.2**	**101.5**	**1.6**	**23**	**nd**	**nd**	**nd**
		20	*0.2*	*10.0*	*0.7*	*7*	.	.	.
Wasilla	99	**212**	**8.0**	**99.5**	**2.3**	**17**	**nd**	**nd**	**84**
		21	*0.3*	*7.7*	*1.7*	*4*	.	.	*30*
Whiskey	93	**59**	**7.0**	**22.0**	**1.0**	**9**	**7.7**	**1.6**	**88**
		.	.	.	.	.	.	.	.

Table 5. Mean values (**bold**) and standard deviation (*italics*) for nutrient concentration, ntirogen to phosphorus ratios (by atoms), and algal pigments for the 25 study lakes. Data are derived for the near-surface (0-2 m) waters. Nd = not determined; decimal indicates standard deviation cannot be calculated (i.e., sample size <1).

Lake	Year	Total-P (µg L^{-1})	Total filter-able-P (µg L^{-1})	Filterable reactive-P (µg L^{-1})	Kjeldahl-N (µg L^{-1})	Ammonia (µg L^{-1})	Nitrate + nitrite (µg L^{-1})	Total-N (µg L^{-1})	N:P	Reactive silicon (µg L^{-1})	Chloro-phyll *a* (µg L^{-1})	Phaeo-phytin (µg L^{-1})
Anderson	98	**11.1**	**nd**	**nd**	**396**	**14.0**	**17.0**	**413**	**83**	**nd**	**1.2**	**0.7**
		1.3	.	.	*110*	*5.6*	*12.4*	*113*	*24*	.	*0.3*	*0.2*
Anderson	99	**10.4**	**4.0**	**2.1**	**461**	**22.9**	**15.5**	**477**	**104**	**668**	**0.7**	**0.7**
		1.8	*0.5*	*0.2*	*17*	*14.1*	*5.4*	*16*	*17*	.	*0.4*	*0.3*
Big	83	**8.5**	**4.2**	**2.1**	**210**	**5.1**	**4.0**	**214**	**57**	**2466**	**nd**	**nd**
		2.3	*1.4*	*0.8*	*57*	*4.0*	*1.1*	*57*	*14*	*561*	.	.
Big	84	**10.3**	**2.9**	**1.8**	**208**	**2.3**	**4.4**	**213**	**51**	**2603**	**nd**	**nd**
		5.1	*0.6*	*0.3*	*41*	*1.2*	*1.8*	*42*	*14*	*150*	.	.
Big	85	**7.6**	**5.4**	**1.9**	**208**	**2.0**	**1.3**	**210**	**63**	**2453**	**1.0**	**0.9**
		1.9	*1.8*	*0.5*	*16*	*0.6*	*1.3*	*16*	*11*	*566*	*0.5*	*0.6*
Big	99	**7.0**	**2.9**	**1.2**	**210**	**9.8**	**5.9**	**216**	**71**	**nd**	**0.3**	**0.2**
		1.8	*0.1*	*0.1*	*21*	*4.4*	*4.4*	*19*	*15*	.	*0.0*	*0.0*
Butterfly	81	**8.1**	**3.8**	**1.2**	**277**	**11.3**	**8.5**	**286**	**81**	**491**	**0.2**	**1.0**
		0.6	*1.7*	*0.6*	*45*	*13.5*	*10.6*	*40*	*16*	*65*	*0.2*	*0.9*
Byers	81	**7.2**	**3.4**	**2.8**	**92**	**2.6**	**493.4**	**585**	**185**	**3278**	**0.6**	**0.5**
		1.3	*0.9*	*0.8*	*28*	*1.0*	*60.8*	*69*	*39*	*166*	*0.3*	*0.1*
Byers	83	**7.6**	**2.9**	**2.1**	**110**	**21.1**	**289.1**	**399**	**116**	**3362**	**0.4**	**0.4**
		1.2	*0.7*	*0.9*	*36*	*22.6*	*247.2*	*214*	*65*	*266*	*0.2*	*0.3*
Byers	84	**7.4**	**2.9**	**2.7**	**100**	**10.8**	**492.4**	**592**	**178**	**3568**	**0.6**	**0.5**
		0.7	*1.2*	*0.8*	*28*	*3.5*	*25.9*	*2*	*16*	*186*	*0.1*	*0.2*
Byers	93	**4.1**	**2.5**	**1.4**	**121**	**10.0**	**356.4**	**477**	**258**	**3646**	**0.4**	**0.3**
		.	.	.	.	.	.	.	.	.	.	.

Table 5. (continued).

Lake	Year	Total-P (μg L^{-1})	Total filter-able-P (μg L^{-1})	Filterable reactive-P (μg L^{-1})	Kjeldahl-N (μg L^{-1})	Ammonia (μg L^{-1})	Nitrate + nitrite (μg L^{-1})	Total-N (μg L^{-1})	N:P	Reactive silicon (μg L^{-1})	Chloro-phyll *a* (μg L^{-1})	Phaeo-phytin (μg L^{-1})
Caswell	83	**9.7**	**3.2**	**2.4**	**156**	**4.3**	**3.3**	**159**	**38**	**3934**	**nd**	**nd**
		3.7	*1.3*	*0.4*	*39*	*1.9*	*1.4*	*40*	*9*	*232*	.	.
Caswell	84	**6.5**	**2.9**	**3.3**	**125**	**10.9**	**1.9**	**126**	**44**	**4799**	**0.4**	**0.5**
		1.0	*0.0*	*0.3*	*5*	*4.9*	*0.8*	*6*	*9*	*1*	.	.
Chelatna	90	**6.6**	**8.9**	**6.4**	**28**	**4.9**	**220.3**	**249**	**83**	**1680**	**0.2**	**0.1**
		1.8	*10.4*	*7.2*	*4*	*2.2*	*66.6*	*63*	*7*	*239*	*0.0*	*0.0*
Chelatna	91	**7.5**	**1.8**	**1.6**	**62**	**2.6**	**142.4**	**204**	**61**	**1606**	**0.3**	**0.2**
		1.7	*0.6*	*0.7*	*11*	*2.2*	*45.4*	*50*	*10*	*155*	*0.1*	*0.1*
Chelatna	92	**4.6**	**2.3**	**2.0**	**101**	**1.8**	**211.9**	**313**	**154**	**1672**	**0.2**	**0.1**
		0.4	*0.1*	*0.2*	*64*	*0.1*	*24.7*	*86*	*54*	*49*	*0.1*	*0.0*
Chelatna	93	**6.3**	**2.3**	**2.2**	**66**	**3.3**	**228.5**	**294**	**217**	**1747**	**0.2**	**0.2**
		7.0	*2.0*	*2.0*	*3*	*2.8*	*42.1*	*45*	*171*	*251*	*0.0*	*0.1*
Chelatna	94	**5.4**	**2.9**	**2.7**	**70**	**12.7**	**235.9**	**306**	**152**	**1705**	**0.5**	**0.1**
		3.0	*1.3*	*1.3*	*27*	*8.7*	*49.9*	*59*	*74*	*64*	*0.3*	*0.1*
Chelatna	95	**6.5**	**2.3**	**1.5**	**57**	**5.6**	**190.4**	**247**	**122**	**1717**	**0.8**	**0.2**
		3.5	*1.1*	*1.0*	*22*	*0.8*	*40.3*	*27*	*106*	*229*	*0.3*	*0.1*
Chelatna	96	**5.3**	**2.1**	**1.9**	**38**	**10.6**	**198.8**	**237**	**112**	**1622**	**0.6**	**0.1**
		1.9	*0.9*	*0.5*	*3*	*3.9*	*27.6*	*26*	*58*	*75*	*0.2*	*0.0*
Cornelius	83	**12.1**	**4.0**	**2.6**	**218**	**44.1**	**23.3**	**241**	**44**	**4008**	**nd**	**nd**
		3.9	*0.9*	*0.6*	*83*	*61.9*	*18.3*	*102*	*11*	*752*	.	.
Cornelius	84	**6.2**	**3.8**	**2.9**	**191**	**10.9**	**56.2**	**247**	**90**	**4190**	**1.0**	**0.4**
		0.4	*0.6*	*0.1*	*19*	*5.0*	*78.0*	*59*	*26*	*285*	.	.
Cornelius	98	**9.8**	**nd**	**nd**	**280**	**42.5**	**61.3**	**341**	**78**	**nd**	**2.5**	**1.4**
		3.1	.	.	*79*	*67.5*	*64.3*	*102*	*13*	.	*2.3*	*1.4*

