Comparative Limnology of Some Lakes in Interior Alaska

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ABSTRACT

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Fifteen lakes in Interior Alaska (from about 62°N to 64°N and 142°W to 151°W) were sampled on three occasions during the open water season (mid-May to early September) in either 1993 or 1994. Lakes varied in elevation from 218 to 1124 m, in area from 33 to 6303 ha and in maximum depth from 4 to 49 m. Deep lakes thermally stratified during summer with lake cooling and destratification in some by August. Lakes with mean depth of <5 m were polymictic during summer. Anoxia was measured at depth in the most fertile lakes, and metalimnetic oxygen maxima in several lakes were associated with conditions favoring sub-surface algal peaks. There were near equal numbers of clear and stained lakes. One lake was eutrophic and the others were either oligo- or mesotrophic. About half the lakes had TN:TP < 11 by weight, indicating a regional potential for N-limitation. Among Interior lakes, salinity, as measured by conductivity and alkalinity was correlated with TN and TP which fits with the long-recognized pattern between parent geology and nutrients. These data are compared with previous lake studies in the Interior.

Key Words: freshwater, nutrients, chlorophyll, water clarity, Alaska.

Recent limnological studies have characterized high latitude lakes in arctic Alaska (Kling et al. 1992 and 2000, LaPerriere et al. 1998, LaPerriere et al. 2003), the Yukon Territory, Canada (Shortreed and Stockner 1986, Pienitz et al. 1997a), the Northwest Territory, Canada (Pienitz et al. 1997b) and the Canadian high arctic (Hamilton et al. 2001, Lim et al. 2001). This paper presents the comparative limnology of 15 lakes located in Interior Alaska between Fairbanks, to the north, and the Alaska Range to the south (from about 62°N to 64°N and 142°W to 151°W, Fig. 1). Much of the area has been glaciated and its climate includes both transitional (relative to maritime to the south) and continental features (Milner et al. 1997). Individual lakes in Interior Alaska have been well characterized (Tangle lakes, Barsdate and Alexander 1971; Ace and Deuce, Alexander and Barsdate 1974; Harding Lake, LaPerriere 1990, 2003; Smith Lake, Alexander and Gu 1997) and several Interior lakes have been sampled as part of statewide inventories (Satoh et al. 1992, Gregory-Eaves et al. 2000). Herein we present data on the general limnological features and trophic state of Interior lakes and compare our findings with previous studies.

Study Area and Lake Characteristics

Study lakes lie within the Northern Forest and Alpine Tundra ecozones of Interior Alaska (Fig. 1, Table 1) previously described by Gregory-Eaves et al. (2000). Physiographically, the lakes studied can be placed in three broad areas: Upper and middle Tanana River valley, Alaska Range, and Middle Copper River basin (Pewe and Reger 1983). The Alaska Range separates the Tanana River basin to the north from the Copper River basin to the south. This mountain range

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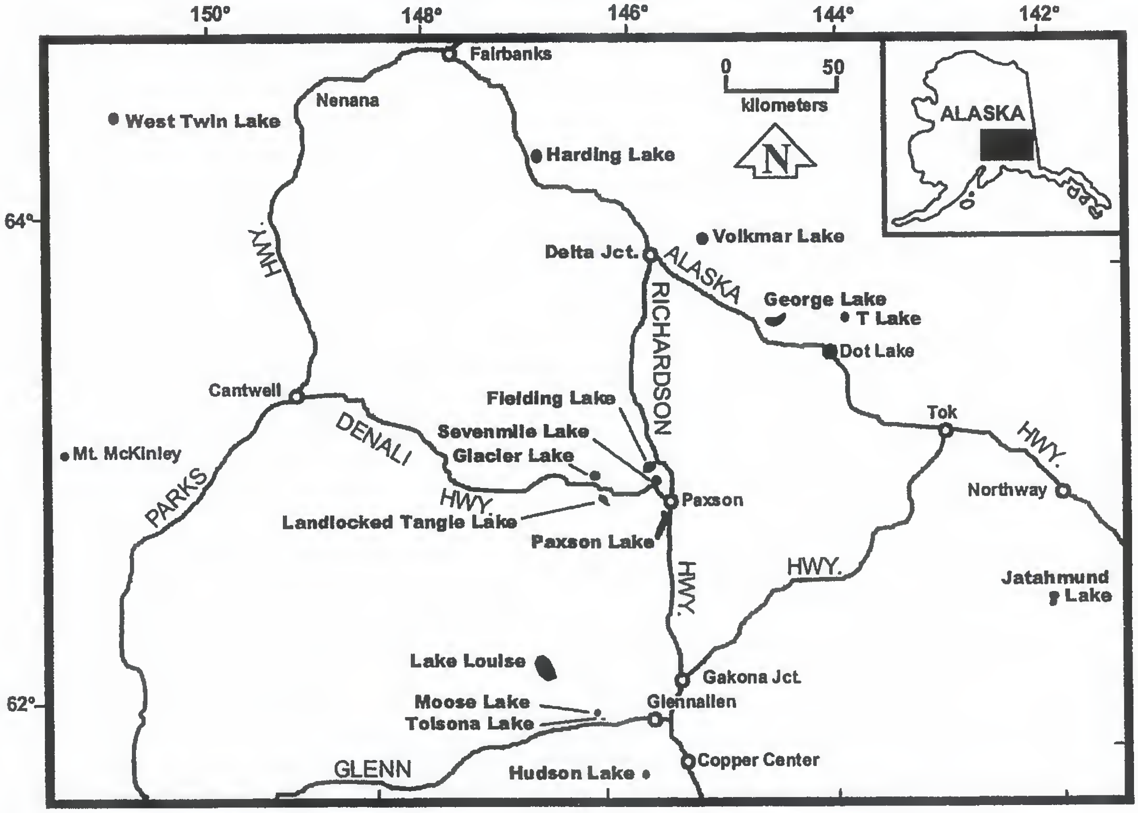

