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# Limnology of Selected Lakes in the Yukon River Basin[1]

by

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# ABSTRACT

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Limnological investigations were carried out on 19 Yukon River Basin lakes in the summer of 1982 and in the early spring of 1983. A wide range of limnological variables were measured, including light, temperature, water chemistry, bacterioplankton numbers, phytoplankton biomass and species composition, and zooplankton biomass and species composition. On the basis of average phosphorus concentrations (range: 2.9-13.5 µg/L), the lakes were oligotrophic to mesotrophic, and the range in average bacterioplankton numbers ($0.78-2.46X10^6$/mL) indicated that several lakes were approaching eutrophy. In most lakes average zooplankton biomass was high (range: 22-202 mg dry wt/$m^3$), further indicating the productive nature of these lakes. The utility of these data in developing fish yield models for Yukon lakes is discussed, and areas requiring additional research are suggested.

# INTRODUCTION

Lakes of the Yukon River Basin either sustain, or have the potential to support, extremely valuable commercial, recreational, and subsistence fisheries for a variety of fish species. In addition, fishing intensity on some Basin lakes is increasing rapidly. In order to improve management of these fisheries, and to determine the relative abilities of selected lakes to sustain a fishery, detailed information on lake productivity was required. Although there have been a number of limnological studies on Yukon lakes (see Ennis et al. 1982 for annotated bibliography), they have generally investigated higher trophic levels (e.g. zooplankton-fish). The data on spatial and temporal variation of ambient nutrient concentrations and their influence on lower trophic levels (phytoplankton-zooplankton), which are required to determine a lake's trophic status, and to determine the factors which limit lake productivity, have not been collected to date.

The objectives of this study were to gather information on the physics, chemistry, and phytoplankton-zooplankton of selected Yukon River Basin lakes in order to provide a first estimate of lake trophic status, and identify potential factors that may limit lake productivity. The utility of these data to the development of fish yield or biomass models for Yukon lakes is discussed, and future experiments which may enhance the Yukon fisheries resource are suggested.

# DESCRIPTION OF STUDY AREA

The nineteen lakes sampled in this study were located in the southwestern portion of the Yukon, and ranged from $60^{\circ}11'$ to $63^{\circ}43'$ in latitude, and $131^{\circ}40'$ to $139^{\circ}49'$ in longitude (Table 1, Fig. 1). The climate in this region is subarctic, with short, cool summers and long cold winters. Annual precipitation is <50 cm through most of the region.

Ice cover occurs on the lakes for 5 to 7 months each year, lasting from October-November to May-June. Sixteen of the lakes in this study were dimictic, and the remainder were cold monomictic. The lakes varied considerably in area

($1.6$ to $90 km^2$), and mean depths ranged from 2.5 m in Taye Lake to 93 m in Little Salmon Lake (Horler 1982). Estimated theoretical water residence times ranged from 0.1 yr to 22 yr.

## METHODS

Twenty-three locations on 19 lakes were sampled monthly from June to September of 1982, and 11 locations on 10 lakes were sampled in March of 1983 (Table 2). During the open water periods a float-equipped Cessna 206 aircraft was used to reach the sampling locations, and in March of 1983 a de Havilland single-engine Otter equipped with skis was used.

Temperature profiles to a depth of 50 m or to bottom (whichever was less) were obtained using a Montedoro-Whitney temperature probe (Model TC-5C). Buoyancy frequencies were calculated (Turner 1973) and used to calculate epilimnion depth. A Li-Cor light meter (Model 185A) equipped with a Li-Cor underwater quantum sensor (Model Li-192S) was used to measure photosynthetically active radiation (400 - 700 nm) from the surface to the compensation depth (1% of surface intensity) and vertical light extinction coefficients were calculated. A standard 22-cm Secchi disc was used to measure water transparency.

A 6-L Van Dorn bottle, rinsed with 95% ethanol, was used to collect all lake water samples. Samples were collected between 0900 and 1200h from 2 epilimnetic (usually 1 and 5 m) and 1 hypolimnetic depths. If lakes were isothermal at the time of sampling, usually only 2 near-surface depths were sampled. From each depth water was placed in a clean, rinsed test tube and in a 2-L polyethylene bottle. Samples were kept cold, dark, and were returned to the field laboratory within 4h. Samples in test tubes were stored at $4^{o}C$ and later analyzed for total phosphorus. Water for other nutrient analyses (total dissolved nitrogen, nitrate, total dissolved solids, and soluble reactive silicon) was filtered through an ashed, washed and rinsed 47-mm diameter Whatman GFF filter and placed in rinsed 125-mL glass and plastic bottles (1 glass and 1 plastic bottle/sample). Samples were stored at $4^{o}C$ in the dark and later analyzed according to the methods of Stephens and Brandstaetter (1983). At every sampling location glass jars were filled completely with water (generally from 1 m), covered with parafilm, and transported to the field laboratory. These samples were collected to measure pH and total alkalinity according to the standard potentiometric method of APHA (1976), using a 100-mL subsample, 0.01 N $H_2SO_4$ and a Cole-Parmer Digi-Sense pH meter (Model 5986-10).

A 1-L sample from each depth was filtered through an ashed 47-mm diameter, Whatman GFF filter. Filters were dried in a dessicator and then frozen, and were later analyzed for particulate carbon and nitrogen using a Perkin-Elmer CHN analyzer (Model 240). An additional 500-mL sample from each depth was filtered through an ashed Whatman GFF filter. These filters were placed in clean glass vials and later analyzed for particulate phosphorus according to the method of Stainton et al. (1977). A further 500-mL sample was filtered through a 47-mm diameter, Millipore AA filter and a few drops of a $MgCO_3$ suspension were added. Filters were dried in a dessicator and then frozen, and were later analyzed for total chlorophyll using a Turner fluorometer (Model III) according to the methods of Strickland and Parsons (1972).

At every depth sampled a test tube rinsed with 95% ethanol was rinsed and then filled with water. In the field laboratory 5 mL were filtered onto a 25-mm diameter, 0.2 µm Nuclepore membrane filter counter-stained with Irgalan Black. Filters were removed when just dry and placed into a 9-cm divided petrie dish lined with Whatman filter paper, air dried at room temperature (approximately 20$^{\circ}$C) and stored. Samples were counted later under epifluorescence using the acridine orange direct count (AODC) method as described by MacIsaac et al. (1981).

Samples for ultraphytoplankton ($<$3 µm equivalent spherical diameter) biomass were collected from every depth in opaque, 125-mL polyethylene bottles and transported to the field laboratory where 15 mL of each sample were filtered under subdued light onto a pre-stained (Irgalan Black), 25-mm diameter, 0.2 µm Nuclepore membrane filter in the same manner as for bacteria biomass. Filters were then air-dried and stored in opaque, 9-cm petrie dishes at room temperature until counted. Just prior to ultraphytoplankton identification and enumeration, each filter was placed on top of a Whatman GFF filter in a Millipore filtering unit and rehydrated with 1-2 mL of cold, filtered, distilled water for approximately 2 min. The water was then drawn through and the moist filter placed on a microscope slide, followed by a drop of Type B immersion oil, a coverslip, then another drop of oil. Counts were made at 1250X magnification using a Zeiss compound microscope (Model KLSM) equipped with epifluorescence. Approximately 20 to 30 random fields were counted and values were converted to numbers/ $m^3$ and volume ($mm^3/m^3$). A minimum of 100 cells were counted per sample.

Phytoplankton samples from all depths were collected in opaque, 125-mL polyethylene bottles and fixed with approximately 1 mL of Lugol's solution. Samples were later shaken and settled overnight in 27-mL settling chambers. One transect at 187.5X and one at 750X magnification were counted using a Wild M40 inverted microscope equipped with phase contrast Utermöhl (1958). Counts were converted to numbers/$m^3$ and volume ($mm^3/m^3$).

Zooplankton were sampled using a 100-µm mesh size SCOR-UNESCO net (mouth area = $0.25 m^2$) which was hauled vertically at approximately 0.5 m/s from 25 m or from near bottom (whichever was less). Samples were preserved in a borax-buffered, 4% formalin-sucrose solution (Haney and Hall 1973). In the laboratory each sample was split in half using a Folsom plankton splitter. One half of the sample was filtered onto a pre-weighed Whatman GFC filter, dried at 90°C for 24 h, and then weighed. Zooplankton biomass is expressed as mg dry weight/ $m^3$. The other half of the sample was used for zooplankton identification and enumeration using the methods of Cone *et al.* (unpublished data).

## RESULTS

Alligator, Dezadeash, and Taye lakes were isothermal for most of the open water period and the remainder of the lakes exhibited varying degrees of vertical stratification (Fig. 2). Average surface temperatures (June-September, n=4) ranged from 8.9°C in Jojo Lake to 14.8°C in Twin Lake, and maximum recorded surface temperatures in each lake varied from 10.8°C to 17.9°C. Average epilimnion depths also exhibited considerable variation, ranging from 6.3 m in Michie Lake to 20.7 m in Sekulmun Lake (Table 3).

Compensation depths exhibited considerable variation, both within and among lakes (Table 3). Averages ranged from 6.2 m at one sampling location in Big Kalzas Lake to 33.3 m in Coghlan Lake. In several lakes (Claire, Coghlan, Fox, Snafu, and Wellesley) compensation depths were considerably deeper (by 1.5 - 3.6X) than the seasonal thermocline, and for part of each open water period a significant amount of hypolimnetic production was possibly occurring, but was not measured in this study.

Most lakes were slightly alkaline throughout the study, and average pH values ranged from 7.0 in Jojo Lake to 8.4 in Fox Lake. Total alkalinities and total dissolved solids were also quite variable, and the highest average values were 8-10X higher than the lowest (Table 3).