Table 5. (continued).

Lake	Year	Total-P (μg L^{-1})	Total filterable-P (μg L^{-1})	Filterable reactive-P (μg L^{-1})	Kjeldahl-N (μg L^{-1})	Ammonia (μg L^{-1})	Nitrate + nitrite (μg L^{-1})	Total-N (μg L^{-1})	N:P	Reactive silicon (μg L^{-1})	Chlorophyll *a* (μg L^{-1})	Phaeophytin (μg L^{-1})
Cornelius	99	**9.7**	**2.2**	**2.0**	**218**	**37.1**	**49.2**	**267**	**65**	**3738**	**0.4**	**0.3**
		5.1	*0.1*	*0.6*	*120*	*42.8*	*56.8*	*116*	*15*	.	*0.1*	*0.2*
Cottonwood	83	**20.7**	**4.9**	**2.9**	**329**	**13.4**	**4.5**	**334**	**34**	**3321**	**0.7**	**1.0**
		13.9	*0.9*	*0.9*	*148*	*11.2*	*0.9*	*149*	*6*	*113*	*0.4*	*0.4*
Cottonwood	84	**9.3**	**4.0**	**3.7**	**227**	**2.5**	**4.1**	**231**	**55**	**3047**	**0.9**	**0.5**
		1.0	*0.3*	*0.4*	*40*	*0.2*	*0.0*	*40*	*4*	*375*	*0.6*	*0.1*
Cottonwood	98	**11.6**	**4.8**	**3.2**	**271**	**8.7**	**7.9**	**279**	**56**	**nd**	**1.7**	**1.0**
		3.4	*3.2*	*1.8*	*26*	*3.6*	*7.5*	*20*	*13*	.	*1.3*	*0.4*
Cottonwood	99	**10.3**	**3.6**	**2.6**	**264**	**18.9**	**26.0**	**290**	**66**	**3280**	**0.7**	**0.3**
		3.0	*1.2*	*0.4*	*30*	*9.8*	*23.3*	*23*	*19*	.	*0.2*	*0.2*
Delyndia	81	**11.2**	**3.8**	**2.2**	**225**	**10.6**	**235.0**	**460**	**91**	**1890**	**0.1**	**0.4**
		4.9	*1.0*	*0.8*	*47*	*12.0*	*345.7*	*313*	*41*	*1080*	*0.1*	*0.2*
Finger	81	**7.5**	**3.2**	**1.3**	**236**	**8.6**	**10.0**	**251**	**78**	**887**	**0.3**	**0.5**
		0.8	*0.9*	*0.5*	*24*	*7.8*	*5.8*	*29*	*10*	*77*	*0.2*	*0.3*
Finger	88	**44.2**	**7.3**	**3.2**	**917**	**9.3**	**3.4**	**920**	**46**	**2806**	**15.7**	**1.5**
		4.6	*0.6*	*0.6*	*13*	*0.4*	*0.0*	*13*	*6*	*25*	.	.
Hewitt	84	**10.5**	**4.0**	**4.1**	**172**	**14.5**	**48.7**	**220**	**47**	**4918**	**5.9**	**2.8**
		3.3	*0.3*	*0.2*	*20*	*21.2*	*54.4*	*74*	*7*	*257*	*4.4*	*2.5*
Hewitt	85	**13.8**	**11.1**	**3.4**	**245**	**32.3**	**45.0**	**288**	**44**	**4345**	**3.8**	**3.2**
		3.1	*1.7*	*0.3*	*37*	*33.5*	*42.2*	*86*	*4*	*606*	*1.3*	*1.3*
Hewitt	93	**7.4**	**3.2**	**2.9**	**143**	**8.9**	**1.5**	**145**	**43**	**4837**	**1.7**	**1.0**
		.	.	.	.	.	.	.	.	.	.	.
Horseshoe	85	**7.7**	**3.2**	**2.6**	**183**	**12.4**	**5.4**	**188**	**55**	**4311**	**nd**	**nd**
		0.8	*1.0*	*0.8*	*47*	*25.4*	*10.4*	*50*	*15*	*1368*	.	.

Table 5. (continued).

Lake	Year	Total-P (μg L^{-1})	Total filterable-P (μg L^{-1})	Filterable reactive-P (μg L^{-1})	Kjeldahl-N (μg L^{-1})	Ammonia (μg L^{-1})	Nitrate + nitrite (μg L^{-1})	Total-N (μg L^{-1})	N:P	Reactive silicon (μg L^{-1})	Chlorophyll *a* (μg L^{-1})	Phaeophytin (μg L^{-1})
Horseshoe	86	**8.2**	**2.8**	**2.3**	**225**	**3.6**	**8.5**	**234**	**66**	**3886**	**nd**	**nd**
		1.4	*0.8*	*0.9*	*35*	*3.6*	*17.6*	*35*	*17*	*844*	.	.
Judd	93	**2.2**	**1.1**	**1.7**	**64**	**11.0**	**200.8**	**265**	**267**	**3644**	**0.2**	**0.1**
		.	.	.	.	.	.	.	.	.	.	.
Larson	81	**8.1**	**3.1**	**1.5**	**173**	**5.3**	**540.7**	**713**	**198**	**2742**	**0.3**	**0.4**
		2.8	*0.9*	*0.6*	*70*	*3.8*	*401.3*	*351*	*102*	*1172*	*0.1*	*0.1*
Larson	84	**7.8**	**2.5**	**1.4**	**201**	**14.9**	**595.5**	**796**	**252**	**3411**	**0.9**	**0.4**
		3.0	*0.5*	*0.4*	*20*	*9.8*	*58.7*	*71*	*89*	*143*	*0.3*	*0.1*
Larson	85	**5.1**	**5.8**	**1.7**	**188**	**20.3**	**579.4**	**767**	**341**	**3247**	**0.7**	**0.7**
		1.3	*1.2*	*0.6*	*21*	*10.8*	*97.0*	*90*	*60*	*756*	*0.5*	*0.2*
Larson	86	**7.4**	**3.0**	**2.0**	**157**	**6.8**	**495.6**	**652**	**213**	**3409**	**1.1**	**0.5**
		2.3	*0.7*	*0.5*	*19*	*4.2*	*96.8*	*99*	*76*	*680*	*1.4*	*0.3*
Larson	87	**14.7**	**7.2**	**4.2**	**215**	**15.3**	**106.2**	**321**	**51**	**3519**	**1.7**	**0.7**
		4.0	*3.7*	*2.4*	*67*	*14.6*	*37.3*	*60*	*15*	*528*	*2.3*	*0.7*
Larson	88	**7.4**	**2.7**	**1.9**	**159**	**5.4**	**516.3**	**676**	**209**	**3417**	**nd**	**nd**
		1.7	*0.6*	*0.6*	*23*	*2.5*	*31.8*	*31*	*40*	*952*	.	.
Larson	93	**3.2**	**2.4**	**1.6**	**159**	**10.5**	**538.3**	**697**	**483**	**2971**	**0.7**	**0.3**
		.	.	.	.	.	.	.	.	.	.	.
Lucile	84	**19.5**	**10.9**	**3.5**	**530**	**16.1**	**24.2**	**554**	**64**	**1572**	**nd**	**nd**
		3.6	*1.3*	*1.0*	*12*	*3.5*	*21.1*	*9*	*13*	*361*	.	.
Monsoon	82	**13.1**	**6.0**	**2.7**	**169**	**4.0**	**3.0**	**172**	**31**	**4073**	**3.1**	**0.2**
		4.6	*1.4*	*0.5*	*23*	*1.3*	*1.0*	*23*	*7*	*381*	*0.2*	*0.3*
Mud	98	**9.3**	**nd**	**nd**	**310**	**27.6**	**18.5**	**329**	**81**	**nd**	**1.2**	**0.8**
		1.7	.	.	*52*	*12.9*	*22.2*	*35*	*22*	.	*0.3*	*0.3*