Figure 1.–Location of the study lakes in Alaska.

is a physiographic barrier to storms from the Gulf of Alaska, thereby exerting a strong influence on regional climate and hydrology.

Northern Forest lakes are located at elevations between 218 and 662 m in the Tanana River basin on outwash fans and loess deposits of glaciofluvial materials derived from the Alaska Range (Fig. 1, West Twin, Harding, Volkmar, George, T, and Jatahmund). Except for some small cirque glaciers, the region has not been glaciated, but perennially frozen ground is common. Its climate is continental with extreme variation between seasons and a mean annual temperature of about -4°C. It is a cold desert, receiving about 37 cm of precipitation annually (LaPerriere 1990). Land cover in the Northern Forest is taiga, composed of spruce, aspen, birch and alder, with muskeg ground cover. Lakes in the region have been formed by various processes, including tectonic movement, cryogenic processes and aggradation (Nakao and Ager 1985, Alexander and Gu 1997, LaPerriere 2003). Bedrock in this area is metamorphic rock (schist) with granitic intrusions.

West Twin Lake is located south of the Tanana River on a well drained alluvial fan extending from the Alaska Range. Sources of water are runoff from its immediate small watershed and regional groundwater. Harding Lake is a scarp lake with tectonic influnce causing it to be much deeper (43 m) than other lakes in the region. Volkmar Lake is located in a reentrat in granitic rocks and gneiss bordering the Goodpaster River flats (Pewe and Reger1983). It receives runoff from hills surrounding three sides of the lake. T Lake is located on the edge of a boggy region and is likely a thermokarst lake. George Lake is the largest of the Tanana River lakes studied (Table 1). It was formed by aggradation of the river and lies below the river at peak flood stage. The lake is fed by George Creek draining the upstream watershed but water chemistry may also be influenced by the Tanana River with its Alaska Range composition. Jatahmund Lake is a kettle lake located at the headwaters of the Tanana River on a glacio-fluvial fan extending from the Nutzotin Hills of the Alaska Range.

Other lakes within the Northern Forest ecozone are located in the Copper River Basin, which is a large intermontane basin rimmed by high mountain ranges that converge in the Interior Alaska (Ferrians et al. 1983, Milner et al. 1997). During the Pleistocene a large proglacial lake was formed in the area by numerous glacial advances. Thick lacustrian deposits remained when the glaciers retreated and the lake drained. Muskegs and wetlands occupy depressions in the old lake floor which consists of poorly drained,

Table 1.–Location, morphometry information, mean water chemistry and light transmission in Northern Forest and Alpine Tundra lakes of Interior Alaska. Trophic state was determined by using criteria of Nürnburg (1996). Oligotrophic lakes (O)have Chl < 3.5 µg · L^{-1}, TP < 10 µg · L^{-1}, and TN < 350 µg · L^{-1}. Eutrophic lakes (E) have Chl > 9 µg · L^{-1}, TP > 30 µg · L^{-1} and TN > 650 µg · L^{-1}. Mesotrophic lakes (M) have values in between these two categories.

	LAT (°N)	LONG (°W)	ALT (m)	AREA (ha)	Z_{max} (m)	pH	ALK (mg · L^{-1})	KSP (µS)	COLOR (Pt)	NTU	TRANS (% · m^{-1})	SECCHI (m)	TP (µg · L^{-1})	TN (µg · L^{-1})	CHL (µg · L^{-1})	TROPHIC STATE
Northern Forest Lakes																
George[a]	63.47	144.31	389	1977	11	7.2	68	173	26	5	25	1.8	48	660	41.9	E
Harding[a]	64.25	146.50	218	1043	43	6.8	33	80	3	0.3	77	9.0	8	190	1.7	O
Hudson[b]	61.53	145.40	657	259	15	8.3	134	310	22	2.4	48	2.3	33	280	9.3	M
Jathahmud[b]	62.37	142.00	662	1147	28	6.8	17	42	7	0.5	78	7.8	15	110	1.1	O
Louise[a]	62.20	146.30	720	6303	49	7.2	46	133	16	0.5	64	5.8	13	280	2.1	O
Moose[b]	62.08	146.05	632	116	7	7.7	89	278	33	1.4	49	3.2	24	450	4.2	M
T[a]	63.48	143.53	434	158	18	6.7	86	191	17	4.5	47	5.2	25	540	11.4	M
Tolsona[a]	62.07	146.03	625	128	4	7.9	103	281	18	1.5	52	2.8	19	660	2.8	M
Volkmar[a]	64.07	145.11	326	372	13	6.8	55	133	20	2.1	45	3.5	19	510	4.9	M
West Twin[b]	64.27	150.50	228	676	34	7.1	45	104	21	0.6	67	5.7	17	180	2.9	O
Alpine Tundra Lakes																
Fielding[a]	63.10	145.42	906	539	23	7.1	56	137	12	1	54	3.3	25	210	8.0	M
Glacier[a]	63.07	146.15	1124	172	26	7.1	9.5	23	4	0.6	76	6.8	10	90	1.4	O
Landlocked																
Tangle[a]	63.00	146.03	876	226	34	7.0	20	59	6	0.6	64	5.3	11	150	2.4	O
Paxson[a]	62.55	145.33	778	1154	28	7.2	51	124	14	1.3	38	3.5	17	180	6.5	M
Sevenmile[b]	63.06	145.38	983	33	13	6.9	30.5	71	13	0.5	71	6.7	15	90	1.6	O