Total dissolved nitrogen concentrations ranged from 158 μg/L in Jojo Lake to 609 μg/L in Taye Lake, and were not as variable as average nitrate concentrations, which ranged from <1 to 102 μg N/L (Table 3). Nitrate concentrations were near or below the analytical detection limit of 1 μg N/L for most of the open water period in 13 of the 19 lakes investigated. Even at the June sampling date, when several of these lakes were still mixing (isothermal) and others were only beginning to stratify, nitrate was depleted in the surface layer. Detectable nitrate concentrations were found in all lakes sampled under ice in March 1983, when concentrations ranged from 13 to 122 μg N/L (Table 3).

Spring (March) total phosphorus concentrations were lowest (1.7 μg/L) in Jojo Lake and highest (11.7 μg/L) in Wellesley Lake. Average concentrations ranged from 2.9 μg/L in portions of Big Kalzas and Mayo lakes, to 13.5 μg/L in shallow Taye Lake. Average concentrations of particulate phosphorus were below the detection limit of 2 μg/L in 5 lakes and were again highest (12.7 μg/L) in Taye Lake. The ratio of particulate phosphorus: total phosphorus ranged from 0.32 in Sekulmun Lake to 1.00 in Alligator Lake, and averaged 0.65 for all lakes.

Bacteria numbers were lowest ($7.80 \times 10^5$/mL) in Little Salmon Lake and highest ($2.46 \times 10^6$/mL) in Wellesley Lake. Bacteria numbers in Taye Lake were too high to measure, because of the mixing of sediments and associated attached bacteria into the water column. Seasonal variation was not generally apparent, although in all lakes lowest bacteria numbers occurred under ice in March.

Algal biomass also did not exhibit marked seasonal variability. Average chlorophyll concentrations ranged from 0.64 μg/L in Coghlan Lake to 3.76 μg/L in Taye Lake (Table 3). Algal volume followed similar patterns, and values ranged between 106 $mm^3/m^3$ and 553 $mm^3/m^3$, except in Ethel and Taye lakes, where averages were 1809 and 1601, respectively. The portion of the phytoplankton community estimated to be utilizable by herbivorous zooplankton was defined in this study as those phytoplankton with a maximum dimension <50µm (nanoplankton). Nanoplankton volumes averaged 61% of total volumes for all lakes, although values for each lake varied from 9% (Ethel Lake) to 88% (Alligator Lake). In 4 of the 10 lakes sampled under ice in March, chlorophyll concentrations were higher than those measured during the open water period. However, this trend was not observed for algal volumes, as the volumes found under ice were lower than the average volumes found during the open water period. Volumes in March of 1983 were 10 - 63% of average volumes in June to September 1982, while March chlorophyll concentrations were 50 - 213% of average 1982 values.

Zooplankton were abundant in virtually all lakes, and populations were composed of relatively large animals. Average biomass ranged from 22 mg dry wt./$m^3$ at one location in Mayo Lake to 202 mg dry wt./$m^3$ in Wellesley Lake. Dezadeash and Taye Lakes were too shallow to obtain quantitative biomass estimates with the technique used in this study. Highest zooplankton biomass in almost all lakes occurred in July or August, and in most lakes highest densities occurred in July. Zooplankton biomass under ice in March was from 11 to 77% (average = 46%) of the June to September averages. Mean size of the zooplankton community (including rotifers and nauplii) was variable among lakes, and ranged from 0.39 mm in Coghlan Lake to 0.66 mm in Wellesley Lake. *Cyclops*, *Daphnia*, and *Diaptomus* were the most common genera in the lakes. *Daphnia* exhibited the greatest size variability of the major genera, and average size ranged from 0.60 mm in Snafu Lake to 1.72 mm in Wolf Lake.

## DISCUSSION

### Trophic Status

Of all variables measured in this study, phosphorus concentration (either average summer or during isothermal conditions in spring) has been most widely used and is most generally accepted as a predictor of a lake's trophic status (Dillon and Rigler 1974; Prepas 1983; Vollenweider 1976).

Vollenweider (1976) utilized data from a large number of temperate North American lakes of varying trophic status and reported a relationship between phytoplankton biomass (as chlorophyll) and total phosphorus concentration at spring overturn.

In order to establish the trophic status of Yukon lakes relative to other North American lakes, data from our study were plotted with those of Vollenweider (Fig. 3). The majority of Yukon lakes fit Vollenweider's regression line well, and fall within the 99% confidence limits of his data set. Most Yukon lakes occur in the middle to upper portion of the oligotrophic category, and several occur in or near the mesotrophic category. The relatively good fit of the Yukon data to that of other North American lakes strongly suggests that productivity of Yukon lakes, as with many other North American lakes, is limited primarily by phosphorus availability.

Although chlorophyll and phosphorus concentrations are strongly correlated (n=19, $r^2$ =0.59) in Yukon lakes, some of the data introduce a relatively large amount of scatter in the relationship (Fig 4). In addition, the particulate phosphorus: total phosphorus ratio varied considerably amoung lakes, and was as low as 0.32 in Sekulmun Lake. These data suggest that in some lakes a substantial proportion of the total phosphorus pool is biologically unavailable, and/or that other factors also play a role in limiting productivity. The very low nitrate concentrations present in some lakes suggest that at some times of the year nitrogen availability may also be a critical factor in limiting production.

Bacteria numbers were also highly correlated with total phosphorus concentrations, and provide further evidence that productivity in most Yukon lakes is controlled by phosphorus availability (Fig. 5). The prominent outlier in the figure is the Sekulmun Lake data point, which supports the conclusion that much of the total phosphorus pool in that lake is biologically unavailable. The range in average bacteria numbers found in this study is typical of that in lakes ranging from oligotrophic to eutrophic (Hobbie and Wright 1979; MacIsaac _et al._ 1981; Spencer 1978). Average numbers in most lakes in this study are typical of relatively productive, mesotrophic lakes.

The data provide strong evidence that Yukon lakes are not extremely unproductive, or "ultra-oligotrophic", but these data may still underestimate the true productivity of these lakes. A number of studies on sub-arctic lakes (Billaud 1968; La Perriere et al. 1975) have found that seasonal maxima in algal biomass occurs under ice in spring, and in this study seasonal averages were calculated from June to September values only. Algal biomass under ice in March was high enough in most lakes sampled in this study to indicate that substantial under-ice production occurs in Yukon lakes also, and that seasonal maxima may occur prior to break-up of ice in spring.

## Prediction of fish yields or biomass

One of the primary goals of fisheries management is to ensure that a particular stock is not subjected to a greater harvest rate than it can sustain. The concept of "maximum sustained yield" (Ricker 1975) has for a considerable time been the major tool used to set policy and determine harvest rates, although the validity of the concept has recently been questioned (Larkin 1977). Fish yield or biomass in lakes has been correlated with a number of limnological variables. These include total phosphorus concentration (Hanson and Leggett 1982), chlorophyll concentration (Jones and Hoyer 1982; Oglesby 1977), and total dissolved solids/mean depth (morphoedaphic index) (Ryder 1965).

The resulting simple empirical models have been widely used as predictive tools. The first, and most widely used predictor of fish yield was the morphoedophic index (MEI) of Ryder (1965). However, it has recently been demonstrated (Prepas 1983) that inclusion of total dissolved solids (TDS) in the MEI does not improve the model's predictive ability, and that there is little justification in using TDS in empirical yield models. The applicability of yield models developed in one geographic area to other geographic areas is difficult to determine, especially in Yukon lakes, where little or no fish yield or biomass data are available. However, these models may provide some insight into relative productivitites of Yukon lakes, and consequently theoretical fish yields were calculated using 4 different models, and the yields for each lake ranked (Table 4). When lake yields were ranked for the various models, 7 of the 19 lakes were ranked similarly in all models, but for several lakes, major differences occurred (Table 4). In almost all cases, the model of Ryder (1965) resulted in the highest potential yields, and that of Oglesby (1977), the lowest. The least variation in potential yields among lakes occurred in the model of Hanson and Leggett (1982), which utilized total phosphorus concentration.

Although very little biomass or fish yield data are available for Yukon lakes, species composition and growth rate data are available from samples collected using gillnets (Horler and Johnson, unpublished data). The total weight of fish caught in each lake during these surveys may be a relative indicator of fish biomass, assuming that fishing effort was similar in each lake. Of all variables measured, total fish weight was most highly correlated with zooplankton biomass ($r^2=0.49$, df=14, $p<0.01$) (Fig. 6). The scatter in the relationship may be due to a number of factors, which include: fishing effort may not have been constant among lakes; large invertebrate predators may have been present in some lakes, but were not sampled in this study; and, the proportion of planktivorous to piscivorous fish may have varied among lakes. If the assumptions are valid, further development of this relationship may be of some value.

Growth rates of 4 of the fish species caught in the fisheries study (lake trout, round whitefish, humpback whitefish, and grayling) were calculated, and to facilitate comparisons among lakes, were expressed as weight at an arbitrary age. The weight of 10 yr old lake trout was significantly correlated ($r^2=0.62$, df=13, $p<0.01$) with particulate carbon concentrations (Fig. 7). Since particulate carbon concentrations increase with increasing lake productivity, this relationship has a sound biological basis; and in future may be of some utility. Deriving relationships between limnological variables and other fish species (8 yr humpback whitefish, 6 yr round whitefish, and 5 yr grayling) was difficult because of small sample sizes, and few significant relationships were found. Surprisingly, however, all three species were positively correlated with mean depth (Fig. 8, 9, 10). Round whitefish weights at 6 yr were significantly correlated with mean depth ($r^2=0.80$, df=5, $p<0.01$). as were humpback whitefish at 8 yr ($r^2=0.90$, df=5, $p<0.01$, Mayo Lake outlier removed). Grayling weights at 5 yr were not significantly correlated ($r^2=0.58$, df=3, $p<0.5$) with mean depth although grayling lengths at 5 years were ($r^2=0.88$, df=3, $p<0.05$).