Table 5. (continued).

Lake	Year	Total-P (μg L^{-1})	Total filter-able-P (μg L^{-1})	Filterable reactive-P (μg L^{-1})	Kjeldahl-N (μg L^{-1})	Ammonia (μg L^{-1})	Nitrate + nitrite (μg L^{-1})	Total-N (μg L^{-1})	N:P	Reactive silicon (μg L^{-1})	Chloro-phyll *a* (μg L^{-1})	Phaeo-phytin (μg L^{-1})
Mud	99	**11.0**	**3.6**	**2.7**	**311**	**47.3**	**53.9**	**365**	**75**	**2619**	**0.5**	**0.8**
		1.6	*0.5*	*0.4*	*36*	*11.8*	*8.2*	*30*	*13*	.	*0.4*	*0.2*
Nancy	83	**16.9**	**5.7**	**2.1**	**298**	**16.6**	**3.8**	**302**	**43**	**2499**	**1.9**	**1.8**
		6.1	*2.5*	*1.6*	*31*	*27.5*	*0.9*	*31*	*11*	*520*	*1.1*	*0.9*
Nancy	84	**11.6**	**5.3**	**3.1**	**301**	**10.9**	**19.7**	**321**	**64**	**2826**	**1.4**	**1.1**
		2.8	*1.1*	*0.7*	*30*	*4.9*	*44.9*	*27*	*14*	*99*	*0.2*	*0.1*
Neklason	98	**11.5**	**nd**	**nd**	**319**	**41.5**	**14.3**	**333**	**68**	**nd**	**2.7**	**2.4**
		5.3	.	.	*91*	*69.0*	*13.7*	*104*	*12*	.	*2.1*	*2.8*
Neklason	99	**10.2**	**2.9**	**2.1**	**258**	**50.2**	**30.7**	**288**	**66**	**4149**	**0.4**	**0.5**
		5.9	*0.7*	*0.7*	*127*	*61.2*	*35.7*	*123*	*10*	.	*0.1*	*0.4*
Red Shirt	84	**10.3**	**5.6**	**3.1**	**250**	**2.0**	**4.1**	**254**	**55**	**2468**	**0.8**	**1.2**
		1.1	*1.0*	*0.7*	*31*	*0.9*	*0.0*	*31*	*12*	*446*	*0.5*	*0.8*
Red Shirt	93	**5.5**	**3.9**	**2.2**	**233**	**8.9**	**4.1**	**237**	**95**	**2937**	**1.2**	**0.8**
		.	.	.	.	.	.	.	.	.	.	.
Shell	81	**8.0**	**2.1**	**2.4**	**190**	**7.7**	**607.1**	**797**	**224**	**3487**	**0.2**	**0.4**
		1.4	*0.9*	*0.6*	*33*	*3.2*	*28.9*	*37*	*34*	*134*	*0.1*	*0.1*
Shell	84	**7.2**	**3.3**	**3.1**	**188**	**5.5**	**472.5**	**661**	**204**	**3883**	**0.7**	**0.4**
		0.6	*0.4*	*0.1*	*15*	*2.4*	*73.9*	*60*	*30*	*172*	*0.4*	*0.0*
Shell	85	**7.1**	**6.9**	**2.7**	**270**	**21.8**	**559.0**	**829**	**261**	**4093**	**0.7**	**0.8**
		0.7	*0.6*	*1.1*	*23*	*5.5*	*30.8*	*22*	*22*	*157*	*0.3*	*0.2*
Shell	86	**7.5**	**3.3**	**4.5**	**216**	**10.2**	**229.3**	**445**	**137**	**4254**	**0.4**	**0.5**
		1.3	*0.3*	*0.3*	*31*	*1.6*	*213.7*	*222*	*73*	*242*	*0.2*	*0.1*
Shell	87	**7.9**	**3.6**	**2.9**	**225**	**6.3**	**651.6**	**876**	**276**	**4993**	**0.5**	**0.4**
		3.3	*0.2*	*0.1*	*13*	*1.6*	*27.8*	*26*	*95*	*120*	*0.2*	*0.0*

Table 5. (continued).