[a]Sampled 1993.
[b]Sampled 1994.

perennially frozen sediment. Lakes sampled are located on moraines and fine materials south of the Alaska Range near the Richardson or Glenn highways at elevations between 625 and 778 m (Fig. 1, Louise, Moose, Tolsona and Hudson). Lake Louise, the largest of the basin lakes studied (Table 1), probably formed in a depression of the old glacial lake and grew by continued thawing of the permafrost. Its water source is local inflow from numerous small streams. Moose and Tolsona lakes are located in depressions of the old glacial lake. These lakes are located near three mud volcanoes and a mineral spring (Nichols and Yehle 1961) and, along with local runoff, seepages of saline water occur to both lakes (Ferrians et al. 1983). Likewise, Hudson Lake receives some inflow from the nearby mineral spring and mud volcano. Herein we refer to these three lakes as the 'mud volcano lakes'.

Alpine Tundra lakes within the Alaska Range are at elevations between 876 and 1124 m (Fig. 1, Paxson, Landlocked Tangle – also called Upper Tangle, Fielding, Sevenmile and Glacier). They occur on the south slope of the Alaska Range and in the Gulkana Upland in an alpine tundra setting (Pewe and Reger 1983). The climate is transitional between the maritime coastal climate and the continental climate further inland, and permafrost is ubiquitous. Vegetation is primarily shrub and heath and bedrock in the region is metamorphosed basalt with granite at high elevation and glacial till at lower elevation where the lakes are kettles (Tangle Lakes). Study lakes ranged in area from 33 to 6303 ha and ranged in maximum depth from 4 to 49 m (Table 1). Except for Paxson Lake which formed in a glaciated trough, these lakes formed in depressions left by stagnating glacial ice. Gregory-Eaves et al. (2000) included Paxson Lake with the Northern Forest group, however, based on Pewe and Reger (1983) we treat it as an Alpine Tundra lake.

Methods

Each lake was sampled three times (monthly) by boat or floatplane during the open water season from mid-May to early September in 1993 or 1994 (Table 1). The exception was Jatahmund Lake which was not sampled in late-summer due to logistical difficulties. Depth-integrated samples were collected using a weighted Tygon tube to a depth equal twice the Secchi depth (Hanna and Peters 1991) or to within 1 m of the bottom in clear, shallow lakes. Samples were placed in 4-L acid-rinsed polyethylene containers and kept cool, in the dark. Most samples were processed within 24-h of returning from the field.

Total chlorophyll-*a* (Chl, uncorrected) was determined by filtering 1-L of lake sample through a Gelman A/E filter, storing filters frozen over silica gel prior to extraction in 90% acetone (Parsons et al. 1984). Total alkalinity (ALK) was determined by titration. Specific conductivity (KSP) and pH were measured using a Ciba Corning Checkmate. Temperature and oxygen profiles were collected using a YSI Model 57 meter. Secchi transparency was measured using a standard black and white 20 cm disc. Light penetration was measured with a LI-Cor LI-189 photometer and underwater sensor. Turbidity (NTU) was measured using a HACH Model 2100P nephelometric turbidimeter. Apparent water color was determined on unfiltered samples using visual comparison (HACH CO-1 comparator). Nitrogen samples (10 mL) were transferred to screw cap culture tubes and preserved with 1 drop of 50% sulfuric acid. Phosphorus samples (20 mL) were also transferred to culture tubes. Analysis of TP (Murphy and Riley 1962) and TN (Crumpton et al. 1992) was performed in culture tubes at the University of Missouri.

Statistical tests were limited to correlation and regression using the arithmetic mean of data collected from the individual lakes (n = 15). Where appropriate $\log_{10}$ transformation was applied, and all significance was at 0.01 unless stated otherwise. Data are tabulated in Simpson (1998).

Results

Thermal Characteristics and Oxygen

Most study lakes were thermally stratified at the time of first sampling in late-May to mid-June, with surface temperatures averaging 13°C and bottom temperatures generally ≥ 5°C in all but the deepest lakes, where values were 4°C. Surface temperatures peaked in most lakes during July as shown in West Twin and Landlocked Tangle lakes (Fig. 2). Surface temperatures averaged 18°C in mid-summer and cooled to an average of 15.5°C by August, when several lakes showed near- or complete de-stratification, as demonstrated in George and Fielding lakes (Fig. 3). Lake cooling begins in early August in this region (Alexander and Gu 1997). Maximum surface temperature ranged between 15°C and 24°C and was negatively correlated with lake elevation (r = -0.79, n = 15). Shallow lakes at high elevation did not permanently stratify and are likely polymictic (Moose Lake, Fig. 3). Tolsona Lake, the shallowest of this suite, was continuously polymictic during summer.