## RECOMMENDATIONS

Although most data collected in this study indicate that many Yukon lakes are relatively productive, the data do consist solely of concentration and biomass information. In order to confirm the lakes' productive nature, production rate measurements should be carried out. These should include direct determination of carbon uptake rates by phytoplankton using standard radiotracer techniques, estimation of zooplankton production rates, and, where possible, calculation of actual fish yields. Measurement of phytoplankton production rates would require experiments to determine if the protracted summer daylight hours which occur in the Yukon increase or modify daily rates and patterns of production. The magnitude of under-ice production should also be determined on selected lakes. These data would improve average growing season values for all limnological variables, which in turn would improve potential fish yields calculated from the various models.

In order to calibrate existing fish yield or biomass models for Yukon lakes, or to develop models specifically for Yukon lakes, population estimates of major fish species in selected lakes should be carried out. Hydroacoustic enumeration, which is currently in use on coastal British Columbia to enumerate both juvenile and adult sockeye, may be feasible on Yukon lakes. If it is applicable, it would provide a rapid, inexpensive way to document fish densities in Yukon lakes. It should be accompanied by trawling, gillnetting, and beach seining to determine species composition and age distribution.

The high zooplankton densities and the abundance of large zooplankton present in many lakes are strong indirect evidence that there are very low densities of planktivorous fish in Yukon lakes. Consequently, the efficiency of energy transfer from primary producers, to zooplankton, to planktivorous fish, and to piscivorous fish, may be very low. If this is the case, then introduction of an efficient planktivorous fish such as kokanee may be of benefit. Martin (1966, 1970) demonstrated that additions of planktivorous fish can result in increased lake trout size and growth rates. Studies should be carried out to determine the feasibility of this experiment in selected Yukon lakes. Pre-stocking studies should include measurement of primary and secondary production rates, determination of zooplankton size-frequency distributions, population estimates of the major fish species found in the lakes, collection of additional growth rate information, and determination of major food items of lake trout.

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Table 1. Morphometric and hydrologic data of selected Yukon River Basin lakes.

| Lake | Latitude | Longitude | Area ($Km^2$) | Mean[a] Depth (m) | Theoretical Residence Time (yr) |
|---|---|---|---|---|---|
| Alligator | $60^{\circ}23^{1}$ | $135^{\circ}21^{1}$ | 6.3 | 5.4 | 1.9 |
| Big Kalzas | $63^{\circ}15^{1}$ | $134^{\circ}35^{1}$ | 42 | 65 | 18 |
| Claire | $61^{\circ}53^{1}$ | $135^{\circ}19^{1}$ | 20 | 53 | 22 |
| Coghlan | $61^{\circ}33^{1}$ | $135^{\circ}29^{1}$ | 8.2 | 24 | 2.5 |
| Dezadeash | $60^{\circ}28^{1}$ | $136^{\circ}58^{1}$ | 82 | 4.1 | 1.2 |
| Ethel | $63^{\circ}22^{1}$ | $136^{\circ}06^{1}$ | 45 | 31 | 21 |
| Fox | $61^{\circ}14^{1}$ | $135^{\circ}28^{1}$ | 17 | 29 | 5.4 |
| Jojo | $60^{\circ}34^{1}$ | $136^{\circ}21^{1}$ | 6.4 | 31 | 6.4 |
| Little Atlin | $60^{\circ}15^{1}$ | $133^{\circ}57^{1}$ | 38 | 11 | 2.0 |
| Little Salmon | $62^{\circ}11^{1}$ | $134^{\circ}40^{1}$ | 63 | 93 | 8.0 |
| Mayo | $63^{\circ}43^{1}$ | $135^{\circ}04^{1}$ | 90 | 57 | 13 |
| Michie | $60^{\circ}41^{1}$ | $134^{\circ}10^{1}$ | 3.9 | 15 | 0.6 |
| Quiet | $61^{\circ}05^{1}$ | $133^{\circ}05^{1}$ | 53 | - | - |
| Sekulmun | $61^{\circ}26^{1}$ | $137^{\circ}33^{1}$ | 50 | - | - |
| Snafu | $60^{\circ}11^{1}$ | $133^{\circ}26^{1}$ | 3.0 | 6.3 | 0.2 |
| Taye | $60^{\circ}56^{1}$ | $136^{\circ}21^{1}$ | 8.1 | 2.5 | 0.2 |
| Twin | $61^{\circ}42^{1}$ | $135^{\circ}59^{1}$ | 1.6 | 16 | 0.1 |
| Wellesley | $62^{\circ}21^{1}$ | $139^{\circ}49^{1}$ | 74 | 24 | 17 |
| Wolf | $60^{\circ}39^{1}$ | $131^{\circ}40^{1}$ | 74 | - | - |

[a] from Horler (1982)

Table 2. Sampling dates for the limnological study of Yukon River Basin lakes, 1982-1983.

| Lake | 1982<br>June | July | August | September | 1983<br>March |
|---|---|---|---|---|---|
| Alligator | 15 | 13 | 19 | 17 | 19 |
| Big Kalzas | 16 | 14 | 17 | 15 | - |
| Claire | 18 | 16 | 20 | 17 | 16 |
| Coghlan | 18 | 16 | 20 | 16 | - |
| Dezadeash | 17 | - | 19 | 17 | - |
| Ethel | 16 | 14 | 17 | 15 | - |
| Fox | 18 | 16 | 20 | 16 | 19 |
| Jojo | 17 | 15 | 19 | 17 | 19 |
| Little Atlin | 15 | 13 | 18 | 14 | 18 |
| Little Salmon | 18 | 16 | 20 | 16 | - |
| Mayo | 16 | 14 | 17 | 15 | - |
| Michie | 15 | 13 | 18 | 14 | 18 |
| Quiet | 15 | 13 | 18 | 14 | - |
| Sekulmun | 17 | 15 | 19 | 18 | 17 |
| Snafu | 15 | 13 | 18 | 14 | - |
| Taye | 17 | 15 | 19 | 17 | - |
| Twin | 18 | 16 | 20 | 16 | 16 |
| Wellesley | 17 | 15 | 19 | 18 | 17 |
| Wolf | - | 13 | 18 | 14 | 18 |

Table 3. Growing season averages of salient information for the 1982 Yukon study lakes.

| Lake and station | Surface temp. (°C) | Epilimnion depth (m) | Secchi depth (m) | Compensation depth (m) | Epilimnetic pH | Total Alkalinity (mg/L $CaCO_3$)[a] |
|---|---|---|---|---|---|---|
| √Alligator | 11.0 | iso | 5.1 | 7.7 | 7.5 | 31.9 |
| Big Kalzas-1 | 11.7 | 9.3 | 4.9 | 8.3 | 7.4 | 50.1 |
| Big Kalzas-2 | 11.5 | 9.8 | 3.5 | 6.2 | 7.4 | 47.4 |
| Claire-1 | 13.2 | 9.3 | 6.5 | 13.0 | 8.2 | 124.2 |
| Claire-2 | 12.7 | 6.6 | 8.2 | 11.8 | 8.2 | 144.1 |
| Coghlan | 12.7 | 9.3 | 9.8 | 33.3 | 8.3 | 153.0 |
| Dezadeash | 10.7 | iso | 3.8 | 5.6 | 7.5 | 50.8 |
| Ethel | 12.3 | 10.5 | 5.2 | 9.3 | 7.3 | 38.2 |
| Fox | 12.0 | 10.4 | 8.1 | 14.4 | 8.4 | 163.5 |
| Jojo | 8.9 | 18.3 | 7.9 | 14.0 | 7.0 | 15.3 |
| Little Atlin | 13.9 | 12.0 | 6.1 | 15.8 | 8.2 | 137.3 |
| Little Salmon | 10.4 | 13.9 | 5.8 | 12.0 | 8.1 | 101.4 |
| Mayo-1 | 9.8 | 12.6 | 3.7 | 6.9 | 7.5 | 52.2 |
| Mayo-2 | 11.6 | 9.7 | 4.2 | 7.0 | 7.4 | 52.1 |
| Mayo-3 | 10.8 | 7.7 | 4.5 | 7.4 | 7.5 | 48.1 |
| Michie | 13.7 | 6.3 | 5.2 | 6.5 | 8.3 | 138.0 |
| Quiet | 11.0 | 16.1 | 7.1 | 12.3 | 7.4 | 38.3 |
| Sekulmun | 9.6 | 20.7 | 7.4 | 15.6 | 7.2 | 35.1 |
| Snafu | 14.4 | 7.8 | 5.1 | 13.1 | 8.2 | 131.0 |
| Taye | 14.4 | iso | > 2.0 | 8.8 | 8.2 | 69.0 |
| Twin | 14.8 | 9.4 | 5.4 | 9.9 | 8.3 | 164.1 |
| Wellesley | 12.5 | 11.1 | 6.2 | 17.2 | 8.2 | 127.8 |
| Wolf | 10.2 | 14.6 | 6.7 | 13.2 | 7.3 | 57.4 |

[a] epilimnetic values

Table 3. Cont'd.