Lake	Year	Total-P (μg L^{-1})	Total filterable-P (μg L^{-1})	Filterable reactive-P (μg L^{-1})	Kjeldahl-N (μg L^{-1})	Ammonia (μg L^{-1})	Nitrate + nitrite (μg L^{-1})	Total-N (μg L^{-1})	N:P	Reactive silicon (μg L^{-1})	Chlorophyll *a* (μg L^{-1})	Phaeophytin (μg L^{-1})
Shell	93	**5.5**	**3.1**	**2.8**	**212**	**13.0**	**511.2**	**723**	**291**	**3679**	**0.9**	**0.5**
		.	.	.	.	.	.	.	.	.	.	.
Stephan	84	**11.7**	**8.8**	**8.1**	**335**	**9.5**	**21.9**	**356**	**66**	**5012**	**1.4**	**0.8**
		1.3	*4.4*	*3.8*	*168*	*7.4*	*25.1*	*193*	*29*	*776*	*1.0*	*0.4*
Stephan	85	**13.1**	**8.5**	**4.0**	**183**	**3.8**	**20.3**	**203**	**35**	**4414**	**2.1**	**1.6**
		3.4	*2.0*	*0.9*	*19*	*1.0*	*14.2*	*33*	*5*	*1337*	*0.5*	*0.2*
Stephan	86	**14.1**	**5.4**	**5.4**	**192**	**5.5**	**5.5**	**198**	**31**	**5151**	**nd**	**nd**
		.	.	.	.	.	.	.	.	.	.	.
Stephan	93	**8.6**	**4.4**	**2.8**	**189**	**10.0**	**3.0**	**192**	**49**	**4719**	**0.8**	**0.3**
		.	.	.	.	.	.	.	.	.	.	.
Wasilla	83	**17.6**	**5.3**	**2.7**	**301**	**18.9**	**6.6**	**308**	**38**	**2883**	**2.0**	**1.5**
		3.0	*0.5*	*0.3*	*73*	*27.1*	*6.6*	*78*	*6*	*218*	*0.9*	*0.5*
Wasilla	84	**12.1**	**4.4**	**3.5**	**281**	**4.8**	**4.1**	**285**	**52**	**2822**	**1.2**	**0.7**
		1.0	*0.3*	*0.7*	*25*	*1.0*	*0.0*	*25*	*4*	*347*	*0.2*	*0.3*
Wasilla	86	**26.8**	**7.5**	**3.3**	**308**	**16.6**	**9.8**	**318**	**27**	**nd**	**nd**	**nd**
		4.1	*2.5*	*1.2*	*38*	*7.3*	*15.6*	*47*	*6*	.	.	.
Wasilla	93	**9.3**	**3.8**	**2.0**	**362**	**8.1**	**2.5**	**364**	**89**	**2257**	**1.4**	**0.7**
		2.9	*2.1*	*0.1*	*101*	*4.5*	*1.0*	*102*	*22*	*90*	*0.5*	*0.2*
Wasilla	98	**12.9**	**4.2**	**2.6**	**383**	**25.8**	**17.6**	**400**	**80**	**nd**	**1.9**	**1.1**
		6.7	*0.9*	*0.8*	*86*	*25.7*	*17.3*	*98*	*29*	.	*2.2*	*0.7*
Wasilla	99	**12.6**	**3.1**	**2.3**	**351**	**37.2**	**45.6**	**396**	**78**	**3205**	**0.7**	**0.6**
		6.6	*0.5*	*0.7*	*73*	*38.0*	*58.6*	*108*	*24*	*348*	*0.3*	*0.6*
Whiskey	93	**9.3**	**4.6**	**4.5**	**241**	**8.9**	**1.5**	**243**	**58**	**4254**	**4.3**	**1.2**
		.	.	.	.	.	.	.	.	.	.	.

Table 6. Statistical summary of Secchi depth for the 25 study lakes.

Lake	Year	N	Minimum	Mean	Maximum	Standard Deviation
Anderson	98	4	2.8	3.6	4.0	0.6
Anderson	99	3	3.0	3.7	4.5	0.8
Big	83	0	.	.	.	.
Big	84	0	.	.	.	.
Big	85	8	4.0	6.0	8.8	1.8
Big	99	4	6.5	7.9	10.5	1.9
Butterfly	81	4	3.0	3.9	5.0	0.9
Byers	81	8	2.9	4.8	6.1	1.3
Byers	83	3	4.8	5.2	5.8	0.5
Byers	84	2	4.8	5.0	5.2	0.3
Byers	93	1	7.3	7.3	7.3	.
Caswell	83	3	3.8	4.0	4.5	0.4
Caswell	84	1	4.9	4.9	4.9	.
Chelatna	90	3	0.8	1.4	1.9	0.6
Chelatna	91	2	1.4	1.7	1.9	0.4
Chelatna	92	3	2.3	4.7	7.3	2.5
Chelatna	93	3	1.3	4.6	9.5	4.3
Chelatna	94	5	2.3	3.4	5.0	1.1
Chelatna	95	4	0.8	2.8	7.0	2.8
Chelatna	96	3	1.8	2.3	3.0	0.6
Cornelius	83	3	3.8	4.9	5.5	0.9
Cornelius	84	2	4.3	4.9	5.4	0.8
Cornelius	98	4	2.8	4.2	6.5	1.7
Cornelius	99	3	2.0	4.1	6.2	2.1
Cottonwood	83	3	2.5	3.5	4.3	0.9
Cottonwood	84	2	4.5	4.7	4.9	0.3
Cottonwood	98	4	3.0	3.8	4.5	0.6
Cottonwood	99	3	3.5	3.7	4.0	0.3
Delyndia	81	8	2.0	2.6	3.0	0.4
Finger	81	7	3.0	3.8	4.5	0.5
Finger	88	1	1.8	1.8	1.8	.
Hewitt	84	0				
Hewitt	85	0				
Hewitt	93	1	2.6	2.6	2.6	.
Horseshoe	85	0				
Horseshoe	86	0				
Judd	93	1	13.0	13.0	13.0	.
Larson	81	6	3.1	4.0	4.8	0.6

Table 6. (continued).

Lake	Year	N	Minimum	Mean	Maximum	Standard Deviation
Larson	84	1	5.6	5.6	5.6	.
Larson	85	2	7.0	8.3	9.5	1.8
Larson	86	2	3.5	4.0	4.5	0.7
Larson	87	7	3.5	4.9	6.5	1.2
Larson	88	2	3.8	4.0	4.3	0.4
Larson	93	1	7.0	7.0	7.0	.
Lucile	84	0				
Monsoon	82	3	1.0	3.8	6.0	2.6
Mud	98	4	2.8	3.6	4.0	0.6
Mud	99	3	3.0	3.7	4.5	0.8
Nancy	83	9	2.5	3.1	3.8	0.6
Nancy	84	6	3.6	4.0	4.5	0.3
Neklason	98	4	2.3	2.9	3.5	0.7
Neklason	99	3	2.5	3.2	3.5	0.6
Red Shirt	84	0				
Red Shirt	93	1	5.3	5.3	5.3	.
Shell	81	6	3.5	3.8	4.1	0.2
Shell	84	0				
Shell	85	0				
Shell	86	2	4.8	5.2	5.5	0.5
Shell	87	4	3.5	3.7	3.8	0.1
Shell	93	1	4.3	4.3	4.3	.
Stephan	84	0				
Stephan	85	1	3.5	3.5	3.5	.
Stephan	86	0				
Stephan	93	1	5.0	5.0	5.0	.
Wasilla	83	6	2.0	2.6	3.3	0.5
Wasilla	84	4	3.9	4.3	4.6	0.3
Wasilla	86	0				
Wasilla	93	0				
Wasilla	98	8	2.0	3.3	5.0	1.0
Wasilla	99	6	3.0	3.9	5.5	1.1
Whiskey	93	1	3.3	3.3	3.3	.

Table 7. Statistical summary of morphometric characteristics, transparency, general water chemistry, nutrients, and algal pigments (*lake mean data set*).

