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ALGAE PRODUCTION AND NUTRIENT ENRICHMENT IN LAKE COEUR D'ALENE, IDAHO

A Thesis

Presented in Partial Fulfillment of the Requirement for the
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ABSTRACT

In situ and *in vitro* (under controlled conditions of light and temperature) primary production rates using radioactive C-14 were measured over a 5-month period in Coeur d'Alene Lake. Distribution of phytoplankton and physicochemical parameters were assessed to distinguish broad area differences. These differences were used to aid in the explanation of variations in productivity throughout the lake.

In situ rates ranged from 0.6-6.6 $gC/m^2/day$ at an enriched open water lake station, where a diatom-dominated phytoplankton community existed.

In vitro rates ranged from 10-2250 $mgC/m^3/4$-hr incubation period and indicated that the northern area of the lake was oligotrophic and the middle and southern areas were strongly mesotrophic.

Concentrations of phosphate, nitrate, and alkalinity were likewise higher in the middle and southern portions of the lake, which supported the productivity measurements.

AUTHORIZATION TO PROCEED WITH THE FINAL DRAFT:

This thesis of Jon Irving Parker for the Master of Science degree with major in zoology and titled "Algae Production and Nutrient Enrichment in Lake Coeur d'Alene, Idaho" was reviewed in rough draft form by each Committee member as indicated by the signatures and dates given below, and permission was granted to prepare the final copy incorporating suggestions of the Committee; permission was also given to schedule the final examination upon submission of two final copies to the Graduate School Office:

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INTRODUCTION

Coeur d'Alene Lake is the second largest lake in Idaho and has been used extensively for commercial boat traffic, potable water, and recreation. However, waste from industry, agriculture, and domestic activity is being transported into the lake by surrounding drainages and possibly from shore dwellings.

Since 1885, waste from the mining industry has been carried down the South Fork of the Coeur d'Alene River into the lake. Kemmerer _et al._ (1923) observed fewer plankton in the river mouth, and Ellis (1932) found the river practically lacking in flora and fauna as compared to the lake.

Silt is being deposited in the lake by runoff from farming practices. In Cottonwood Bay alone, over 1 1/2 acre-feet of silt build-up has been measured. The bay area is 15 acres, and the maximum thickness of the deposit is 12 feet (Freckleton, per. comm.). Quantities of raw sewage have enriched areas of the lake causing the development of blue-green algal types indicative of excess nutrients. Macrophyte growth in areas of the lake support these observations.

A number of studies have dealt with the Coeur d'Alene Drainage System in relation to water quality problems (Sappington, 1969; Williams, 1969; Savage, 1970; Minter, 1971). However, there has been relatively little documented information concerning enrichment or eutrophication problems in the lake basin. To compare water quality conditions objectively, a knowledge of phytoplankton and their photosynthetic rates is quite important. Phytoplankton are the major photosynthetic agents in most parts of Lake Coeur d'Alene and supply a basic transfer of energy to heterotrophic organisms. Excess amounts of nutrients such as nitrates and phosphates would be expected to increase biomass and change composition of the phytoplankton community together with an effect on carbon uptake or photosynthesis.

In vitro tests under controlled light and temperature conditions were employed to assess carbon fixation rates at 12 stations located on a north-south gradient throughout the lake. A control station was selected in the open waters, and *in situ* productivity was measured by algal fixation of radioactive carbon-14. Phytoplankton community structure, nutrient concentrations, and other basic physicochemical parameters were examined to complete the description of each station. Least squares analysis of variance was used to evaluate the data and to test for enrichment-caused differences in carbon fixation rates.

The following objectives were established:

1. To measure *in vitro* carbon fixation by phytoplankton under controlled conditions of light and temperature and to compare these findings with primary production rates measured *in situ*.
2. To assess the distribution of phytoplankton, enriching nutrients (nitrates and phosphates), light intensity, incident solar radiation, pH, dissolved oxygen, specific conductance, carbon available for photosynthesis, and alkalinity.

Information from this investigation will be used to develop recommendations for pollution control and to serve as a base line for the evaluation of enrichment-caused changes in Coeur d'Alene Lake.

DESCRIPTION OF THE STUDY AREA

Coeur d'Alene Lake is located in Kootenai and Benewah Counties of north Idaho. The southern area is divided into Chatcolet, Benewah, and Round Lakes which are connected to the main body of water through shallow bays and the mouth of the St. Joe River. The St. Joe and Coeur d'Alene Rivers are the main inlets to the lake. The elevation of Coeur d'Alene Lake is 645 m above sea level and is maintained by the Post Falls Dam on the Spokane River which is the outlet for the lake. The lake is 38.6 km long with an average width of 3.13 km and an area of 120 km^2. The shore length is 213 km with a shore line index of 5.5 (Reid, 1961). Maximum depth was recorded by Kemmerer *et al.* in 1923 at 56 m.

Coeur d'Alene Lake is generally classified as oligotrophic with a tendency toward mesotrophy in some areas (Minter, 1971). Rich algae populations support the development of microcrustaceans, *Oncorhynchus nerka*, *Salmo clarki*, *Salmo gairdneri*, *Perca fluviatilis flavescens*, and *Micropterus salmonides*. A more comprehensive description of the lake and surrounding area has been prepared by Minter (1971) and by Williams (1969).

STATION SELECTION AND SAMPLING SCHEDULE

Twelve stations (see map Fig. 1) were selected along a north-south axis to include bays and open water. The bay stations were located in both developed and undeveloped sites. Sampling stations were located in water greater than 4 m to insure that phytoplankton development was not inhibited by macrophyte communities. Stations were selected to prevent topographic features from obstructing sunlight for any appreciable part of the day.

The sampling period consisted of two consecutive days each month from July to November, 1971.