| Lake and station | Particulate Nitrogen (µg/L) | Total dissolved Nitrogen (µg/L)[b] | Nitrate (µg N/L)[b] | Spring Nitrate (µg N/L)[b] | Total phosphorus (µg/L)[b] | Spring Tot. phosphorus (µg/L) | Particulate Phosphorus (µg/L)[b] |
|---|---|---|---|---|---|---|---|
| Alligator | 79 | 255 | <1.0 | 13.5 | 5.8 | 3.3 | 5.8 |
| Big Kalzas-1 | 35 | 272 | 91.1 | - | 2.9 | - | <2.0 |
| Big Kalzas-2 | 37 | 292 | 78.0 | - | 4.9 | - | 2.7 |
| Claire-1 | 66 | 312 | 22.1 | 71.7 | 5.1 | 3.3 | 2.7 |
| Claire-2 | 64 | 307 | 9.9 | 69.7 | 4.2 | 3.7 | 3.5 |
| Coghlan | 48 | 286 | <1.0 | - | 4.2 | - | 2.3 |
| Dezadeash | 95 | 203 | <1.0 | - | 7.8 | - | 7.6 |
| Ethel | 48 | 229 | 5.2 | - | 3.2 | - | <2.0 |
| Fox | 64 | 335 | <1.0 | 12.7 | 5.6 | 5.3 | 2.5 |
| Jojo | 55 | 158 | 1.9 | 15.0 | 5.0 | 1.7 | 2.2 |
| Little Atlin | 76 | 306 | 1.4 | 37.3 | 6.1 | 4.5 | 3.5 |
| Little Salmon | 55 | 288 | 87.1 | - | 3.8 | - | 2.5 |
| Mayo-1 | 48 | 303 | 102.3 | - | 3.2 | - | <2.0 |
| Mayo-2 | 50 | 285 | 98.5 | - | 3.4 | - | 2.5 |
| Mayo-3 | 43 | 304 | 101.1 | - | 2.9 | - | <2.0 |
| Michie | 80 | 269 | <1.0 | 40.0 | 7.5 | 9.0 | 4.7 |
| Quiet | 60 | 177 | 15.5 | - | 4.0 | - | 3.0 |
| Sekulmun | 42 | 266 | 81.8 | 121.7 | 6.9 | 3.7 | 2.2 |
| Snafu | 85 | 350 | 1.1 | - | 8.2 | - | 4.8 |
| Taye | 213 | 609 | <1.0 | - | 13.5 | - | 12.7 |
| Twin | 71 | 293 | <1.0 | 49.3 | 6.1 | 4.7 | <2.0 |
| Wellesley | 80 | 420 | 1.1 | 39.0 | 9.2 | 11.7 | 6.5 |
| Wolf | 61 | 193 | 2.0 | 28.3 | 3.5 | 3.7 | 2.3 |

[b] mean epilimnetic values

Table 3. Cont'd.

| Lake and station | TDS (mg/L)[b] | Bacteria numbers ($x10^6$/mL)[b] | Total chlorophyll (μg/L)[b] | Total algal volume ($mm^3/m^3$)[b] | Nanoplankton volume ($mm^3/m^3$)[b,c] |
|---|---|---|---|---|---|
| Alligator | 52 | 2.09 | 1.56 | 483 | 425 |
| Big Kalzas-1 | 90 | 0.88 | 1.03 | 108 | 76 |
| Big Kalzas-2 | 96 | 1.22 | 1.41 | 235 | 178 |
| Claire-1 | 183 | 1.74 | 1.18 | 118 | 102 |
| Claire-2 | 209 | 1.71 | 1.04 | 106 | 91 |
| Coghlan | 290 | 1.25 | 0.64 | 153 | 61 |
| Dezadeash | 71 | 2.20 | 2.05 | 376 | 207 |
| Ethel | 78 | 1.06 | 1.83 | 1809 | 164 |
| Fox | 228 | 1.54 | 0.62 | 203 | 115 |
| Jojo | 34 | 1.26 | 1.06 | 204 | 166 |
| Little Atlin | 161 | 2.16 | 1.55 | 306 | 162 |
| Little Salmon | 139 | 0.78 | 1.01 | 160 | 118 |
| Mayo-1 | 94 | 1.26 | 1.00 | 152 | 100 |
| Mayo-2 | 101 | 1.04 | 1.19 | 170 | 133 |
| Mayo-3 | 97 | 0.93 | 1.08 | 130 | 96 |
| Michie | 169 | 2.33 | 2.17 | 385 | 180 |
| Quiet | 57 | 1.45 | 1.11 | 163 | 120 |
| Sekulmun | 55 | 1.12 | 0.65 | 119 | 104 |
| Snafu | 185 | 2.34 | 2.08 | 553 | 248 |
| Taye | 113 | - | 3.76 | 1601 | 428 |
| Twin | 232 | 1.95 | 1.37 | 221 | 164 |
| Wellesley | 150 | 2.46 | 1.82 | 416 | 324 |
| Wolf | 80 | 1.18 | 1.04 | 454 | 149 |

[b] mean epilimnetic values.

[c] Nanoplankton is defined as that portion of the phytoplankton whose maximum dimension does not exceed 50 μm.

Table 3. Cont'd.

| Lake and station | Particulate Carbon (mg/L)[b] | Soluble reactive silicon (mg/L)[b] | Zooplankton biomass (mg dry wt./m$^3$) | Zooplankton mean size (mm) |
|---|---|---|---|---|
| Alligator | 0.65 | 1.99 | 138 | 0.58 |
| Big Kalzas-1 | 0.28 | 2.07 | 35 | 0.44 |
| Big Kalzas-2 | 0.36 | 2.10 | 54 | 0.48 |
| Claire-1 | 0.39 | 3.81 | 101 | 0.52 |
| Claire-2 | 0.46 | 4.29 | 114 | 0.60 |
| Coghlan | 0.40 | 3.88 | 65 | 0.39 |
| Dezadeash | 0.67 | 1.88 | - | - |
| Ethel | 0.35 | 0.61 | 49 | 0.54 |
| Fox | 0.40 | 1.53 | 114 | 0.47 |
| Jojo | 0.42 | 2.52 | 95 | 0.56 |
| Little Atlin | 0.54 | 2.70 | 182 | 0.48 |
| Little Salmon | 0.33 | 3.02 | 38 | 0.41 |
| Mayo-1 | 0.43 | 1.64 | 35 | 0.49 |
| Mayo-2 | 0.40 | 1.65 | 26 | 0.47 |
| Mayo-3 | 0.35 | 1.79 | 22 | 0.39 |
| Michie | 0.59 | 4.30 | 88 | 0.55 |
| Quiet | 0.46 | 2.38 | 86 | 0.43 |
| Sekulmun | 0.31 | 3.18 | 72 | 0.61 |
| Snafu | 0.61 | 3.51 | 107 | 0.46 |
| Taye | 1.76 | 3.49 | - | - |
| Twin | 0.42 | 3.93 | 56 | 0.43 |
| Wellesley | 0.58 | 1.49 | 202 | 0.66 |
| Wolf | 0.49 | 2.60 | 52 | 0.47 |

[b] epilimnetic values

Table 4. Salient fish yield information on the Yukon study lakes.

| Lake | Fish Yield (kg/ha) a | b | c | d | Ranked fish yields from model a | b | c,d |
|---|---|---|---|---|---|---|---|
| Alligator | 3.81 | 1.21 | 0.25 | 2.41 | 8 | 9 | 7 |
| Big Kalzas | 1.63 | 1.07 | 0.19 | 1.50 | 18 | 15 | 10 |
| Claire | 2.48 | 1.12 | 0.17 | 1.20 | 11 | 12 | 11 |
| Coghlan | 4.22 | 1.09 | 0.09 | 0.07 | 6 | 13 | 19 |
| Dezadeash | 4.96 | 1.35 | 0.31 | 3.20 | 3 | 4 | 4 |
| Ethel | 2.10 | 1.02 | 0.33 | 3.14 | 13 | 18 | 5 |
| Fox | 3.49 | 1.20 | 0.09 | 0.13 | 9 | 10 | 18 |
| Jojo | 1.46 | 1.15 | 0.16 | 1.06 | 19 | 11 | 14 |
| Little Atlin | 4.66 | 1.23 | 0.25 | 2.39 | 4 | 7 | 8 |
| Little Salmon | 1.66 | 1.07 | 0.15 | 0.93 | 17 | 16 | 16 |
| Mayo | 1.76 | 1.02 | 0.17 | 1.14 | 16 | 19 | 13 |
| Michie | 4.08 | 1.33 | 0.37 | 4.06 | 7 | 5 | 2 |
| Quiet | 1.77 | 1.08 | 0.17 | 1.20 | 15 | 14 | 12 |
| Sekulmun | 1.88 | 1.29 | 0.12 | 0.36 | 14 | 6 | 17 |
| Snafu | 6.25 | 1.38 | 0.35 | 3.82 | 2 | 3 | 3 |
| Taye | 7.64 | 1.66 | 0.71 | 8.35 | 1 | 1 | 1 |
| Twin | 4.55 | 1.23 | 0.22 | 1.90 | 5 | 8 | 9 |
| Wellesley | 3.15 | 1.45 | 0.30 | 3.11 | 10 | 2 | 6 |
| Wolf | 2.26 | 1.04 | 0.16 | 1.01 | 12 | 17 | 15 |

[a] from Ryder (1965). (MEI=TDS/mean depth)

[b] from Hanson and Leggett (1982). FY = 0.072 TP + 0.792

[c] from Oglesby (1977). log Yf = $-1.92 + 1.17 \log \mathrm{Chl}_s$ (Yf=FY as dry wt(g/m$^2$/y)=75% wet wt. $\mathrm{Chl}_s$=summer chl.)