Parameter	Units	Number of Lakes	Mean	Std. Dev.	Median	Max.	Min.
Area	km^2	25	2.6	3.7	1.3	15.8	0.2
Mean Depth	m	23	9.4	12.2	6.5	61.0	1.0
Maximum Depth	m	23	24.3	25.0	17.3	122.0	5.2
Volume	$m^3 \times 10^6$	23	68.1	214.0	7.8	971.0	0.2
Turbidity	NTU	21	1.4	0.7	1.5	3.8	0.3
Color	Pt-co units	21	14	6	15	25	3
Secchi Depth	m	23	4.3	2.2	3.8	13.0	1.8
Conductivity	$\mu S\ cm^{-1}$	25	106	65	92	203	18
pH	units	25	7.4	0.7	7.2	8.4	6.3
Alkalinity	$mg\ L^{-1}$	25	48.7	33.7	37.1	99.2	6.0
Calcium	$mg\ L^{-1}$	22	13.3	9.2	10.6	30.6	2
Magnesium	$mg\ L^{-1}$	22	2.1	1.5	1.8	5.9	0.2
Iron	$\mu g\ L^{-1}$	25	71	44	65	242	23
Total P	$\mu g\ L^{-1}$	25	11.2	7.7	9.5	44.2	2.2
Total Filterable P	$\mu g\ L^{-1}$	25	4.4	1.9	3.8	10.9	1.1
Filterable Reactive P	$\mu g\ L^{-1}$	25	2.7	0.9	2.6	5.1	1.2
Kjeldahl N	$\mu g\ L^{-1}$	25	263	170	227	917	60
Ammonia	$\mu g\ L^{-1}$	25	14.0	10.4	10.9	45.9	4.0
Nitrate + Nitrite	$\mu g\ L^{-1}$	25	92.2	156.1	14.4	505.1	1.5
Total N	$\mu g\ L^{-1}$	25	356	189	284	920	143
N:P Molar Ratio		25	92	67	67	267	31
Reactive Silicon	$\mu g\ L^{-1}$	25	3014	1259	3216	4824	491
Chlorophyll *a*	$\mu g\ L^{-1}$	23	1.8	3.2	1.0	15.7	0.1
Phaeophytin	$\mu g\ L^{-1}$	23	0.8	0.5	0.7	2.3	0.1

Table 8. Number and percentage of the 25 study lakes within different trophic categories based on mean total phosphorus, chlorophyll, and Secchi depth.

Trophic State Boundaries[1]			Lakes		
			n	%	Mean
Total P	<10 μg L^{-1}	Oligotrophic	13	52	7.4
Total P	10-20 μg L^{-1}	Mesotrophic	11	44	12.8
Total P	>20 μg L^{-1}	Eutrophic	1	4	44.2
Chlorophyll	<3 μg L^{-1}	Oligotrophic	19	83	0.8
Chlorophyll	3-7 μg L^{-1}	Mesotrophic	3	13	3.7
Chlorophyll	>7 μg L^{-1}	Eutrophic	1	4	15.7
Secchi	>4 m	Oligotrophic	9	39	6.0
Secchi	2.5-4 m	Mesotrophic	13	57	3.4
Secchi	<2.5 m	Eutrophic	1	4	1.8

1/ Total - P (Chapra and Robertson 1977); Secchi depth and chlorophyll (Forsberg and Ryding 1980)

Table 9. Lake typology of the 25 study lakes based on the amount of color and turbidity.

Typology		
Clear	Stained	Glacial
(<12 Pt-Co units; <5 NTU)	(≥12 Pt-Co units; <5 NTU)	(<12 Pt-Co units; ≥5 NTU)
Anderson	Butterfly[a]	Chelatna
Big	Cornelius	
Byers	Cottonwood	
Caswell	Delyndia[a]	
Hewitt	Finger [Crooked][a]	
Judd	Finger	
Larson	Horseshoe	
Whiskey	Lucile	
	Monsoon[b]	
	Mud	
	Nancy	
	Neklason	
	Red Shirt	
	Shell	
	Stephan	
	Wasilla	

a\ typology inferred from pH, alkalinity, and secchi depths

b\ typology described by Koenings and McDaniels (1983)

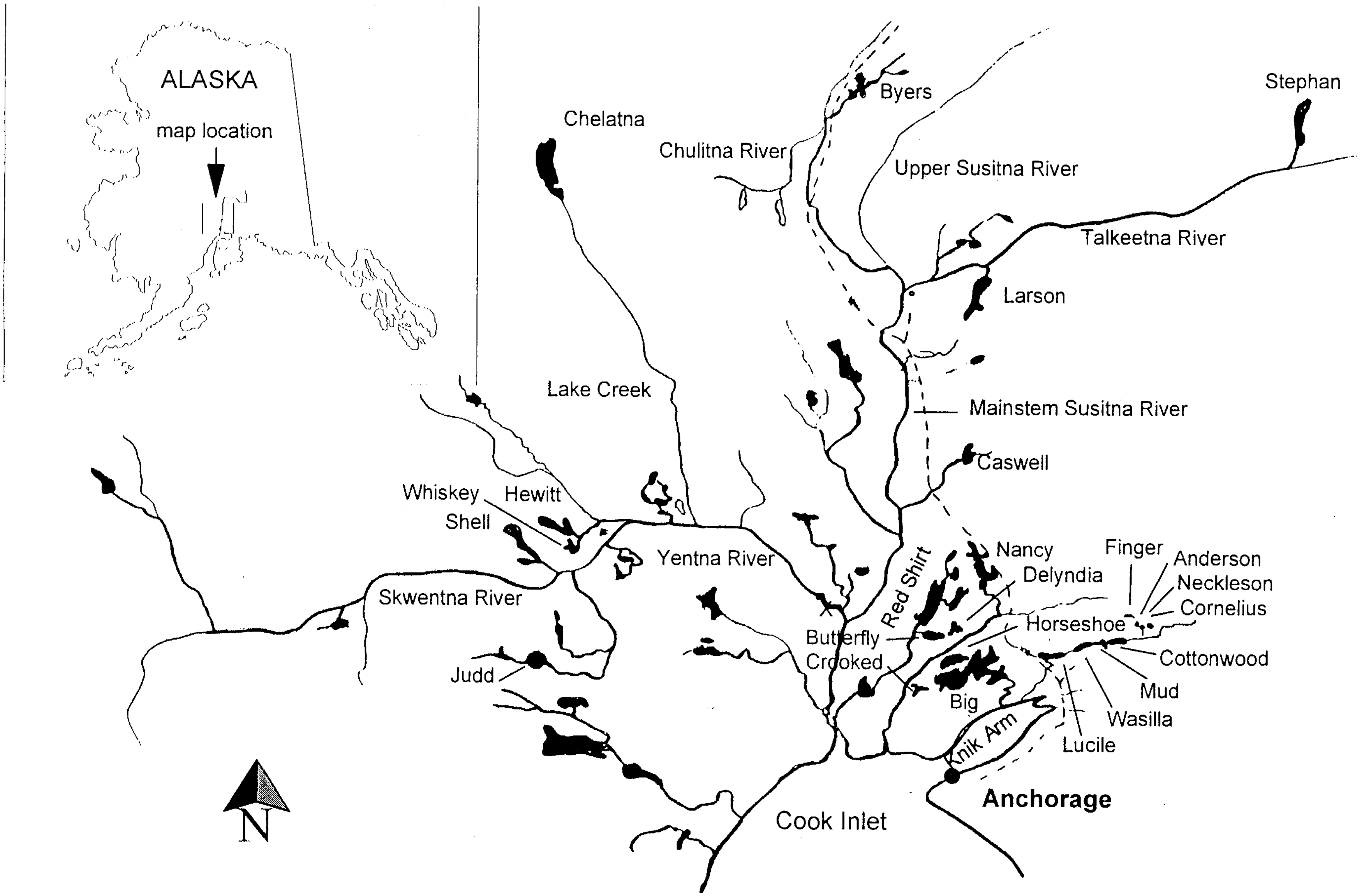

Figure 1. Location of the study lakes within the Matanuska-Susitna area (Monsoon Lake is not shown).