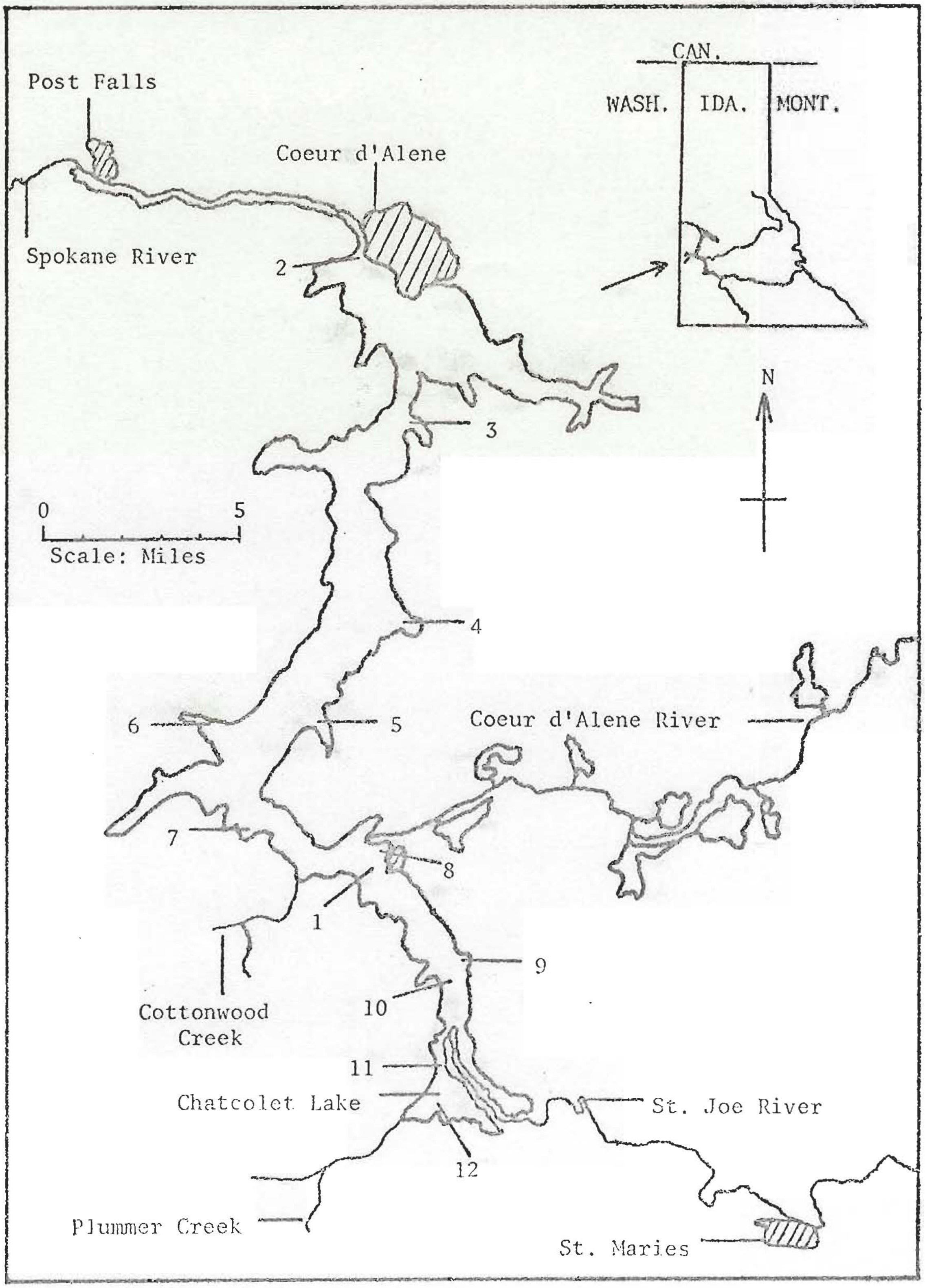

Fig. 1.--Coeur d'Alene Lake and station locations.

MATERIALS AND METHODS

Ten physicochemical parameters were measured at 12 stations from July-November, 1971. Water temperature was measured with an Applied Research Associates Electronic Thermometer and recorded as degrees Centigrade. Transparency was measured with a standard Secchi Disc. Depth-light intensity profiles were calculated from foot-candle measurements recorded at half-meter intervals from the surface to the bottom with a submarine photometer. Incident solar radiation was measured with a Belfort pyrheliograph. Graphs were integrated by planimetry to find a conversion factor to calculate daily production rates (Vollenweider, 1969).

Measurements of specific conductance and dissolved oxygen concentrations were made with electronic instruments (Sol Bridge and YSI D.O. meter). A Hellige Pocket Comparitor was used for estimating pH. Alkalinity was measured according to techniques described in Standard Methods (1971) and expressed as milligrams per liter. The Brucine technique was used for nitrates and reported as milligrams per liter nitrate-nitrogen and milligrams per liter nitrates. Phosphates were measured with the ascorbic acid technique and reported as milligrams per liter phosphate-phosphorus and milligrams per liter phosphates (Standard Methods, 1971). Inorganic carbon available for phososynthesis was determined using a nomographic technique described by Bachmann (1961).

Phytoplankton community structure was evaluated in a 500-ml aliquot of mixed test water from the top 4 m at each station. Each sample was centrifuged, and a 1-ml subsample of the concentrate was pipetted into a Sedgwick-Rafter Cell for counting and identification of the algal genera. Counts were expressed as cells per milliliter. Standard five-cell lengths per milliliter of filamentous algal forms were counted as 1 unit/ml.

In situ carbon-14 phytoplankton production measurements were made at station 1, which is located half way between Spokane Point and the town of Harrison, Idaho. Water was collected with a Van Dorn type sampler on a hand-operated winch. Samples were transported in refrigerated light-proof containers similar to those described by Goldman (1960).

Replicated light and dark bottles were filled with water from depths of 0.5, 1.0, 2.0, 3.0, 5.0, 7.0, 9.0, and 12.0 m. Each bottle was injected with 1 ml of a standardized 3-5 microcurie/ml solution of sodium bicarbonate labeled with C-14 and suspended at the selected depths from buoys.

Bottles were incubated for 4 hrs from 10:00 a.m. to 2:00 p.m. and then retrieved and transported to the shore station where a 200-ml aliquot from each bottle was filtered on Millipore HA 45-μ 47-mm plain white filters. Vacuum was provided by the intake manifold of an automobile engine as described by Bugbee (1967). The wet filters were placed in glass scintillation vials and desiccated over indicator silica gel for 3 days or until they became transparent when placed in toluene. After drying, a toluene-based fluor solution was added to each vial. Counting was done with a Packard Liquid Scintillation Spectrometer with a preset count of 50,000 counts/min. Time elapsed to collect these counts was used to calculate total counts/min with less than 1% error in counting (Nuclear-Chicago, 1966). Corrections were made for machine efficiency and background radiation. Procedures outlined by Lind and Campbell

(1969) were used for quench corrections. Carbon fixation (mgC/m^3) was calculated as described in Standard Methods (1971). Aerial production estimates were calculated and corrected to whole day production rates using the methods described by Vollenweider (1969).

On the second day of sampling, water was collected from each of the 12 stations for the experimental assessment of carbon fixation, measured under controlled conditions in a culturing tank. A mixed haul of water from the first 4 m at each station was used to fill replicate light and dark bottles and transported to the laboratory.

After injection with the same standardized C-14 solution as used *in situ*, the bottles were incubated in a 300-gallon tank at 400 ft-c of light and 18 C ± 1 C for 4 hrs. The bottles were placed on a submerged Plexiglass bottle rack. They were held securely in position by a woven divider of Tygon tubing, with mesh size slightly smaller than the diameter of the light and dark bottles. During incubation, a 30 rpm reduction gear motor was connected to this cam-operated 96-bottle shaker rack. The shaker was controlled on a 10-min on-off cycle by a timer switch. The purpose of this procedure was to insure thorough mixing of the sample with the C-14 solution and to prevent settling of the algae community. After 4 hrs, a 200-ml aliquot from each bottle was filtered, prepared, counted, and corrected as described earlier. Carbon fixation data are presented as mgC/m^3/4-hr incubation period. All values were corrected for dark bottle activity, machine efficiency, background, and quench. The information on carbon fixation rates will be used to compare the 12 stations.

RESULTS

Physical Parameters

Temperature measurements were made at 1-m depths during the middle of the day. Maximum readings of 23 C occurred in August, and minimum readings of 6 C were observed in November. There was only a 1-2 C degree difference between stations on any specific date. Temperature-depth profiles were recorded at station 1. Stratification was observed until mid-October when overturn took place, producing homothermous conditions.

Standard Secchi Disc transparency ranged from 2-4.5 m. The maximum reading of 4.5 m was recorded at station 1 in August, and a minimum of 2 m was recorded at station 12 in November. Photometer readings of light intensity were measured at station 1 and used to calculate foot-candles of intensity at the various depths. Surface radiation was reduced to 1% at approximately 10 m; this depth closely approximated the depth of the euphotic zone where light bottle carbon fixation equaled dark bottle fixation. Incident solar radiation ranged from 66-528 cal/cm^2/day, and the maximum was measured in August.

Chemical Parameters

The mean and range of selected chemical parameters for each station from July-November, 1971, are presented in Table 1. Specific conductance ranged from less than 50-100 micromhos throughout the lake. Highest readings were recorded at station 8 which is close to the mouth of the Coeur d'Alene River. Williams (1969) reports similar results, with no

TABLE 1.--Mean and range of specific conductance, dissolved oxygen, available carbon, and range of pH for each station (July-November, 1971).