[d] from Jones and Hoyer (1982). FY = $-1.8 + 2.7$ Chl

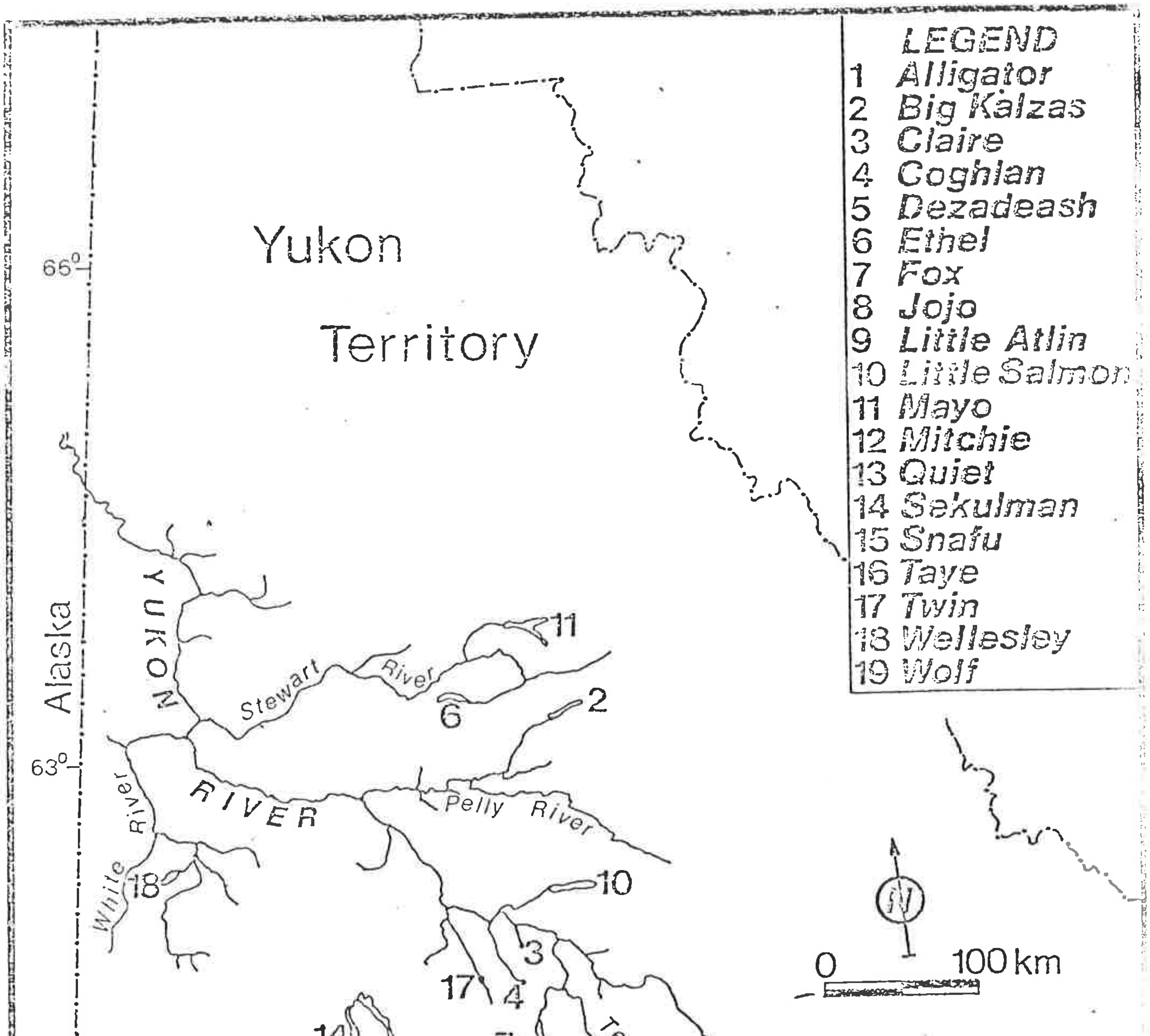

Fig. 1 Location of study lakes

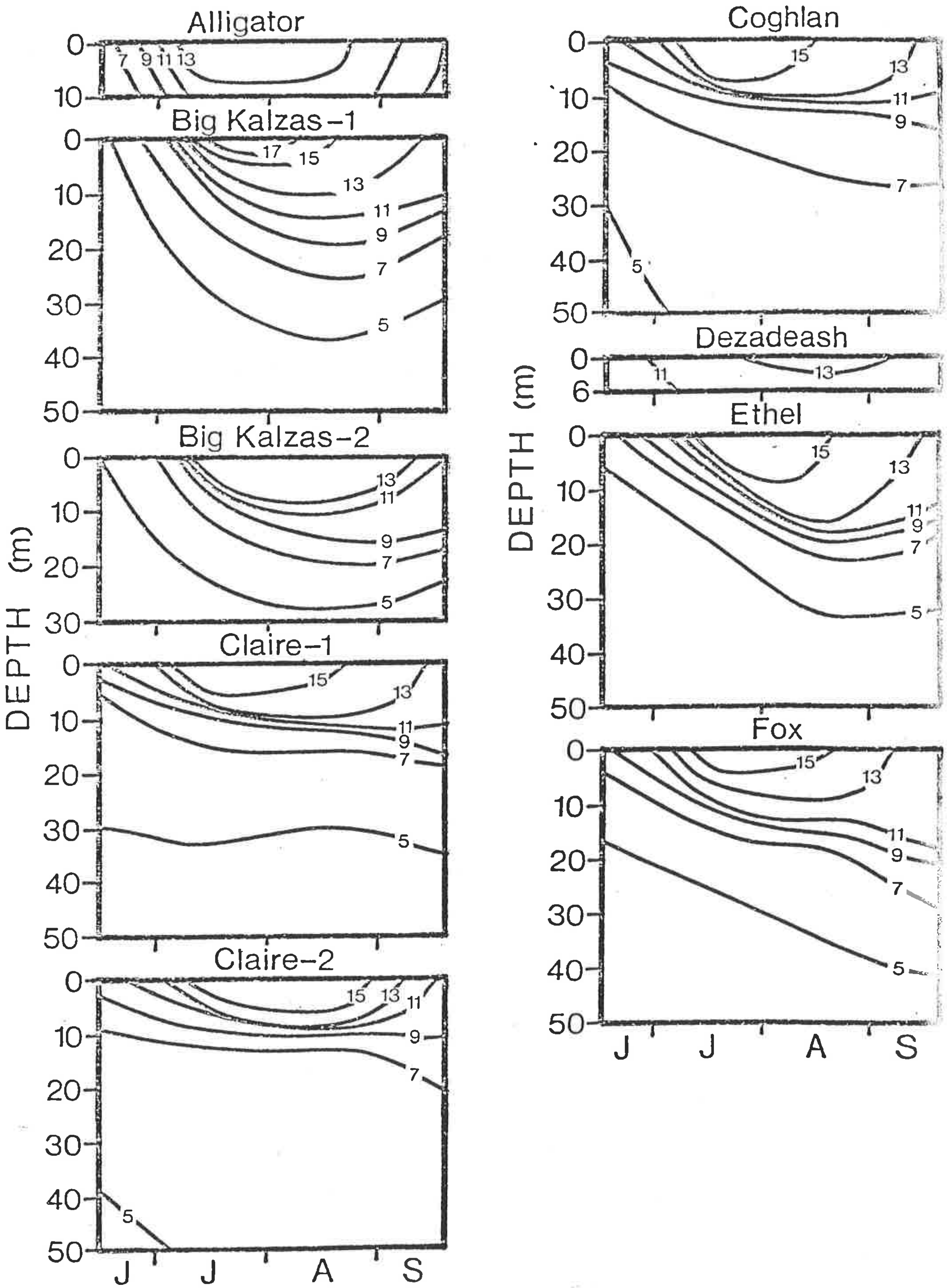

Fig. 2 Seasonal temperature isopleths from the study lakes

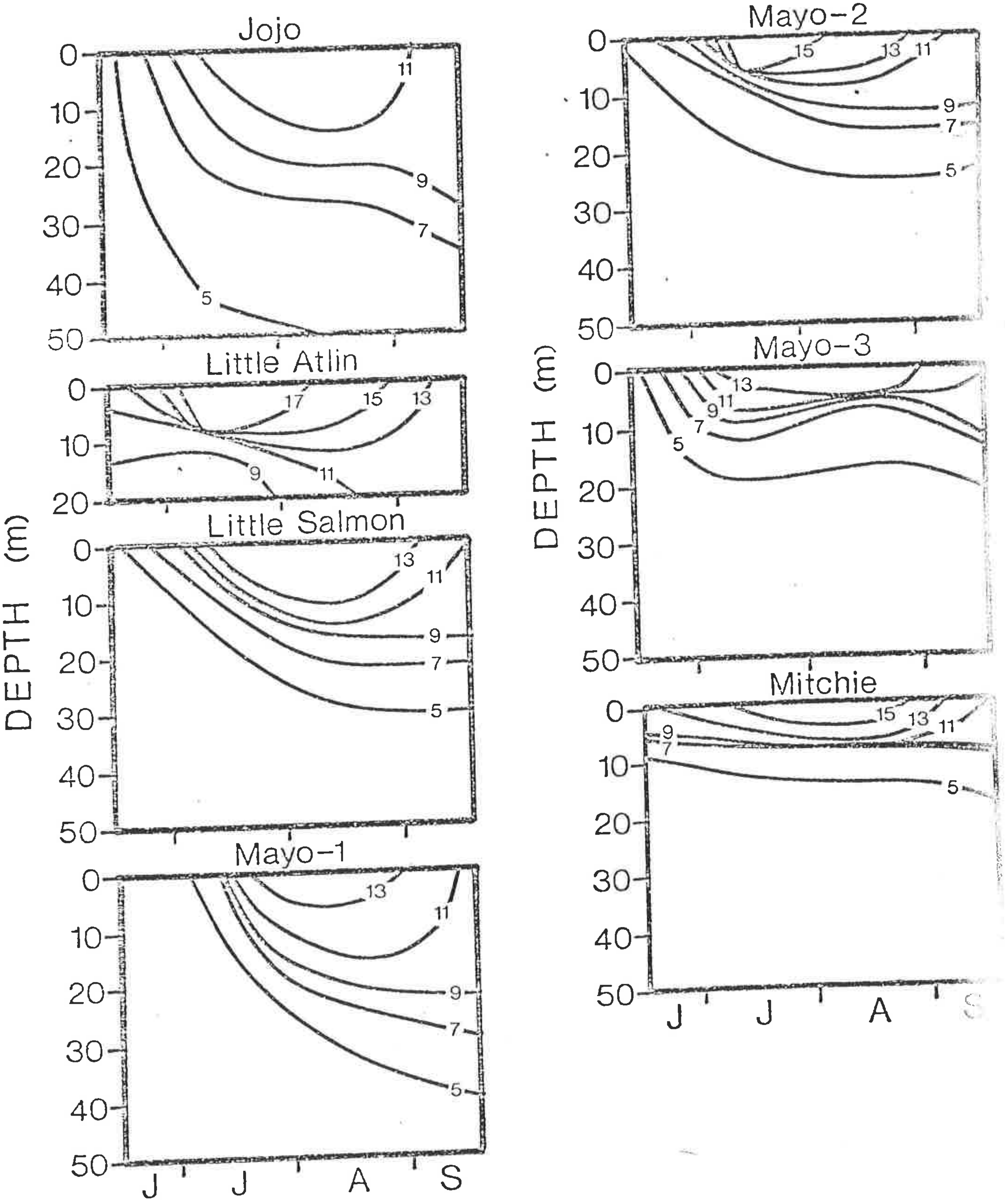
Jojo
Little Atlin
Little Salmon
Mayo-1
Mayo-2
Mayo-3
Mitchie
DEPTH (m)
DEPTH (m)
0
10
20
30
40
50
5
7
9
11
13
15
17
J
J
A
S