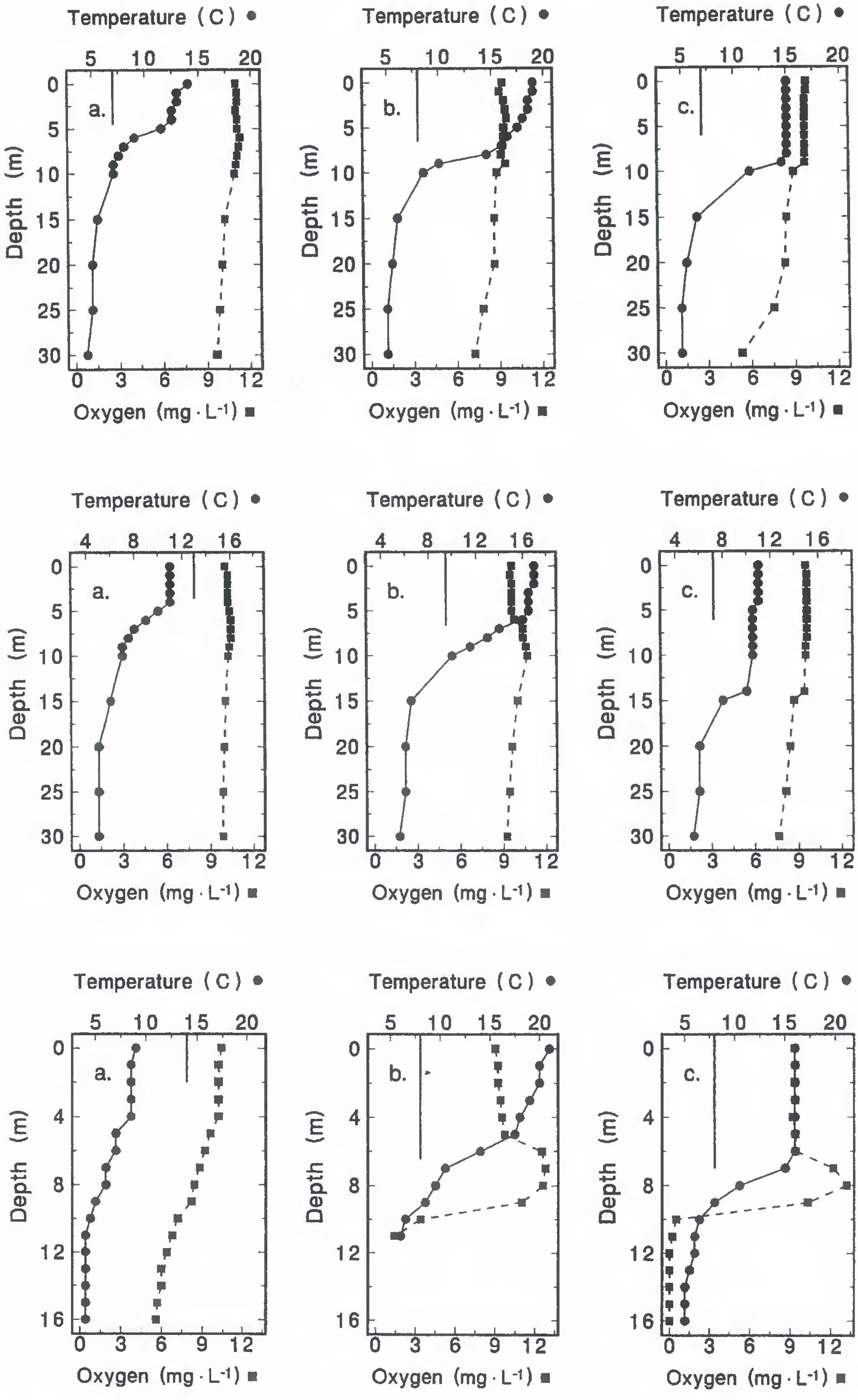

Figure 2.–Temperature and oxygen data from: West Twin Lake (top panels) collected in 1994 on 8 June (a.), 27 July (b.) and 26 August (c.); Landlocked Tangle Lake (middle panels) collected in 1993 on 18 June (a.), 29 July (b.) and 24 August (c.); and Lake T (bottom panels) collected in 1993 on 22 May (a.), 15 July (b.) and 17 August (c.). Vertical lines represent the Secchi depth on the date of collection.

Dissolved oxygen was >8 mg · L^{-1} at depth in about half the lakes; lakes in this category had maximum depths of >25 m and Chl levels <2.5 µg · L^{-1} (Table I) or underwent frequent polymixis. Oxygen values at depth were <2 mg · L^{-1} on at least one sampling date in four study lakes – George (Fig. 3), Hudson, T (Fig. 2) and Volkmar. Based on nutrient and Chl content, George Lake was the most fertile lake we sampled (Table 1). The other lakes with depleted oxygen were among the most fertile and each showed evidence of strong thermal stratification for some period during summer. Metalimnetic oxygen maxima evident in several lakes, best shown in T Lake (Fig. 2), were likely produced by sub-surface algal peaks commonly found in clear stratified lakes in Alaska (Jones et al. 1990, LaPerriere et al. 1998, LaPerriere et al. 2003). Sub-surface algal peaks were not directly sampled in this study but have been documented in shallow Smith Lake in Interior Alaska (Alexander and Gu 1997) and nearby shallow lakes (Alexander and Barsdate 1974).