Station	Specific Conductance (Micromhos)	Dissolved Oxygen (mg/1)	Available Carbon (mg/1)	pH
1	50 (<50- 75)	7.5 (4 -10)	8.2 (7.3- 9)	(6.8-7.4)
2	50 (<50- 75)	7.5 (6 - 9)	7.0 (6 - 8.4)	(6.7-7.5)
3	50 (<50- 75)	8.0 (6.5- 9)	6.6 (5.9- 7.4)	(6.9-7.7)
4	50 (<50- 75)	8.0 (6.5-10)	7.2 (6.2- 8.4)	(6.9-7.5)
5	55 (<50- 95)	8.0 (6.5-10)	7.2 (6.2- 8)	(6.9-7.4)
6	60 (<50-100)	7.5 (4 -10)	7.6 (6.1- 9.3)	(6.9-7.5)
7	60 (<50-100)	8.0 (6.5-10)	6.8 (6 - 7.5)	(7.0-7.5)
8	65 (<50-100)	7.0 (4 - 9)	7.8 (6.7- 8.7)	(7.0-7.7)
9	55 (<50- 75)	8.0 (5 -10)	8.8 (8.2- 9.9)	(6.8-7.8)
10	55 (<50- 75)	8.5 (4 -10)	8.8 (7 - 9.3)	(6.9-7.5)
11	60 (<50- 95)	8.0 (4 - 9)	9.3 (7.5-10)	(6.8-7.8)
12	60 (<50-100)	7.5 (5.5- 9)	9.0 (6.7-10)	(6.8-7.9)

open water values in excess of 75 micromhos. Dissolved oxygen ranged from 4-10 mg/l in the upper layers of water examined. However, in July, Minter (1971) recorded a value of less than 1 mg/l at station 1 in 12 m of water, indicating that oxygen depletion can occur. Hydrogen ion concentration was estimated, and the observed range of pH was 6.7-7.9. Maximum values were recorded in August in the shallower southern end of the lake. Minimum values were obtained in the most northern portions of the lake. Inorganic carbon available for photosynthesis was determined from pH, temperature, and alkalinity data. The observed range for available carbon was 5.8-10.0 mg/l.

Station averages of methyl orange alkalinity, phosphate-phosphorus, and nitrate-nitrogen for the period July-November, 1971, are presented in Fig. 2. Alkalinity ranged from 21-35 mg/l with maximum concentrations occurring in the southernmost reaches of the lake. Nitrate-nitrogen ranged from 0.003-0.13 mg/l. Maximum values were measured at the southern lake stations during September with a rapid decline and leveling-off in October and November. Phosphate-phosphorus ranged from 0.002-0.363 mg/l with maximum levels occurring in August at stations 10, 11, and 12, in the southernmost portions of the lake.

Community Structure

Numerically the most abundant organisms were the yellow-green algae (Division--Chrysophycophyta), which comprised 80% of all samples. The true diatoms made up 65% of the total community and ranged from 8-1154 cells/ml. The maximum numbers were reached at station 10 in November where *Melosira* was dominant. The six most numerous genera of diatoms counted are presented in Table 2. Other Chrysophycophyta frequently observed were *Tribonema* and *Dinobryon*. They comprised 15% of all cells counted and ranged from 0-284 cells/ml.

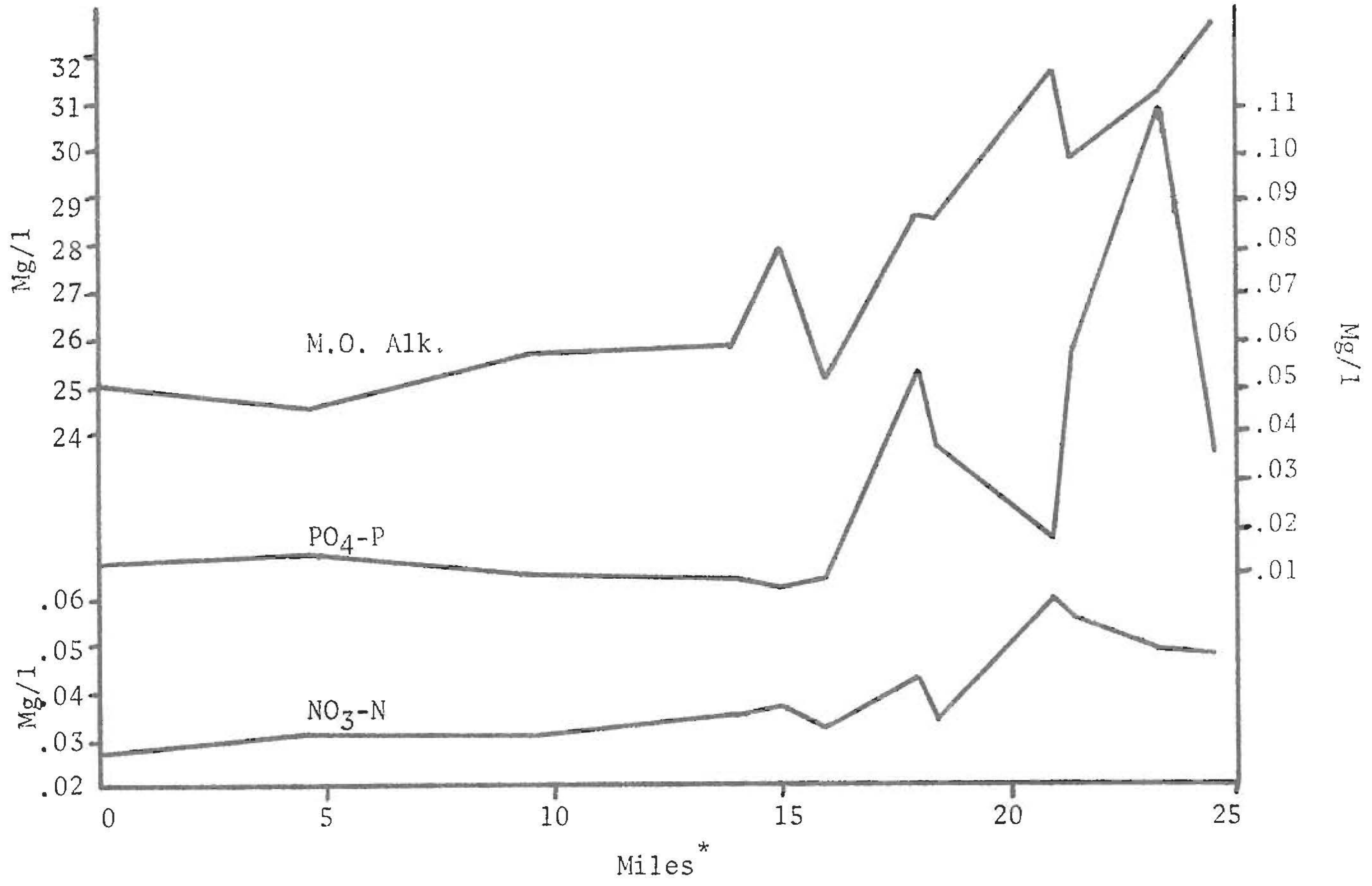

Fig. 2.--Station means of methyl orange alkalinity, PO_4-P, and NO_3-N. July-November, 1971. *Distance measured from north end of Coeur d'Alene Lake.

TABLE 2.--Abundance of diatom genera expressed as percentage occurrence (July-November, 1971).