Fig. 2 cont'd.

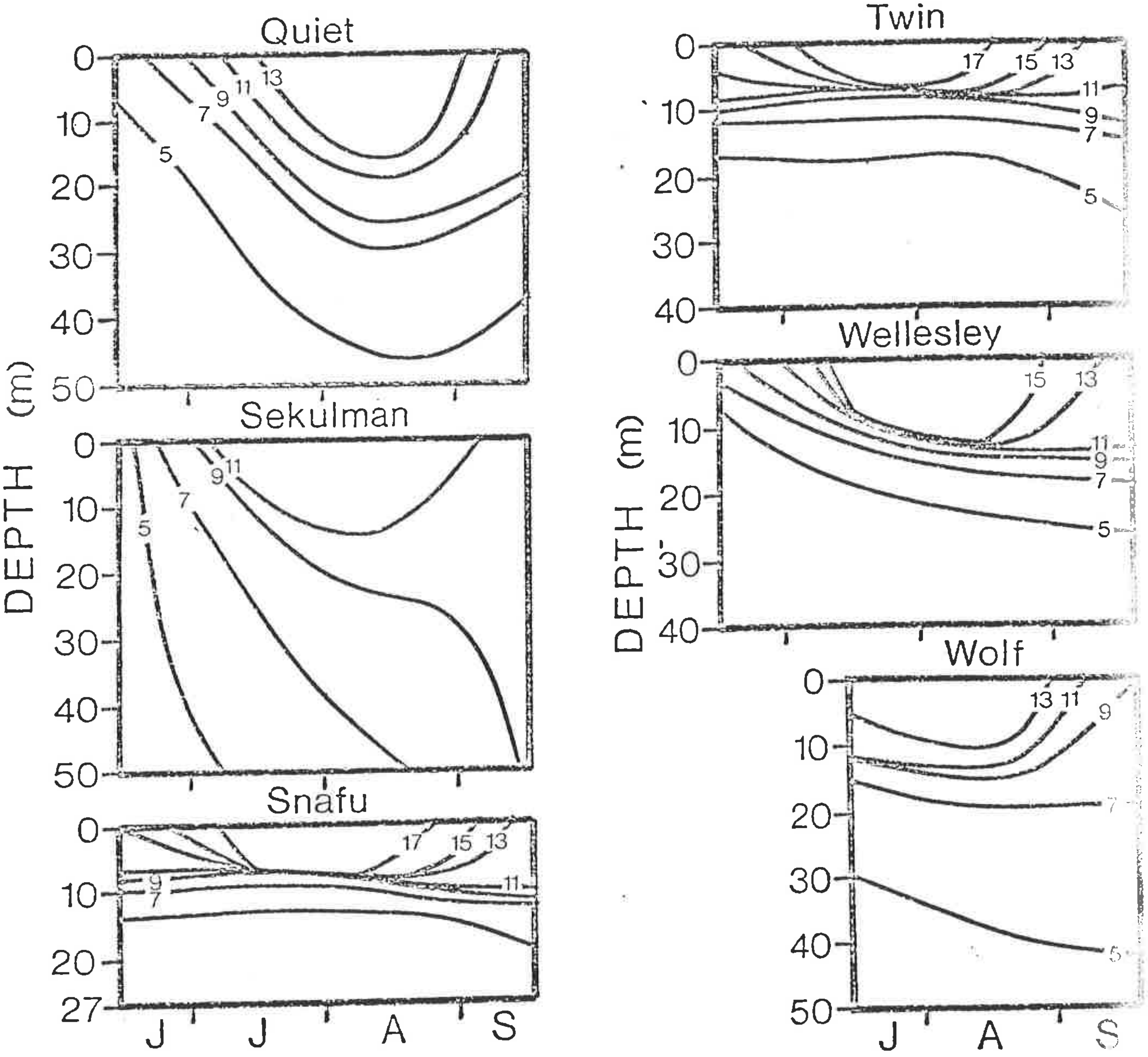
Quiet
Sekulman
Snafu
Twin
Wellesley
Wolf
DEPTH (m)
0
10
20
30
40
50
27
5
7
9
11
13
15
17
J
J
A
S

Fig. 2 cont'd.

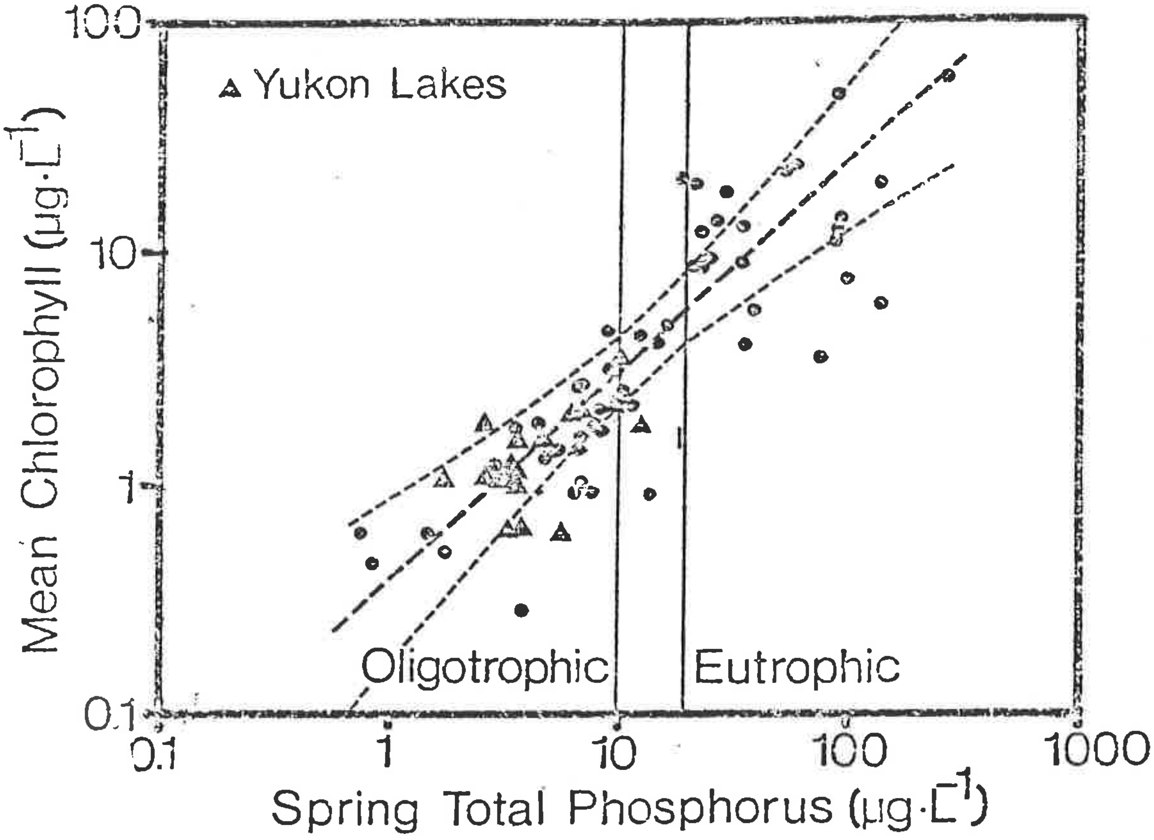

Fig. 3 Relationship of average summer chlorophyll concentration to phosphorus concentration at spring overturn for a number of North American lakes (Vollenweider 1976).