Color, Turbidity and Water Clarity

Unfiltered measurements of color (Pt-units) in the Interior lakes averaged 15, and ranged from 3 to 33 Pt units. There were near equal numbers of clear and stained lakes within our sample (Table 1). The among-lake pattern showed a quadratic decline in color (R^2 = 0.43) with maximum lake depth (Z_{max}). These Interior lakes were characterized by low turbidity, with only two lakes having >4 NTU (Table 1). Turbidity was correlated with Chl (r = 0.83, n = 15), suggesting a biogenic origin during summer.

Secchi transparency (SD) ranged from 1.8 m in stained George Lake, with the highest measurements of Chl and turbidity (Table 1), to 9 m in Harding Lake where color, turbidity and Chl were modest (Table 1). Incident light at SD averaged 11%, and ranged from ~5% in T Lake where the oxygen and temperature measurements suggest SD was determined by a sub-surface algal peak (Fig. 2), to 19% in Hudson Lake (Table 1) where, on two sampling occasions, SD was approximately half of the mixing depth. On average, the 1% light depth was twice the SD, but this ratio varied from 1.5 (T Lake) to 3 (Hudson). This ratio is somewhat low relative to other clear lakes in Alaska (2.4, Koenings and Edmundson 1991) and we attribute this truncation of the euphotic depth to light attenuation within the metalimnion of some lakes by sub-surface algal peaks. Among the Interior lakes 1/SD was more strongly correlated with TP and Chl (r = 0.89 and 0.76, respectively, n = 15) than either color or turbidity (r = 0.67, for both). Values of K_d ranged from ~0.2 in several lakes to 1.2 (George). The optical metric, K_d x SD, averaged 2.3; this value is consistent with other clear and stained lakes in Alaska (Koenings and Edmundson 1991).

Water Chemistry

Conductivity (KSP) ranged from 23 µS (Glacier) to >~280-310 µS in the mud volcano lakes (Hudson, Moose and Tolsona). Alkalinity (ALK) ranged from 9.5 mg · L^{-1} to 134 mg · L^{-1} and was strongly correlated with KSP (r = 0.98, n = 15). Mean pH values varied from 6.7 (T) to 8.3 (Hudson) and were positively correlated with both KSP and ALK (r ≥ 0.76, n = 15).

Total Phosphorus (TP) averaged 20 µg · L^{-1} (median 17 µg · L^{-1}), and varied from 8 µg · L^{-1} (Harding) to 48 µg · L^{-1} (George, Table 1). Depth-integrated measurements of T Lake in August (Fig. 2) included water from the anoxic hypolimnion and likely contained P released from decomposition or the sediments. The August TP value in T Lake was ~6 µg · L^{-1} greater than earlier measurements, an increase of ~30%. In this case our sampling procedure likely over-represented the TP content of the photic zone. George Lake exhibited oxygen depletion deep in the water column both in June and July and was deeply mixed in August (Fig. 3). In this lake, the August TP measurement was ~3-times that of June (73 vs. 23 µg · L^{-1}, respectively), suggesting internal loading may have been important. Excluding internally loaded George Lake, there was a strong cross-system relation between TP and KSP (R^2 = 0.63, n = 14, Fig. 4), and the relation between TP and ALK was similar. This TP-KSP empirical relation (Fig. 4) predicts a TP value of 20 µg · L^{-1} for George Lake (KSP = 173 µS), which approximates the value in early summer, prior to evidence of internal loading. Among the Interior lakes there was a negative correlation (r = -0.57, n = 15) between TP and Z_{max}. TP was strongly correlated with turbidity (r = 0.83), color (r = 0.68), TN (r = 0.63) and Chl (r = 0.89).

Total Nitrogen (TN) averaged 300 µg · L^{-1} (median 210 µg · L^{-1}) among the Interior lakes, and varied from 90 µg · L^{-1} (Glacier and Sevenmile) to 660 µg · L^{-1} (George and Tolsona). The relation between TN and altitude was not significant. The lowest values were in lakes at the highest elevation (Table 1) but about half of the sampled lakes, located at elevations between 218 and 1124 m, had TN that matched or were less than the TN content in rainfall in remote regions of Alaska (~190 µg · L^{-1}, Kling et al. 1992).