Genus	Percentage
Melosira	42
Tabellaria	33
Asterionella	13
Navicula	4.6
Fragilaria	2.9
Synedra	2.1
Others (12 genera)	2.4

Least squares analysis of variance was used to test for differences in distribution of diatoms. Cells per milliliter were transformed with $\log_{10}$ to provide a normal distribution of the data. F-tests were used to test the null hypothesis that diatoms were distributed evenly among stations and sampling dates. Sampling dates were found to be significantly different at the 1% probability level. Tukey's mean separation procedures (Mendenhall, 1968) revealed that diatom counts in August were significantly lower and diatom concentrations were significantly higher in November. Minter (1971) found in sampling the lake over the entire year that diatom counts were highest in December. My sampling in the lake ceased in November. Although variations in counts among individual stations were not found significant, differences were observed when groups of stations were considered. The northern- and southernmost group of stations had lower diatom concentrations, but the group of stations in the middle portion of the lake had higher concentrations. These group differences are illustrated in Fig. 3.

Green algae (Division--Chlorophycophyta) made up 10% of all samples collected. Open water genera were the non-filamentous varieties and included *Phacotus*, *Chlamydomonas*, *Ankistodesmus*, *Genicullaria*, *Chlorella*, and assorted desmids. Many filamentous varieties were observed as periphyton in the littoral zone, including *Spirogyra*, *Zygnema*, *Ulothrix*, *Oedogonium*, and *Mougeotia*. Mean and standard error of planktonic green algae cells per milliliter are presented in Fig. 4, which illustrates variations for each station. Most genera slowly disappeared during colder water conditions in November. An October maximum showed a total of 256 cells/ml. Extremely low concentrations of green algae were observed during August at most stations. The community at this time was dominated by blue-green algae.

Blue-green algae (Division--Cyanophycophyta) made up 10% of all cells collected. Planktonic blue-greens included *Aphanizomenon* with rare occurrences of *Nostoc* and *Anabaena*. Minter (1971), in addition, observed *Oscillatoria* in vertical hauls from station 1. A maximum concentration of 488 standard units/ml of *Aphanizomenon flos-aquae* occurred in August at station 7. Other blue-green algae included *Oscillatoria* and *Plectonema* observed as periphyton in the littoral zone throughout the lake. The percentage of blue-green algae in the community for each station from July-November, 1971, is shown in Table 3. Blue-green algae dominated the community at most stations during August when water temperatures were highest. No blue-green algae were observed during October.

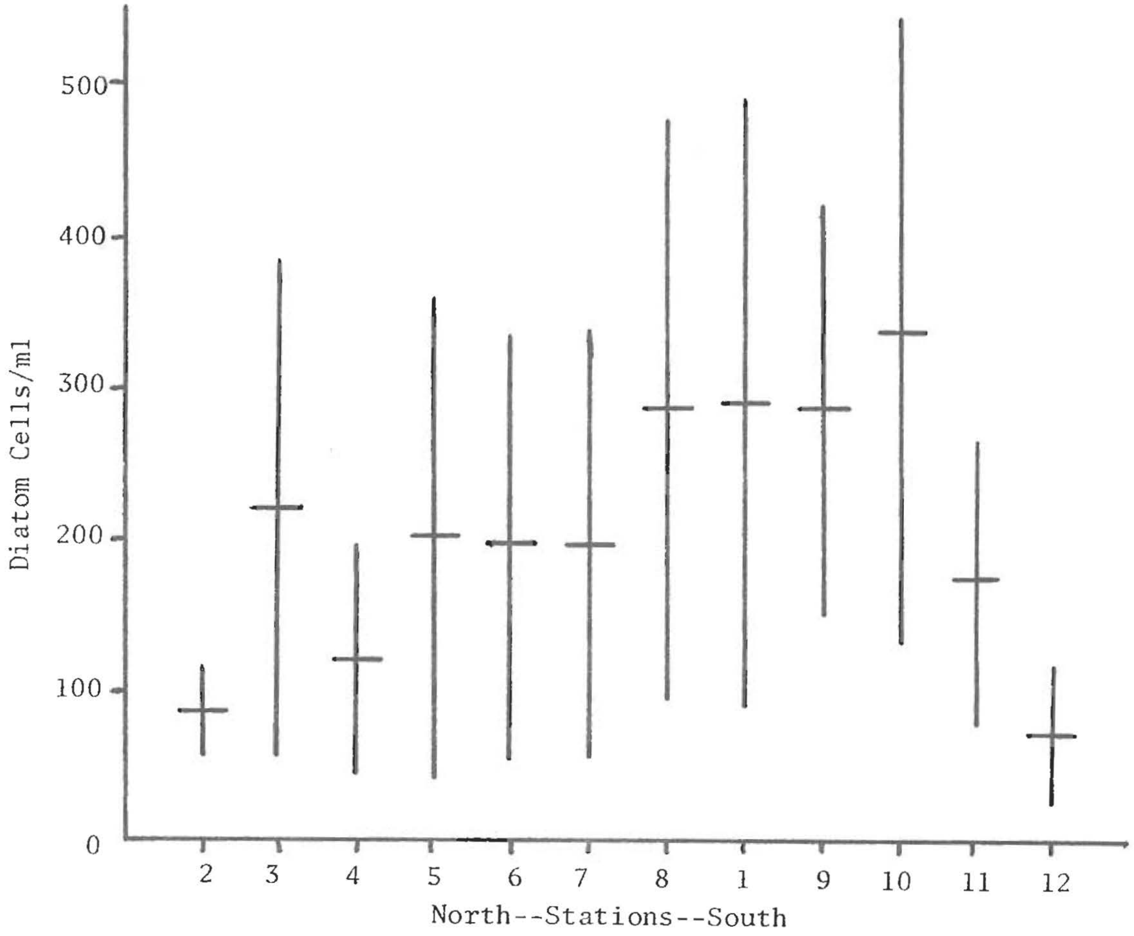

Fig. 3.--Mean and standard error of diatom cells/ml for each station. Shown on a north-south gradient. July-November, 1971.