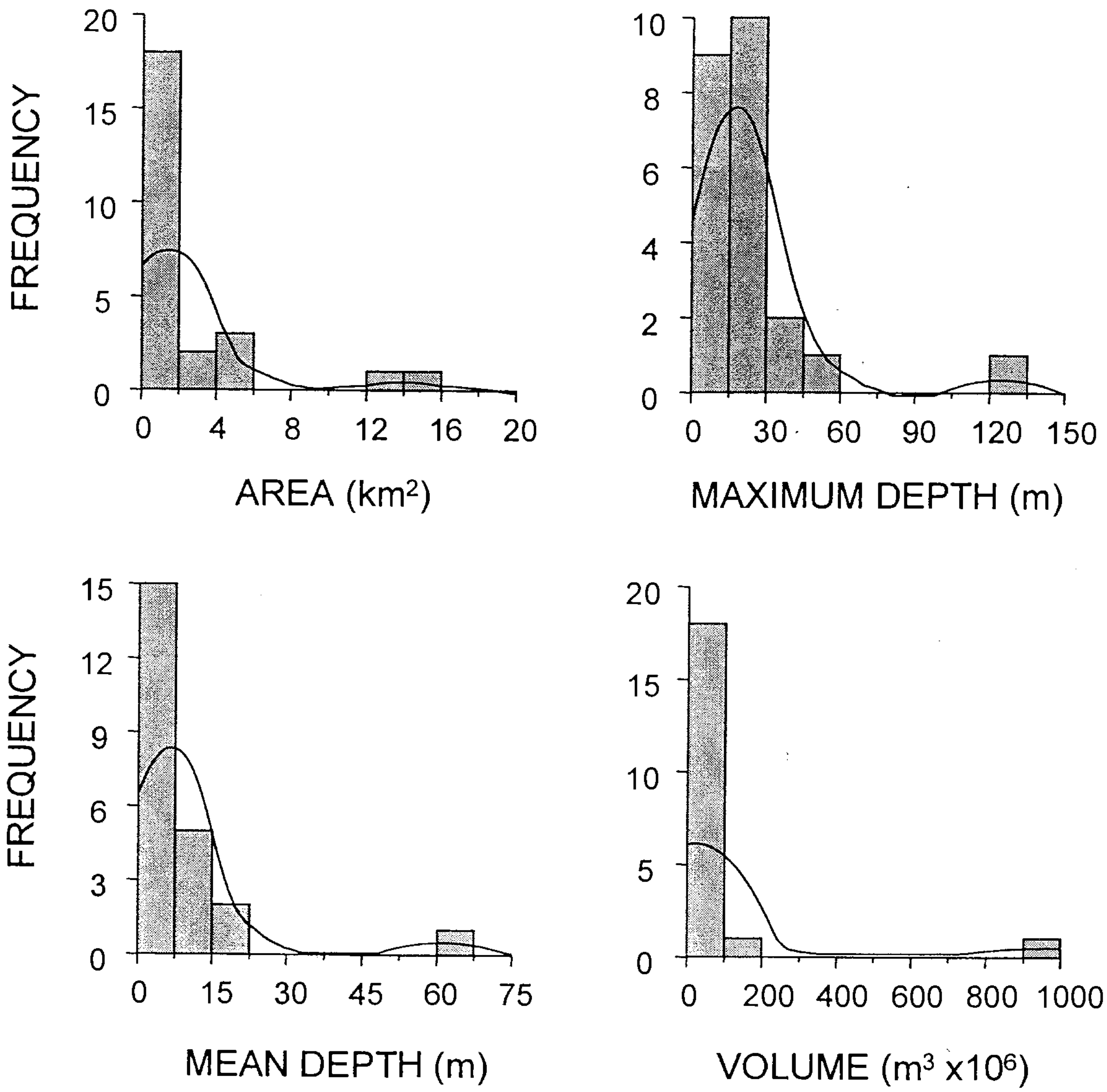

Figure 2. Distribution of morphometric characteristics for the 25 study lakes, the curved line showing the non-parametric density estimator.

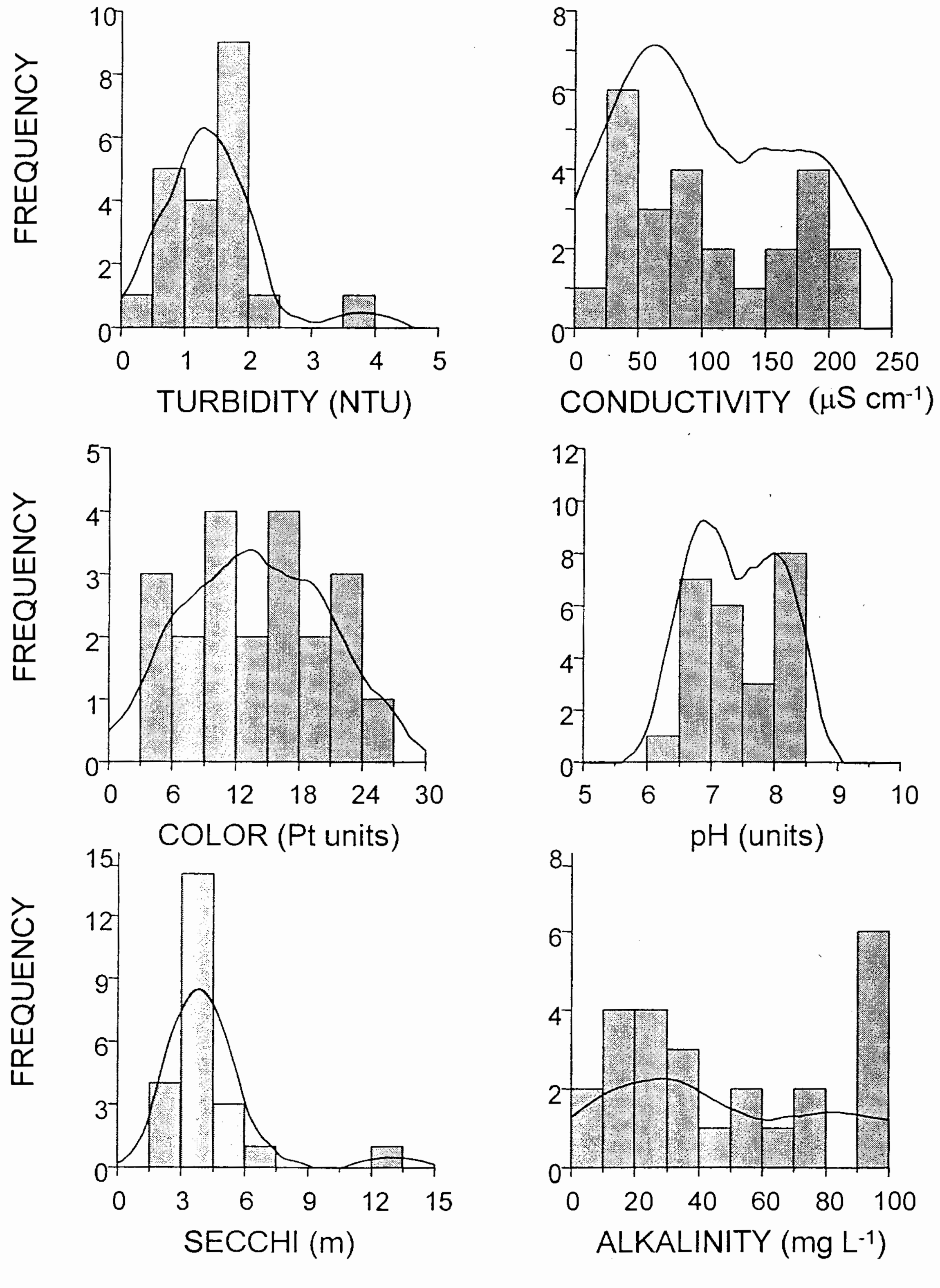

Figure 3. Distribution of general water chemistry and optical parameters for the 25 study lakes, the curved line showing the non-parametric density estimator.