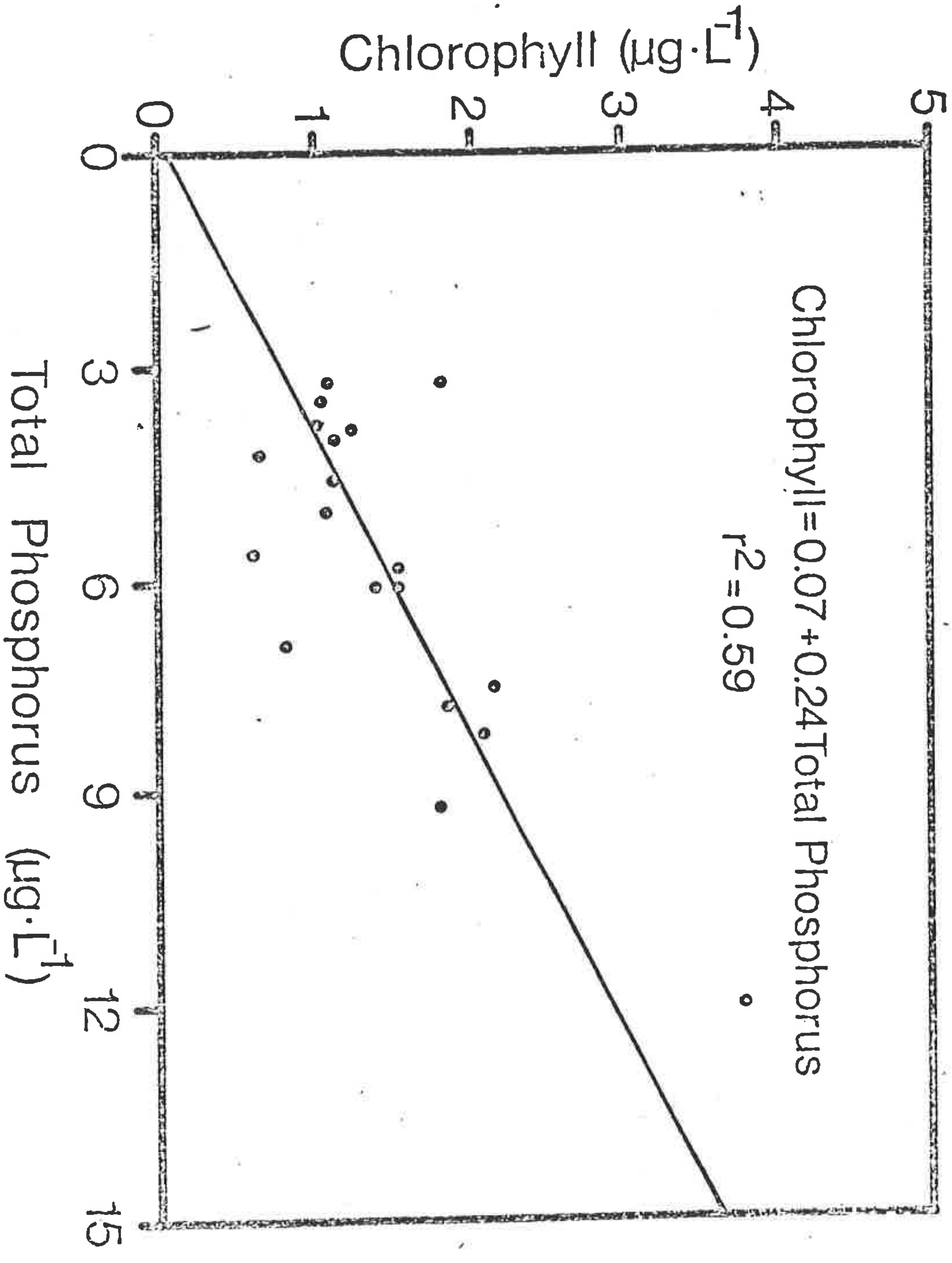

Fig. 4 Relationship of average chlorophyll concentration to average total phosphorus concentration

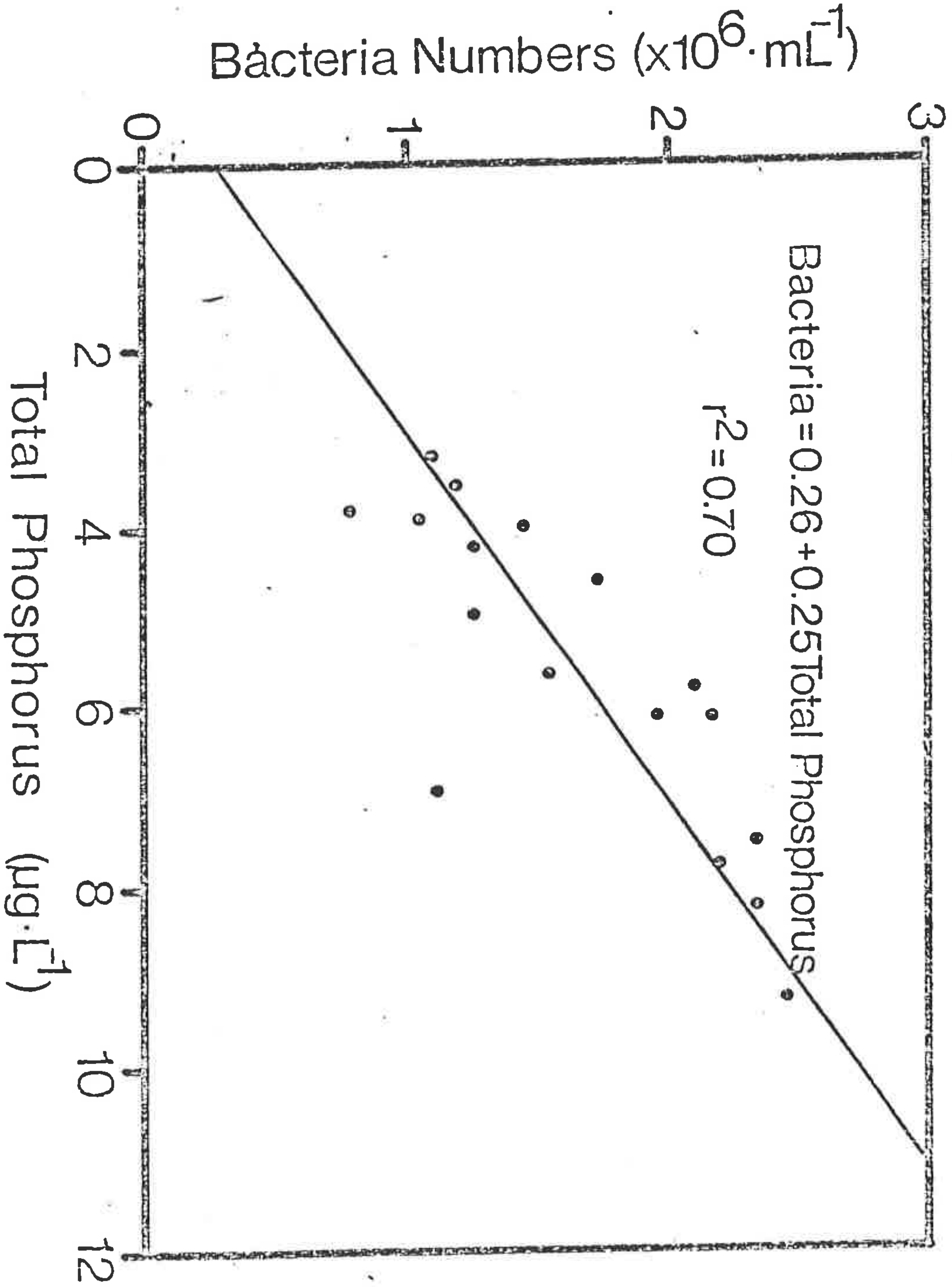

Fig. 5 Relationship of average bacteria numbers to average total phosphorus concentration