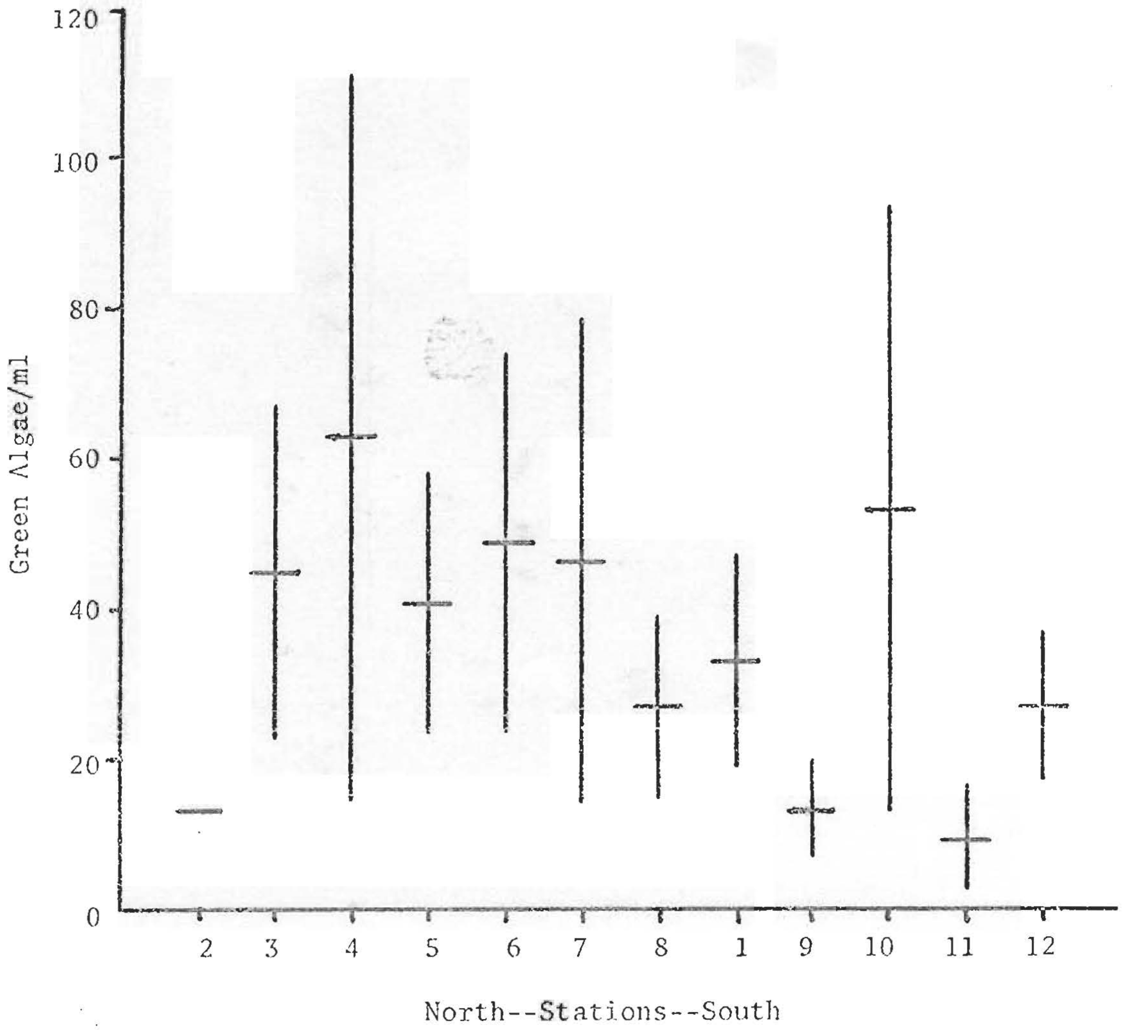

Fig. 4.--Mean and standard error of green algae cells/ml for each station. Shown on a north-south gradient. July-November, 1971.

TABLE 3.--Percentage of blue-green algae distributed among lake stations (July-November, 1971).

Station	Percentage				
	July	Aug.	Sept.	Oct.	Nov.
1	5	47	0	0	0
2	10	87	0	0	0
3	6	50	0	0	0
4	0	13	0	0	0
5	9	96	5	0	0
6	12	89	0	0	0
7	3	99	0	0	0
8	0	97	0	0	0
9	2	25	0	0	0
10	0	6	0	0	0
11	43	0	0	0	0
12	0	0	0	0	0

Primary Production

Primary production measurements were made *in situ* on samples of natural lake communities from station 1. These values provided an estimate of production rates for the open waters of the lake. They are also used as a basis for validating *in vitro* estimates of carbon fixation obtained under controlled conditions of light and temperature.

In situ primary production rates were measured at station 1 during the sample period, July-November, 1971. Calculations of daily rates per unit of lake surface were made, and the resulting range was 0.6-6.6 $gC/m^2/day$. Other examinations at this station revealed that carbon available for photosynthesis was not limiting, the euphotic zone extended downward to 12 m, and the maximum phytoplankton density yielded the maximum production. Maximum *in situ* production occurred in November when total diatom concentrations were measured at 1100 cells/ml.

Seasonal variations in production measured *in situ* were observed, and seasonal changes in the phytoplankton community structure account for some of this variability. A mixed community of diatoms and green algae were present in July, whereas blue-green algae were predominant in August. Dwindling populations of summer diatoms and green algae account for the September-October lows in production. These forms were replaced by a community of fall diatoms which were responsible for peak production in November. Seasonal differences in production and community structure are listed in Table 4.

A depth profile of production at station 1 for August 19, 1971, represents the type of vertical production distribution found in Lake Coeur d'Alene (Fig. 5). A distinct reduction in production at the surface is followed by a maximum occurring within the top 3 m of lake water.

TABLE 4.--Aerial primary production rate and community structure for station 1. July-November, 1971.

Month	$mgC/m^2/day$	Community Structure
July	3744	Green algae and diatoms
Aug.	2793	Blue-green algae
Sept.	607	Few diatoms
Oct.	811	Few diatoms
Nov.	6610	Very abundant diatoms

Production rapidly declines through the lower reaches of the euphotic zone, and the compensation point is reached at about 10-12 m where light intensity is 1% of the surface value. Vollenweider (1969) reports similar findings concerning light intensity and the compensation point. Findenegg (1964) describes this distribution as a Type I curve. He suggests that production is inhibited by excess light at the surface. The depth profile production maximum for the study was 1.14 gC/m^3/4-hr incubation period. The highest values occurred within the top 3 m of water where light intensity ranged from 125-750 ft-c with an average of 400 ft-c.

In vitro experiments were used to test for station variability in production. Results are expressed as counts per minute and mgC/m^3/4-hr incubation period. Counts per minute were used for all statistical analyses. First four moments analysis indicated that $\log_{10}$ transformations would yield a normal distribution. The initial step in this analysis required a close correspondence between carbon fixation rates measured *in situ* and *in vitro*, obtained under similar conditions of light and

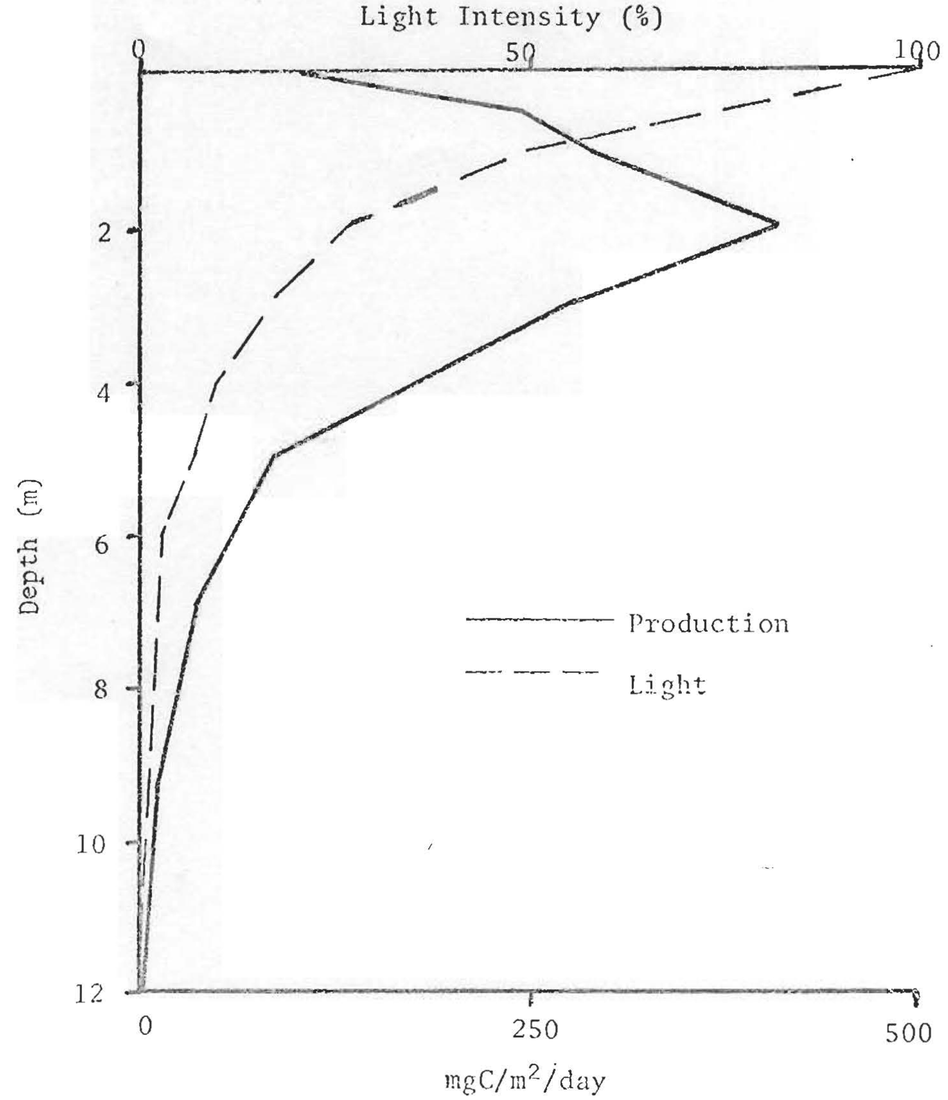

Fig. 5.--Primary production and light attenuation-depth profile. Station 1 on August 19, 1971.