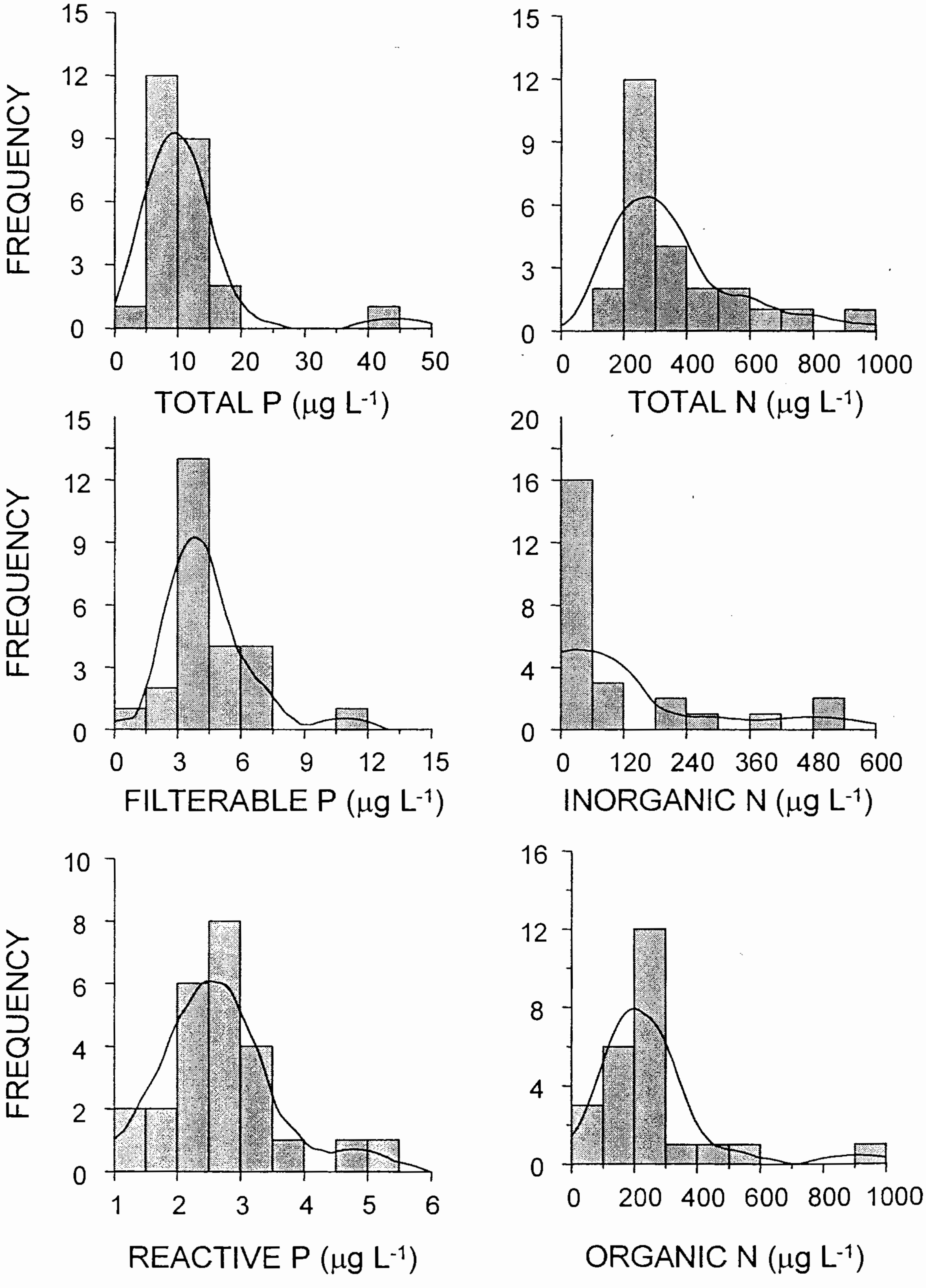

Figure 4. Distribution of nitrogen (N) and phosphorus (P) concentrations for the the 25 study lakes, the curved line showing the non-parametric density estimator.