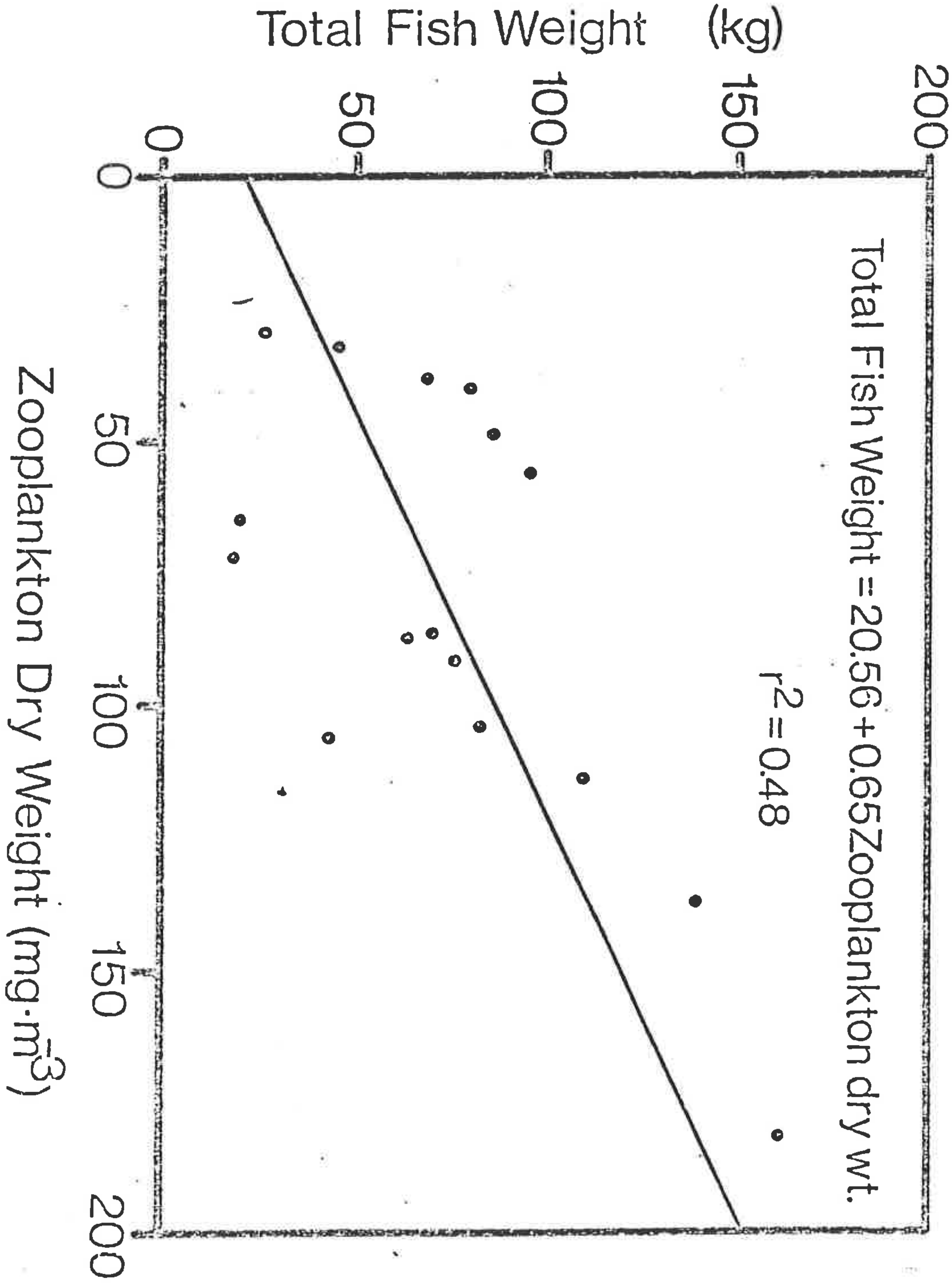

Fig. 6 Relationship of total fish weight caught in each lake to average zooplankton biomass

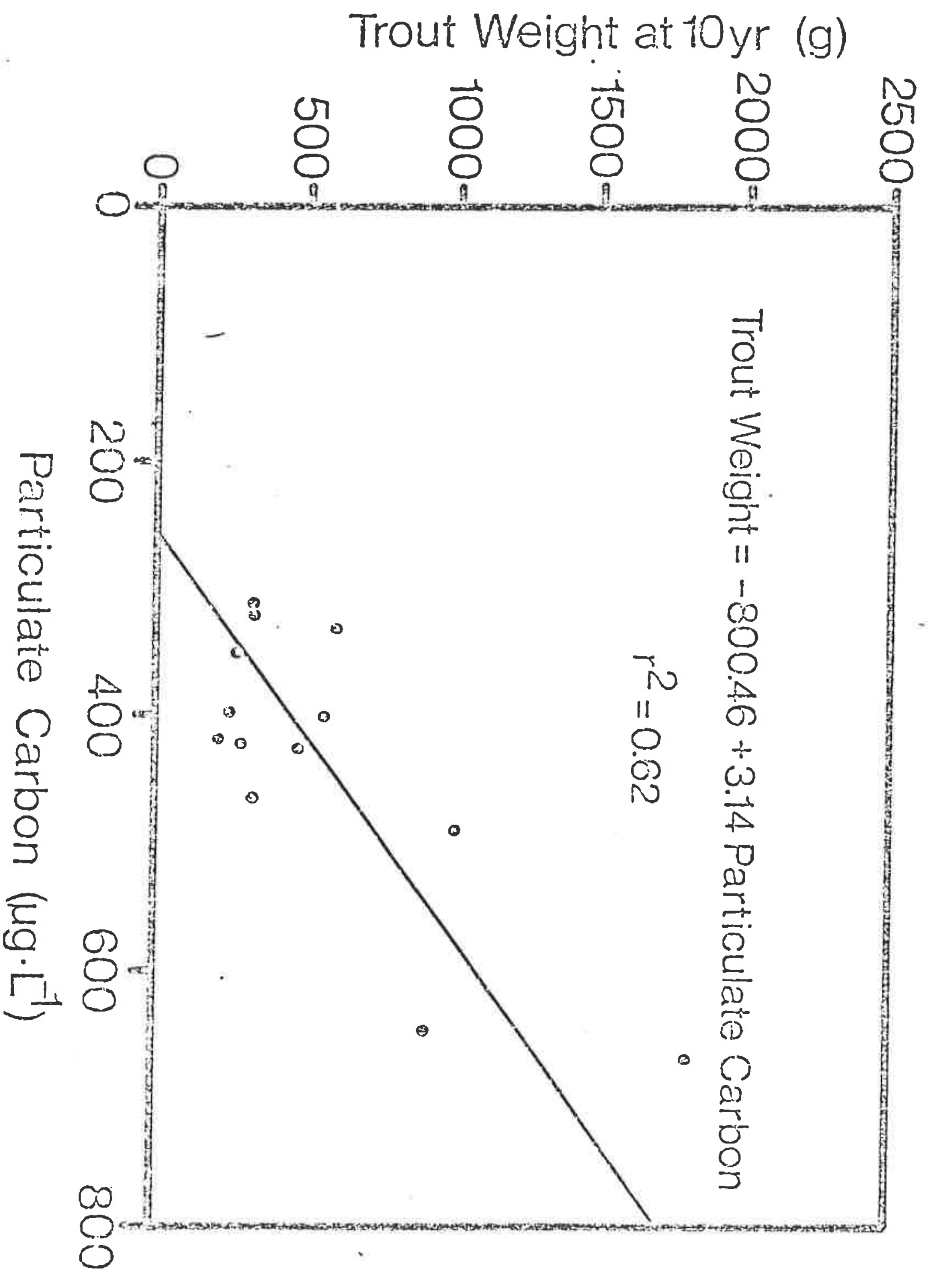

Fig. 7 Relationship of lake trout weight at 10 years to average particulate carbon concentration

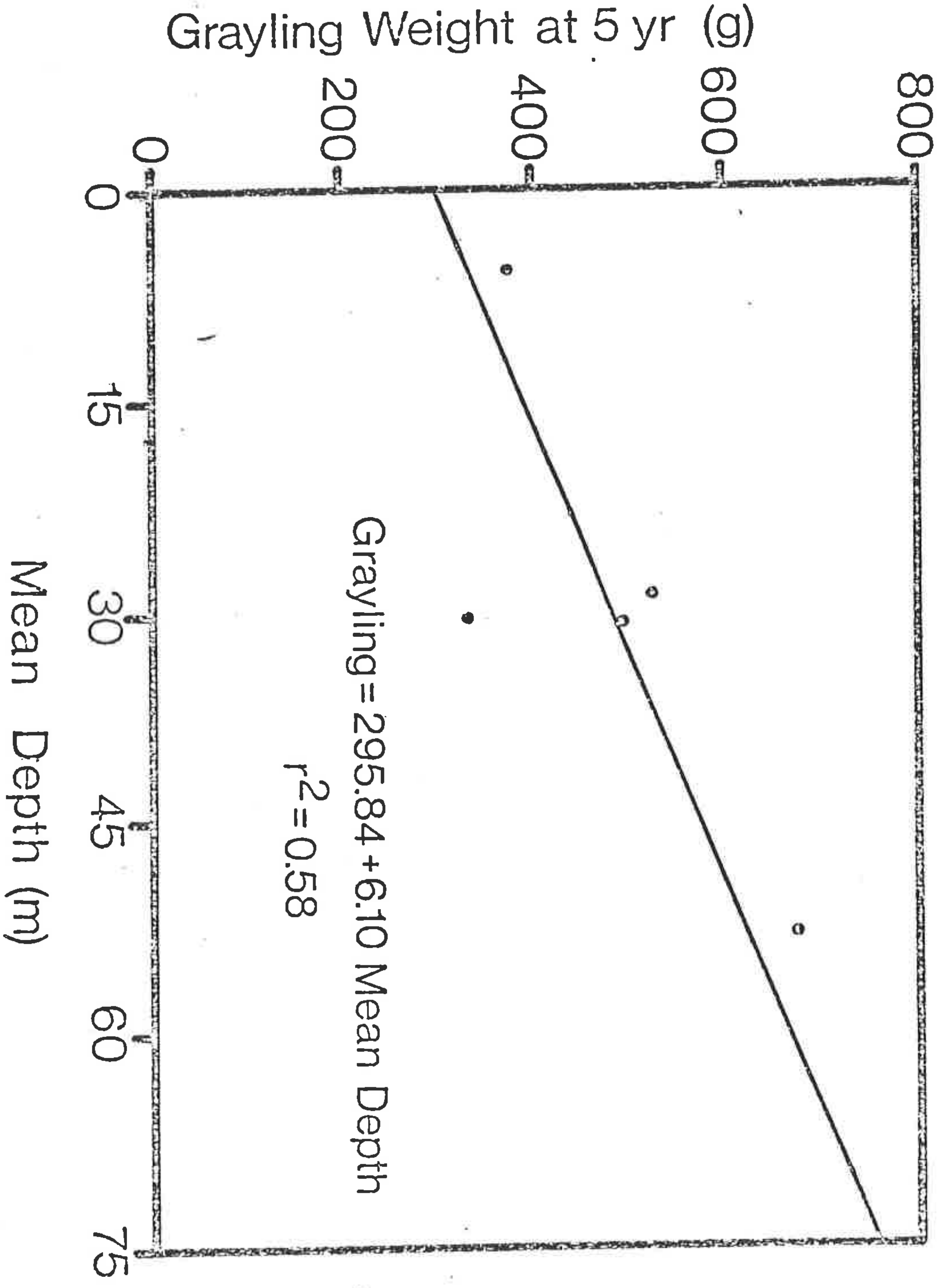

Fig. 10 Relationship of grayling weight at 5 years to mean depth (not significant)