temperature. Counts per minute and the respective physical conditions used to select the in situ values are shown in Table 5 for both techniques. Since the results show close agreement, further statistical analysis of carbon fixation was performed.

Analysis of variance was used to test the null hypotheses that all stations and sampling date effects on carbon fixation measured under controlled conditions were alike. F-tests at the 5% level of significance indicated that both independent variables were significantly different. Tukey's mean separation procedures showed station 11 to be significantly lower in carbon fixation than all others, and station 1 and 10 were higher than all other stations. The production estimates obtained by culturing water samples from each station and for each sampling date were used to calculate monthly and station averages which are presented in Table 6.

Selected chemical parameters and diatoms per milliliter were also tested in the same manner. F-tests at the 5% level of significance indicated that a significant quantity of the variation in carbon fixation was accounted for by concentrations of phosphate-phosphorus and numbers of diatom cells per milliliter. The relation between diatoms and carbon fixation is illustrated in Fig. 6.

TABLE 5.--Comparison of *in situ* and *in vitro* counts per minute from station I. July-November, 1971.

Date	*In Situ* CPM	*In Vitro*[a] CPM	*In Situ* Depth[b] (m)	*In Situ* Temp.[b] (°C)	*In Situ* Ft-cd[b]
July	22,700	17,300	2	21	450
Aug.	36,820	33,375	2	21	331
Sept.	7,560	7,050	2	16	270
Oct.	9,560	10,740	2	10	250
Nov.	90,100	120,920	Surface	7	200

[a] *In vitro*: Temp. = 18 C ± 1 C; 400 ft-cd.

[b] Physical parameters used to select *in situ* values.

TABLE 6.--Carbon fixation measured *in vitro* at all lake stations. July-November, 1971. Expressed as mgC/m^3/4-hr incubation period.

Station	Carbon Fixation (mgC/m^3/4-hr incubation period)					
	July	Aug.	Sept.	Oct.	Nov.	Avg.
1	150	435	73	114	1956	546
2	119	166	18	40	1880	445
3	73	205	20	48	1845	438
4	85	206	22	96	1292	340
5	48	215	28	98	1763	430
6	245	234	17	51	2249	559
7	122	259	25	108	1994	502
8	169	360	78	69	1642	464
9	136	612	68	83	1146	409
10	168	699	109	215	1378	514
11	10	45	59	106	610	166
12	49	44	68	227	907	259
Avg.	115	290	49	105	1555	

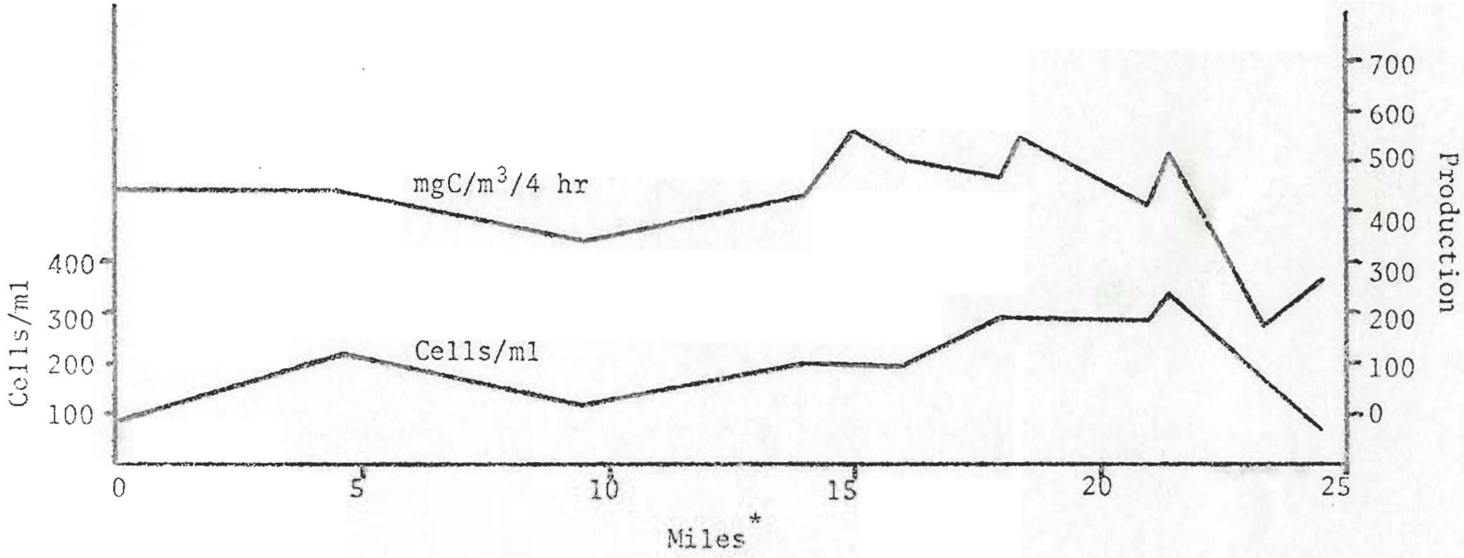

Fig. 6.--Mean of carbon fixation and diatom concentrations for each station. July-November, 1971. *Miles measured from north end of lake.

DISCUSSION

Greater station-to-station variability in the parameters examined was expected in the southern areas of the lake due to the complexity of habitat types and more productive appearance of this water. Therefore, more sampling stations were concentrated in this area. Uniformity of the water quality in the northern section of the lake required fewer stations at greater distances apart. Sampling in this manner revealed important variations in the entire lake among the specific parameters examined.

Temperature throughout the lake was quite uniform for the deep water stations. However, the shallower waters in the southern end of the lake appeared to warm earlier in the year. Under controlled temperature conditions, Patrick (1971) demonstrated a shift from diatom populations to blue-green algal forms by raising the water temperature. The same type of shift appeared during July in the southern end of Coeur d'Alene Lake but did not occur until August in the northern portions of the lake. Perhaps this shift provides some evidence of early warming in this area.

At no time during the study period did transparency severely limit production. The southern end of the lake, however, did exhibit lower transparency values and frequently appeared to be more turbid than the northern portions of Coeur d'Alene Lake. Runoff from streams caused extremely turbid conditions in Chatcolet Lake during high flow late in February. The dependence of production on light penetration during this study can be seen in the curve presented in Fig. 5.

Total alkalinity was due to the bicarbonates since no phenolphthalein alkalinity was observed. Alkalinity was considered low in comparison to other bodies of water where carbonate materials in the soil and rock are higher than in the Coeur d'Alene Drainage System (Anderson, 1940). There is a trend of increasing alkalinity from the north toward the southern end of the lake. High standard errors of alkalinity for these southern stations indicate either that inputs into the area are not constant or that biological activity effectively alters the concentrations (Ruttner, 1952).