The TN content of George Lake increased by two-thirds between the June and August measurements (from 480 to 810 µg · L^{-1}). This increase may, like TP, result from internal loading but nitrogen fixation is also possible. Nitrogen fixing algae occur in Smith

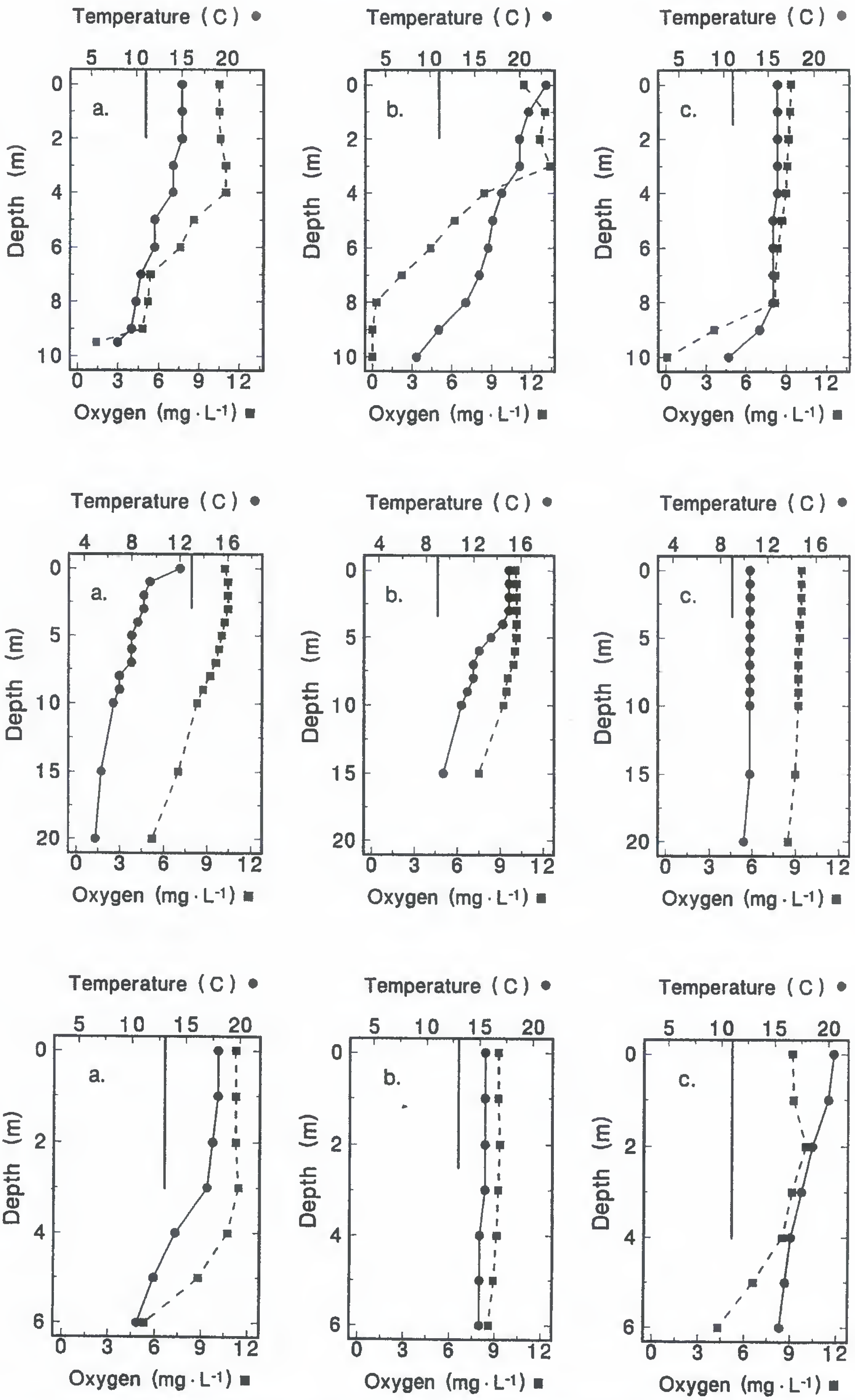

Figure 3.–Temperature and oxygen data from: George Lake (top panels) collected in 1993 on 9 June (a.), 15 July (b.) and 17 August (c.); Fielding Lake (middle panels) collected in 1993 on 17 June (a.), 20 July (b.) and 25 August (c.); and Moose Lake (bottom panels) collected in1994 on 13 June (a.), 5 July (b.) and 2 August (c.). Vertical lines represent the Secchi depth on the date of collection.