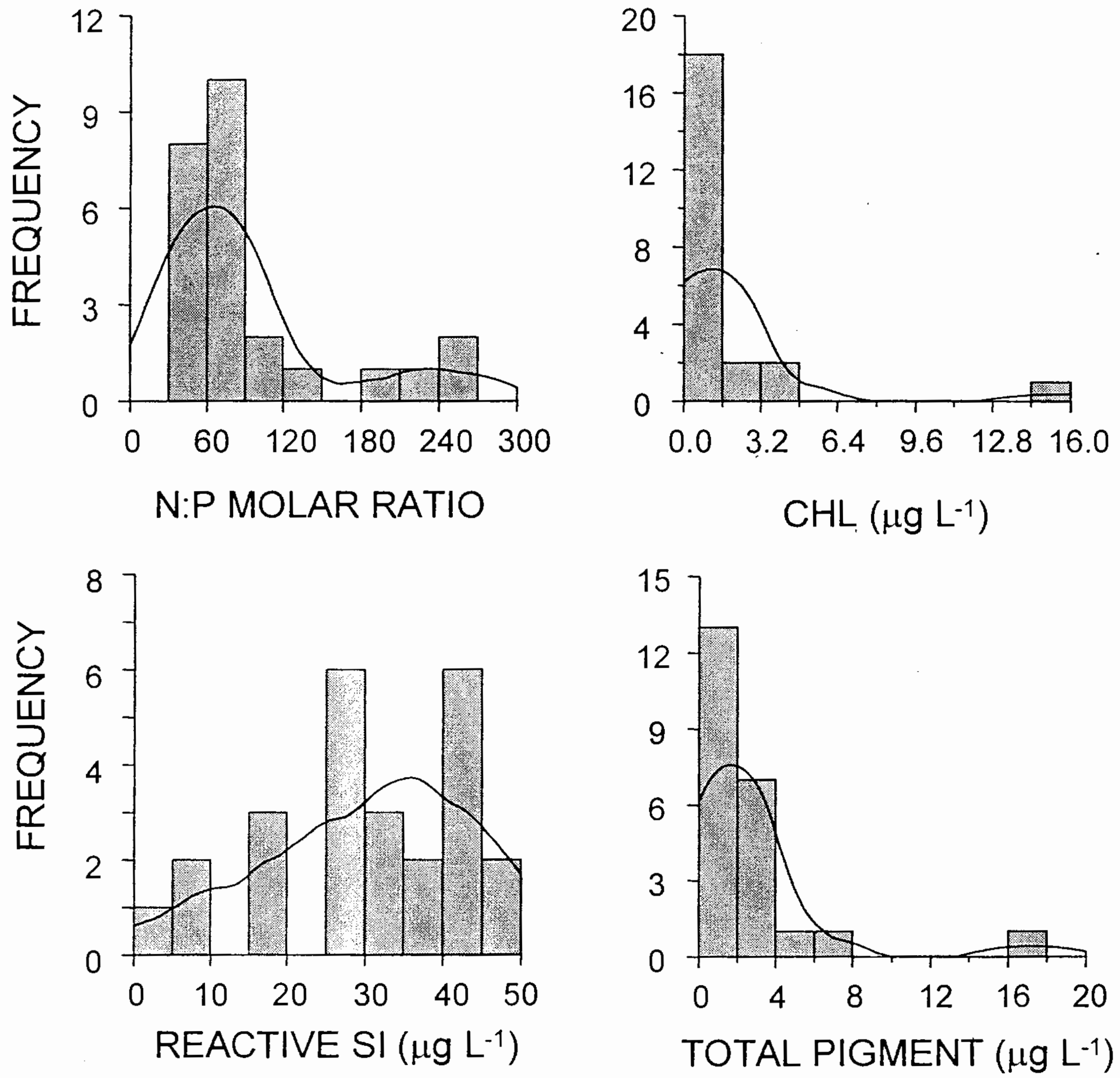

Figure 5. Distribution of total nitrogen to phosphorus ratio (N:P), reactive silicon (SI), chlorophyll (CHL), and total pigment (chlorophyll + phaeophytin) concentration for the 25 study lakes, the curved line showing the non-parametric density estimator.

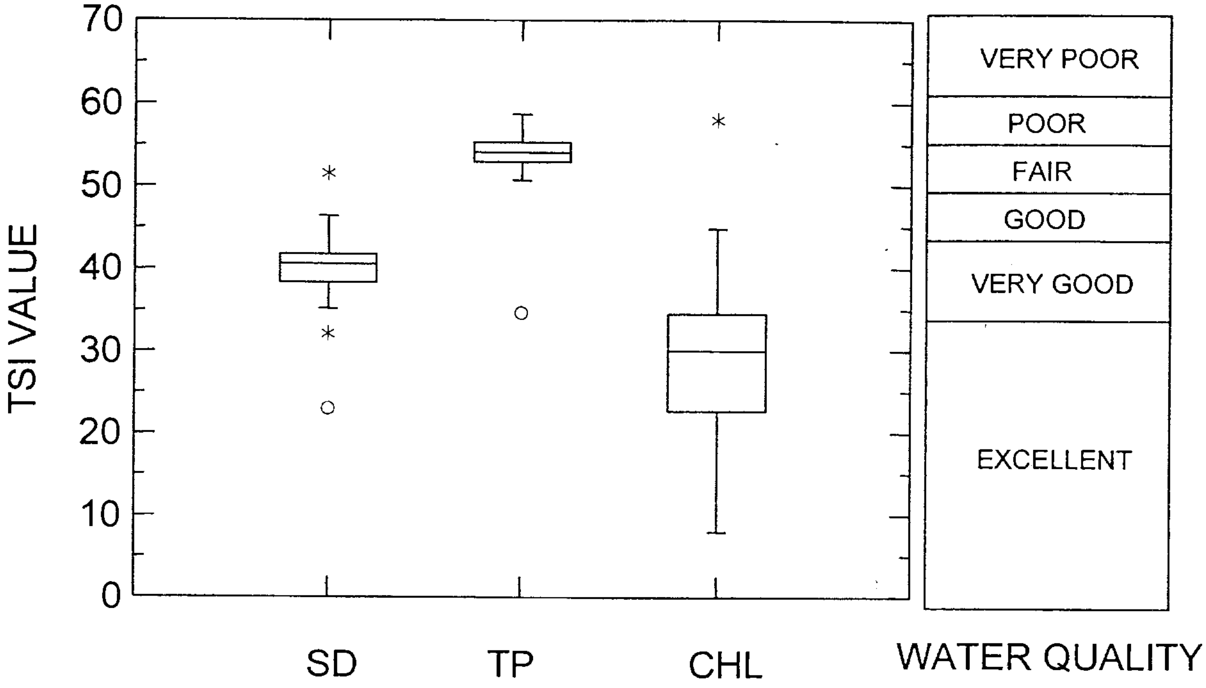

Figure 6. Box plots of Carlson's (1977) trophic state index (TSI) values based on secchi depth (SD), total phosphorus (TP), and chlorophyll *a* (CHL) in relation to apparent water quality for the 25 study lakes. Values between 1.5 and 3 times the inter-quartile are plotted as asterisks. Values greater than 3 times the inter-quartile are plotted as circles.

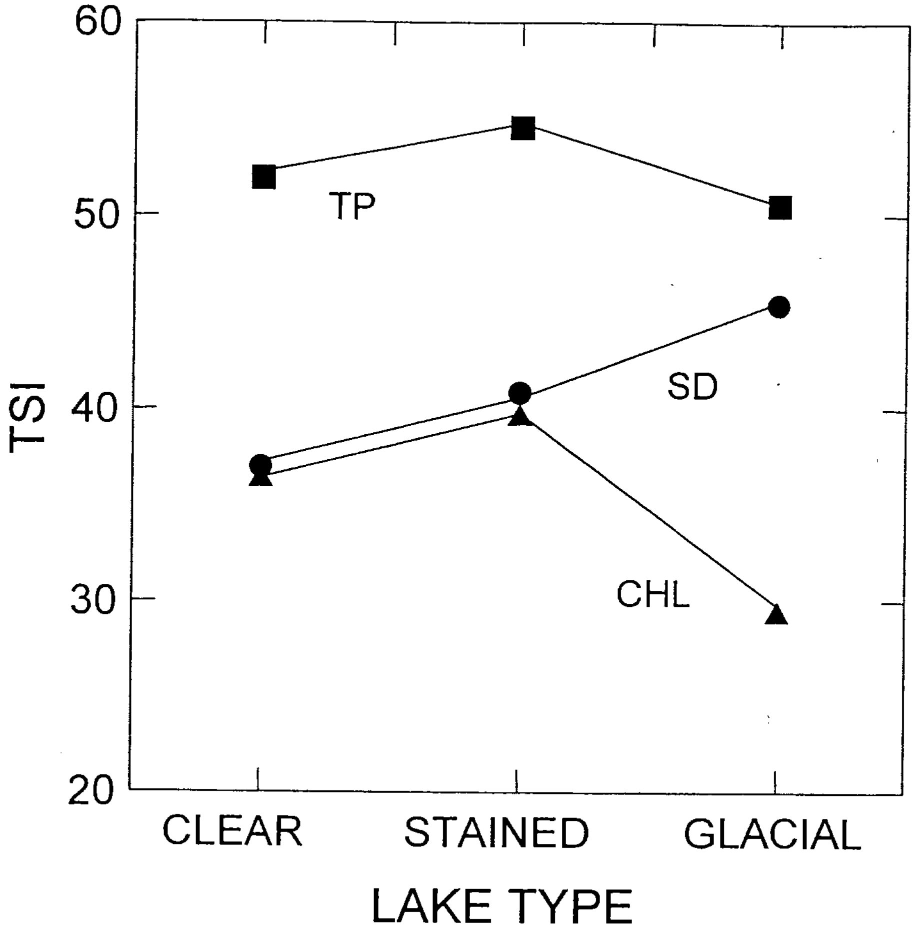

Figure 7. Interaction plot by method and lake type for mean responses in Carlson's (1977) trophic state index values derived from Secchi depth (SD), total phosphorus (TP), and chlorophyll *a* (CHL) for the 25 study lakes