Hydrogen ion concentration was observed to fluctuate seasonally. Highest values of pH were recorded where green algae and macrophyte development were at their maximum. This generally occurred in the southernmost reaches of the lake. Ruttner (1952) describes such an increase in pH as a result of photosynthetic uptake of available carbon ions by both algae and macrophytes. This effectively reduces the carbonic acid concentrations in the water. However, uptake of carbon was never great enough to limit available forms of carbon for photosynthesis.

Evidence to support the correlation between phytoplankton production and available dissolved nitrate and phosphate content of the water has been offered by Sawyer (1947, 1966) and Ketchum _et al_. (1958). It is important to observe the nitrate and phosphate data in relation to general averages of these two nutrients for unpolluted fresh water systems. Reid (1961) lists world averages of nitrates for fresh water as 0.30 mg/l and 0.01-0.03 mg/l phosphate for most lakes. The overall averages for Coeur d'Alene Lake were 0.177 mg/l nitrates and 0.01 mg/l phosphate, which are slightly lower than those presented above. However, averages calculated for the southern portions of the lake system were 0.21 mg/l nitrates and 0.51 mg/l phosphates, which are much higher values than the lake averages. Phosphates were approximately 2-5 times greater than the range given by Reid for most lakes. The shallower depths and smaller volume of this southern area allow more rapid turnover of the phosphates as compared to the deeper large volume of water in the northern sections (Odum, 1971). In the northern portions of the lake, phosphate turnover is apparently slower, and therefore this area possibly acts as a semi-permanent sink for available dissolved phosphate in the water.

There are a number of probably causes for this nutrient-rich southern portion of the lake. The west shore of the area has a substantial development of lake-side cottages and resorts. There is some speculation that sewage from this development is seeping into the lake because of the shallow soil and the rocky nature of the shore. However, this was not substantiated by Williams (1969), who concluded that dwellings or boating facilities contributed non-significant amounts of chlorides, phosphates, or total dissolved solids to the bay waters. He did find, though, that ground water discharge from basalt and gneiss rocks contributed phosphates to the bay areas.

A second source is boats which flush sewage into the lake, since only one pumping station for discharge of boat wastes presently exists on Coeur d'Alene Lake. Another possibility is surface runoff, since the southern end of the lake receives water from two large drainages and eight smaller streams. The communities of Wallace and Kellogg on the South Fork of the Coeur d'Alene River, Calder on the St. Joe River, and Harrison on the lake shore have inadequate sewage treatment facilities (Idaho State Health Dept.). Williams (1969) lists the Coeur d'Alene River as a source of phosphate and dissolved solids into the lake.

Nutrients from agricultural practices apparently provide a substantial input to runoff in the above drainages. Farming is most extensive in the watershed areas bounding the southernmost part of the lake drainage. Here, 30-50 lbs/acre of nitrogen fertilizers are applied to the grain fields (Judd, per. comm.). Most of the fertilizer is applied here in the spring after runoff. Winter fallow methods are still employed in some areas. Musgrave (1954) lists this farming procedure as having the highest relative erosion rate in comparison to other methods of farming used in the Pacific Northwest. The possibility strongly exists that nitrate residuals and phosphates adherent to soil particles are carried into the lake by surface runoff. Larson and Larson (1968) have shown a direct correlation between the use of industrially fixed nitrogen fertilizers and nitrate concentrations in surrounding natural waters. Measurements of nitrates and phosphates were made in February-March, 1972, on selected streams that drain agricultural land into the southern portions of Coeur d'Alene Lake. Values were high, ranging from 0.44-3.82 mg/l nitrates and 0.2-1.22 mg/l phosphates.

Shallow areas in the southern end of Coeur d'Alene Lake are quite extensive and provide less dilution for nutrients. A combination of deep light penetration and silted substrate conditions provides a very suitable habitat for the growth of algae and rooted aquatic plants. Dense communities of Potamogeton, Meriophyllum, and Anacharis grow annually in the shallow areas (less than 4 m) of Chatcolet, Round, and Benewah Lakes. The lowest concentrations of planktonic algae were observed within this area. Kofoid (1903), Pond (1905), and Hasler and Jones (1949) have suggested that macrophytes either compete better for nutrients than phytoplankton or that some antagonistic mechanism or extrametabolic substance (Odum, 1971) tends to limit phytoplankton development in the water surrounding these plants.

As we proceed north, deeper water with rocky shores and less suitable substrate preclude the growth of macrophytes. In this area, well developed communities of algae replace the submergents. However, in some undetermined area just north of the mouth of the Coeur d'Alene River, high concentrations of nitrates and phosphates decline rapidly along with simultaneous reduction in phytoplankton abundance and carbon fixation rates. Such a condition prevails for all stations sampled from this point to the Spokane River outfall.

Primary production measurements and estimates of carbon fixation were chosen as the basic tools to assess variations in productivity among the stations. In situ production measurements were used to construct production-depth profiles. All sampling dates showed a similar type curve with a distinct maximum in the upper strata of the euphotic zone, followed by a rapid reduction in production rate at the lower depths. In reference to the representative profile for August (Fig. 5), production appears to be very light-dependent as the curves illustrate. Findenegg (1964) describes curves of this type as characteristic of lakes rich in phytoplankton and nutrients. Wissmar (per. comm.) found similar curves for station 1 from the previous summer.

Rates of primary production are compared for various western lakes in the United States and Canada (Table 7). The measurements given for the Experimental Lakes Area (ELA) in Canada are of particular interest, since they showed low carbonate alkalinities and low counts of diatoms similar to parts of Coeur d'Alene Lake. The range in production values appears higher for Coeur d'Alene Lake because of the greater light transparency.

The euphotic zone in Coeur d'Alene averaged 12 m, considerably deeper than the ELA lakes that had a similar production profile. It was later observed that station 1 was much more productive than other similar habitats of the lake and therefore might be atypical of the open water situation. Production values for station 1 fall within the range of strong mesotrophy as described by Winberg (1963), and therefore this area is probably much more productive than most water in the northern sections of the lake, which would tend toward oligotrophy.

TABLE 7.--Comparative primary production rates in natural lake systems of western United States and Canada

Lake	Range (mgC/m^2/day)	Remarks
Clear Lake, Calif.	2.0-2440	Shallow eutrophic
Lake Tahoe, Nev.	28-238	Oligotrophic
ELA lakes, Can.	50-2570	Oligotrophic; low carbonates
Coeur d'Alene Lake, Idaho	607-6610	Mesotrophic; nutrient rich

In vitro carbon fixation experiments were conducted on water from all stations to define conditions better in different areas of the lake. From this experimentation, three distinct areas of the lake were recognized. A summary of the distinguishing characteristics of each area is presented in Table 8. Area I includes that northern section of Coeur d'Alene Lake from the city of Coeur d'Alene south to East Point (stations 2, 3, 4, and

TABLE 8.--Selected characteristics of the three trophic areas of Lake Coeur d'Alene. July-November, 1971.

Parameter	Area I	Area II	Area III
Nitrates (mg/1)	0.13	0.19	0.21
Phosphates (mg/1)	0.03	0.09	0.22
Alkalinity (mg/1)	24.2	27.6	31.0
pH	7.2	7.2	7.25
Average depth (m)	>20	>15	<7
Transparency (m)	3	3	2.5
Diatoms/ml	150	260	120
$MgC/m^3/4$ hrs	400	525	275
Macrophytes	Very rare	Rare	Very abundant
Periphytic blue-green algae	Rare	Common	Abundant

5). The open water here is deep, averaging greater than 20 m, with transparency not less than 3 m. Nutrient levels are not excessive, and community structure consists of low concentrations of diatoms. Carbon fixation rates for the period of study averaged approximately 400 mgC/m^3/4-hr incubation period. Water in this section would be considered closer to oligotrophic with the exception that certain bay areas are somewhat eutrophied.