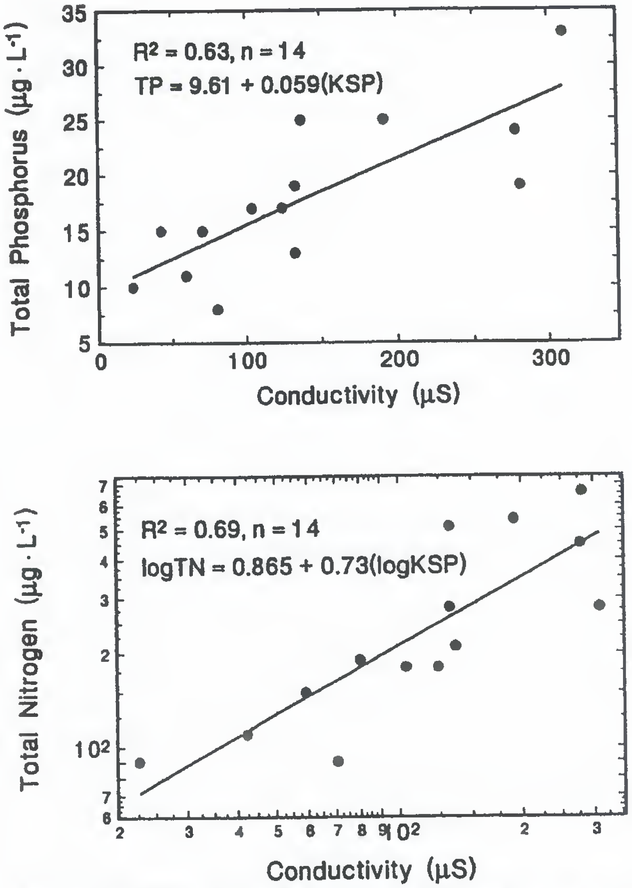

Figure 4.–Upper Panel: Total Phosphorus ($\mu g \cdot L^{-1}$) data from lakes in Interior Alaska (n = 14) regressed on Conductivity (µS) excluding data from internally loaded George Lake. Lower Panel: Total Nitrogen ($\mu g \cdot L^{-1}$) data from all study lakes (n= 15) regressed on Conductivity (µS), both parameters are log transformed.

Lake located within the Tanana Valley (Alexander and Gu 1997) and plays an important role in the nitrogen budget of that fertile lake. None of the other lakes, however, showed appreciable changes in TN across the sampling season. Shallow Lake Tolsona had an average TN value that matched George Lake (Table 1). Among the study lakes TN was correlated with TP and color ($r \geq 0.63$, n = 15) and showed a quadratic decline with Z_{max} ($R^2 = 0.58$). However, the best among-lake predictor of TN was a log transformation with KSP ($R^2 = 0.69$, n = 14, Fig. 4), and the result using log ALK was similar. Data from George Lake was not included in the TN-KSP relation (Fig. 4) because of the mid-summer increase in its TN content. The cross-system TN-KSP relation predicts a TN value of 316 $\mu g \cdot L^{-1}$ for Lake George which is about two-thirds of the early summer value. Using the approach of Ryder (1965) and dividing the independent variable by mean depth or Z_{max} did not improve this relation, nor did it improve the analysis with TP.

The ratio of TN:TP by weight averaged 16 and ranged from 6 (Sevenmile) to 35 (Tolsona). About half the sampled lakes had TN:TP < 11, indicating potential for N-limitation (Smith 1982).

Phytoplankton

Chlorophyll (Chl) varied from 1.1 $\mu g \cdot L^{-1}$ (Jatahmund) to 41.9 $\mu g \cdot L^{-1}$ (George) with an overall average of 6.8 $\mu g \cdot L^{-1}$ (median 2.9 $\mu g \cdot L^{-1}$). The Chl:TP ratio averaged 0.26 (median 0.21) which closely matches the ratio in less fertile lakes of Gates of the Arctic, Alaska (LaPerriere et al. 2003) and the ratio in Yukon lakes (Shortreed and Stockner 1986) but less than the average Chl:TP found in global data sets for this TP range (Jones and Bachmann 1976, mean = 0.34, n = 91; Watson et al. 1992, mean = 0.37, n = 420). The minimum Chl:TP in Jatahmund Lake (< 0.1) was based on only two collections. The maximum in George Lake (0.87) is indicative of bloom conditions, perhaps a response to internal nutrient supply and/or nitrogen fixation. Ratios of TN:TP in George Lake declined from ~20 to 11 during summer sampling, indicating an increased potential for N-limitation. Grazing pressure may also contribute to among-lake variation in Chl:TP. Herbivore predators were not measured but each of the study lakes supports a permanent fish community (Simpson 1998).

Among the Interior lakes, Chl was better correlated with TP (r = 0.89) than TN (r = 0.57) but worldwide nutrient-Chl models by Nürnberg (1996) provide reasonable estimates of Chl using either measured TP or TN (mean observed Chl/predicted Chl = ~1 in both cases). This fit suggests there was nothing unusual about the relation between nutrients and algal biomass in the Interior lakes.

Discussion

About half of the Interior lakes in this study were oligotrophic based on criteria suggested by Nürnberg (1996, Table 1). Among these, Harding and Glacier lakes matched all nutrient, Chl and SD criteria for oligotrophic status, while the others – Jatahmund, Landlocked Tangle, Louise, Sevenmile and West Twin – had mesotrophic TP levels, with other factors consistent with oligotrophy. Among the mesotrophic lakes – Fielding, Hudson, Moose, Paxson, T, Tolsona and Volkmar – the most interesting was T Lake with mesotrophic nutrient levels, oligotrophic transparency, eutrophic Chl and anoxia in the deep hypolimnion (Table 1, Fig. 2). We attribute these inconsistences to our integrated samples likely including a sub-surface algal layer and hypolimnetic water in late season samples. Several mesotrophic lakes had TN levels either larger or smaller than the general criteria for this trophic state category (Table 1). Hudson Lake was classified mesotrophic based on low TN, whereas other trophic state features were near the cut-points between meso- and eutrophic lakes. Internally loaded George Lake was eutrophic (Table 1), with anoxia in the deep waters (Fig. 3). Nutrient and Chl values in George Lake are matched or exceeded by measurements in other shallow lakes in the Interior (Alexander and Barsdate 1974, LaPerriere 1990, Alexander and Gu 1997). Our limited data set showed no clear difference between the trophic state of lakes in the Northern Forest relative to those in the Alpine Tundra (Table 1). There was no relation between elevation and lake trophic state in this study because oligotrophic lakes occurred at both low and high elevation. Also, there was no relation between trophic state and lake area. Most trophic state factors decreased with lake depth but there was no clear pattern because all three trophic state categories were represented among lakes with maximum depth <10 m (Table 1). All lakes with maximum depth >30 m, however, were oligotrophic.