Area II includes that section of the lake from Rockford Bay south to Conklin Park (stations 6, 7, 8, 1, 9, and 10). This area is deep, averaging greater than 15 m, rich in nutrients, and supporting a very dense diatom community with seasonal developments of blue-green algae populations in August. Carbon fixation levels averaged 520 mgC/m^3/4-hr incubation period. The data support the conclusion that this area is enriched and can be classified as strongly mesotrophic. However, station 9, which is located within the area, is somewhat different than the other stations. It has lower values of algae production and lower diatom concentration. There is abundant macrophyte growth in the area, and this growth accounts for a considerable part of the autotrophic production at this station. In this sense, it is considered the dividing zone between Areas II and III, and it further indicates the north-south gradient in production and nutrient levels.

Area III includes the southernmost portion of the lake from Shingle Bay south to Rocky Point in Chatcolet Lake (stations 11 and 12). This water is quite shallow with sounded areas averaging less than 7 m. Dense growths of macrophytes persist from late July to early October. Nutrient supplies are abundant. Weak thermal stratification does occur, but thorough mixing is more common. Carbon fixation rates by phytoplankton averaged 275 mgC/m^3/4-hr incubation period, the lowest values found in the lake. The phytoplankton community structure was poorly developed, and it is assumed that the dense macrophyte growth restricted the phytoplankton production in some manner not completely understood. Also, more turbid conditions in this area could have inhibited phytoplankton growth.

Although no estimates of production by macrophytes in this area were made, it is likely that they are the major source of autotrophic production. Field observations of Area III, which includes Chatcolet, Round, and Benewah Lakes, indicate that over 60% of this water area is inhabited by a very dense growth of macrophytes. The evidence indicates that these waters are strongly mesotrophic, with most shallow areas being heavily enriched and eutrophic.

The area differences are further illustrated in Fig. 6 which shows north-to-south variation in carbon fixation and diatom concentrations. A map of these areas is shown in Fig. 7.

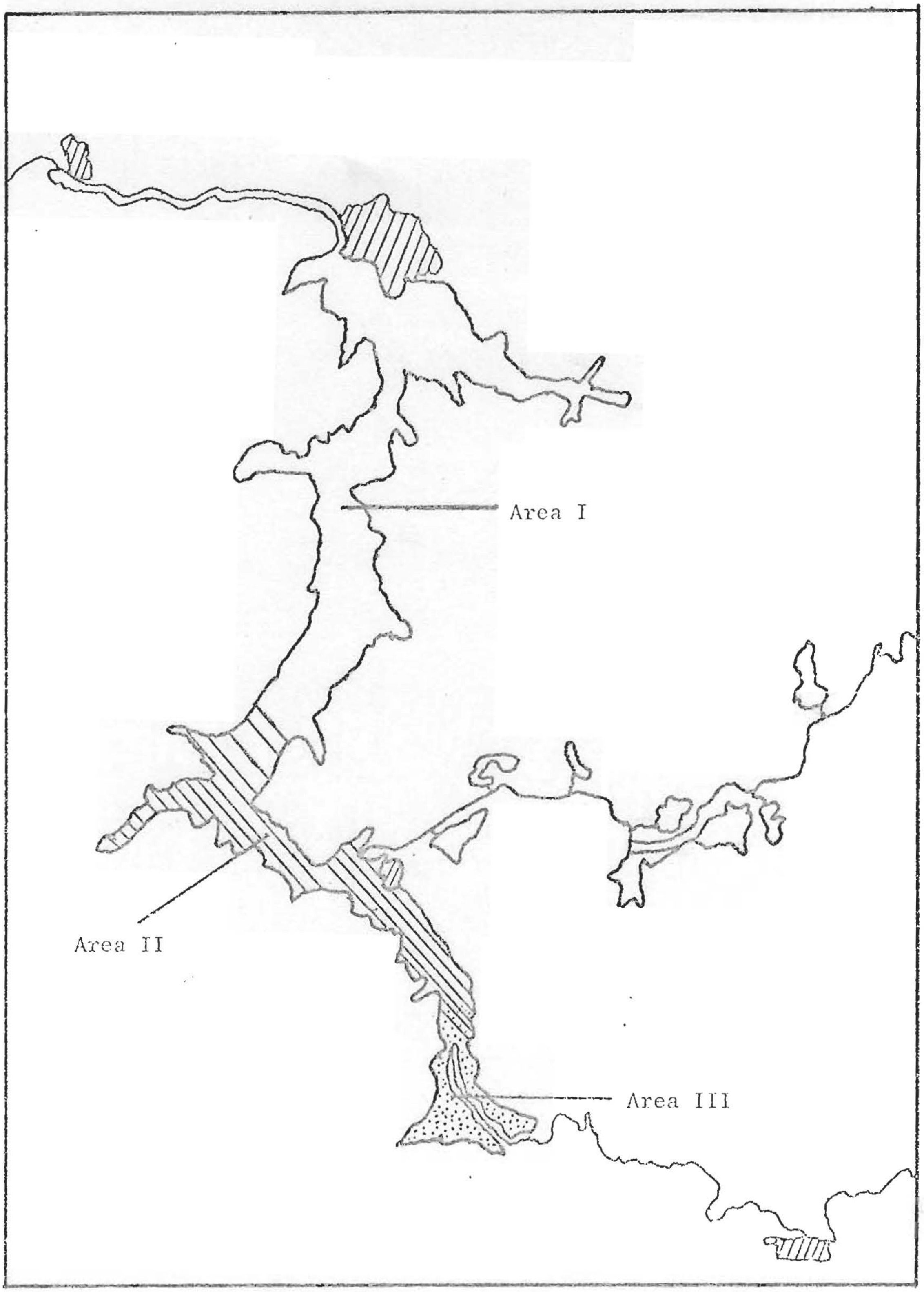

Fig. 7.--Trophic areas (I--oligotrophic; II--mesotrophic; III--strongly mesotrophic) of Coeur d'Alene Lake.

SUMMARY

1. An investigation of algal production and water quality of Coeur d'Alene Lake was conducted from July-November, 1971, in an attempt to evaluate enrichment conditions in the lake.

2. Twelve sampling stations were located throughout the lake along a north-south gradient.

3. Primary production was measured _in situ_ at one station to provide estimates of aerial productivity and to function as a base for validating examinations of carbon fixation made under controlled conditions of light and temperature. The experiments were performed in a culturing tank on water from all stations.

4. Basic limnological examinations of phytoplankton community structure, nitrates, phosphates, alkalinity, dissolved oxygen, hydrogen ion concentrations, specific conductance, transparency, and temperature were conducted at each station to define causes for trophic differences among stations.

5. There are higher nutrient concentrations in the southern areas of Coeur d'Alene Lake, apparently carried by river and stream discharge.

6. Carbon fixation rates were found significantly dependent upon diatom and phosphate concentrations in the lake, and maximum fixation rates

were observed where phosphates and diatoms were in highest concentrations.

7. The middle and southern areas of the lake from Rockford Bay south to Rocky Point produced dense growths of algae and macrophytes and appeared to be strongly mesotrophic.

8. The open water of the northern areas in the lake from East Point north to the city of Coeur d'Alene appeared to be oligotrophic with low concentrations of nutrients and diatoms.

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