Recently Gregory-Eaves et al. (2000) collected data from lakes in the Northern Forest (n = 15) and Alpine Tundra (n = 5) within the same general region of the Tanana Valley and Alaska Range. Overall, their suite of lakes were smaller, less deep (half were ≤ 5 m), and for those within the Northern Forest ecozone, at lower elevation than our study lakes (several <200 m). Their range of KSP values was greater than ours, but the inter-quartile distributions were similar between the two studies (75 to ~200 μS) and both studies found similar pH values. Their data show that Interior lakes were dominated by divalent cations (mean = ~85% of cations) and inorganic carbon dominated the anions (mean = 90% of anions), which is consistent with measurements in the Tangle lakes by Barsdate and Alexander (1971). This composition reflects the sedimentary materials in the region (Wetzel 2001).

Only about one-third of the lakes sampled by Gregory-Eaves et al. (2000) were oligotrophic based on nutrients and Chl, and all of the eutrophic lakes in their statewide study were located the Northern Forest ecozone. Their TP values spanned two orders of magnitude (4 to 476 $\mu g \cdot L^{-1}$) but the median value matched ours (17 $\mu g \cdot L^{-1}$) and the inter-quartile range of their distribution (9-28 $\mu g \cdot L^{-1}$) encompassed most of our TP measurements (Table 1). Their median TN value, however, was ~3-times ours (627 vs. 210 $\mu g \cdot L^{-1}$, respectively) and about one-third of their values exceeded our maximum measurement (660 $\mu g \cdot L^{-1}$). Levels of TN in 30% of their lakes consistent with hyper-eutrophic conditions (>1200 $\mu g \cdot L^{-1}$, Nürnberg 1996). These differences are likely the result of internal loading processes and perhaps nitrogen fixation, particularly in the shallow lakes (Alexander and Gu 1997). Data of Barsdate and Alexander (1971), LaPerriere (1990) and Satoh et al. (1992) from this region also show a broad nutrient range, with most lakes in the mesotrophic and eutrophic categories. Collectively, these data suggest lake trophic state is heterogenous in Interior Alaska.

Differences in TN values between the two studies caused Gregory-Eaves et al. (2000) to conclude P limitation was prevalent within the region whereas our data, and that of Satoh et al. (1992), suggest N limitation was equally important. Two lakes, Harding and Paxson, were common to all three surveys, and there was close agreement regarding lake TN content. This consistency suggests there are real differences in the N content of Interior lakes, rather than systematic differences in N measurements among the various surveys. Differences in lake morphology, and processes associated with shallow, potentially polymictic lakes, likely account for discrepancies in TN:TP ratios among these regional studies. N-limitation has been demonstrated elsewhere in Alaska (Levine and Whalen 2001, LaPerriere and Jones 2002, LaPerriere et al. 2003, Heglund and Jones 2003) at high latitude (Lim et al. 2001).

Among these Interior lakes, TP and TN were strongly related with KSP when internally loaded George Lake eliminated (Fig. 4). This finding is consistent the conceptual framework linking measures of salinity (dissolved solids) in undisturbed areas to lake fertility, as measured by the plant nutrients nitrogen and phosphorus (reviewed by Chow-Frazer 1991). When these cross-system relations developed for our lakes (Fig. 4) were applied to those lakes sampled by Gregory-Eaves et al. (2000) within the same KSP range as ours (n = 16, also omitting one lake with a TP value of 476 $\mu g \cdot L^{-1}$) about 60% the TP predictions matched observed values within ±40%, but predicted TN values were less precise, with half being within ±80% of observed values. In their shallow lakes, at elevations below the lowest elevation in our study (6 m and <200 m), observed TP and TN values exceeded predictions by 3 to 7-fold. Several of these lakes are nutrient rich and productive, with the potential for nitrogen fixation (Alexander and Barsdate 1974, Alexander and Gu 1997, LaPerriere 1990). Salinity can serve as a general surrogate of fertility in the Interior lakes, but numerous outliers in the Gregory-Eaves evaluation suggests empirical predictions may be imprecise for shallow lakes. The role of lake morphometry has long been recognized as a factor in the relation between the geologic setting and lake chemistry (Duarte and Kaff 1989, LaPerriere 1990). The linkage between dissolved solids and lake fertility is often used to predict potential fish yields in lakes (Ryder 1965). Simpson (1998) found the biomass of the sport fish burbot (*Lota lota)* strongly correlated to KSP and ALK (r = 0.78) in a subset of the study lakes.

This paper is a contribution to the regional limnology of Alaska and extends the available data base and general characterization of Interior lakes. As pointed out by Alexander and Gu (1997) the Interior lakes provide an excellent opportunity for comparative limnological work. Our data show Interior lakes are not homogenous in their trophic state characteristics and that additional limnological studies are warranted to document regional patterns and link them with geological and edaphic conditions within the region.

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